MVR-200 series

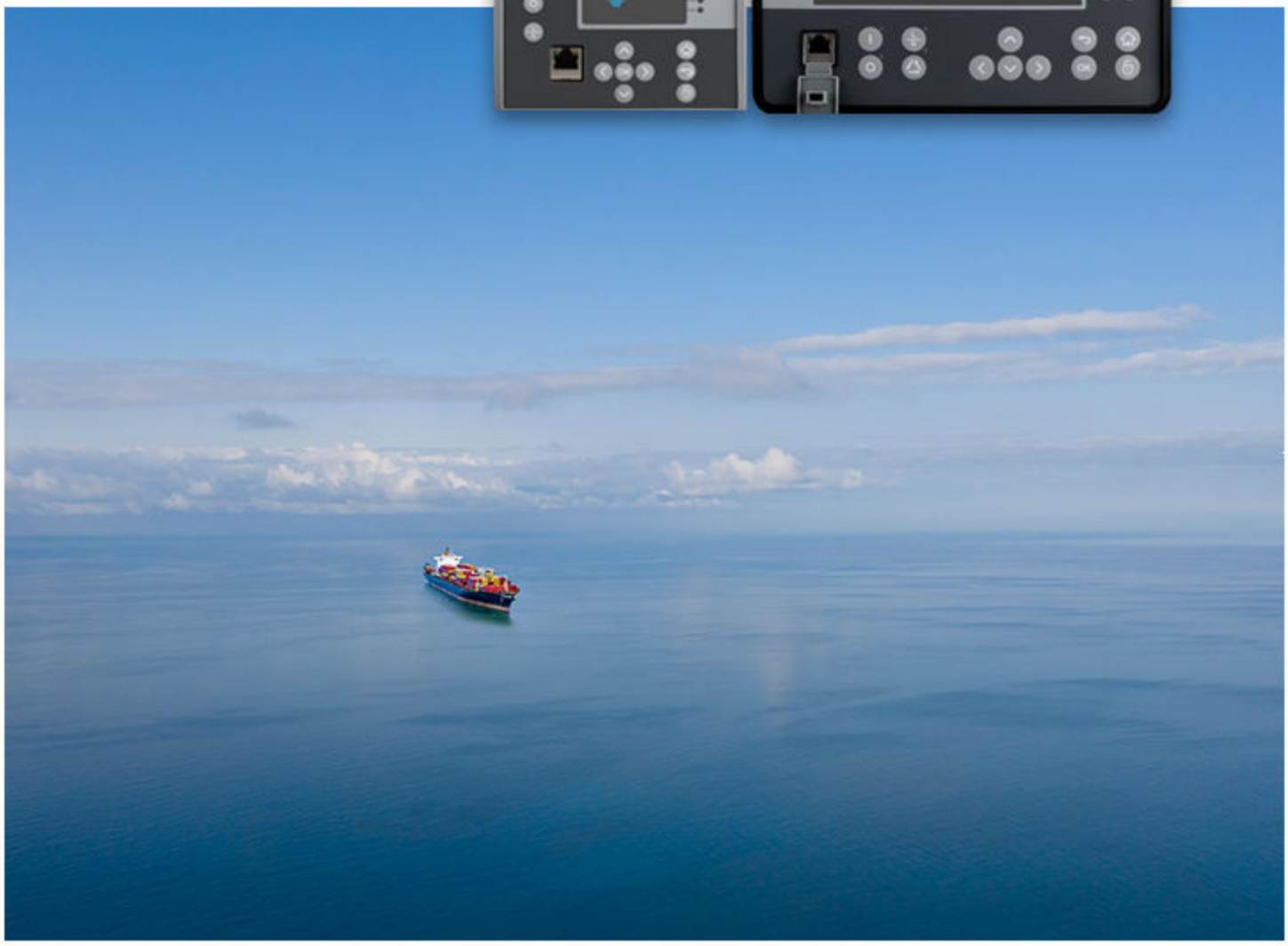
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Medium Voltage Relay

Designer's handbook

DEIF Improve Tomorrow





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1. Introduction

1.1 About the Designer's handbook

1.1.1 Intended users of the Designer's handbook

This is the Designer's handbook for DEIF's Medium Voltage Relay MVR-200. The Designer's handbook describes the MVR functions and communication. This includes selecting and setting up the protections and functions. The Designer's handbook is primarily for the person who designs the control system, electrical system, and communication system where the MVR-200s are installed.

More information
See the **Data sheet** for the functions supported by each controller, as well as all the technical specifications.

More information
See the **Installation instructions** for applications, connections and wiring.

DANGER!

High voltages and currents

Incorrect design can result in human injury or damage to the equipment

Read this manual before designing the system.

The Designer's handbook can also be used during commissioning to check the design drawings and the controller parameters. Operators may find the Designer's handbook useful for understanding the system and for troubleshooting.

1.1.2 Abbreviations

CB – Circuit breaker

CBFP – Circuit breaker failure protection

CT – Current transformer

CPU – Central processing unit

EMC – Electromagnetic compatibility

HMI – Human machine interface

HW – Hardware

IED – Intelligent electronic device

IO – Input output

LED – Light emitting diode

LV – Low voltage

MV – Medium voltage

NC – Normally closed

NO – Normally open

RMS – Root mean square

SF – System failure

TMS – Time multiplier setting

TRMS – True root mean square

VAC – Voltage alternating current

VDC – Voltage direct current

SW – Software

uP - Microprocessor

1.1.3 Technical support

You can read about service and support options on the DEIF website, www.deif.com. You can also find contact details on the DEIF website.

You have the following options if you need technical support:

- Help: The display unit includes context-sensitive help.
- Technical documentation: Download all the product technical documentation from the DEIF website: www.deif.com/documentation
- Training: DEIF regularly offers training courses at the DEIF offices worldwide.
- Support: DEIF offers 24-hour support. See www.deif.com for contact details. There may be a DEIF subsidiary located near you. You can also e-mail support@deif.com.
- Service: DEIF engineers can help with design, commissioning, operating and optimisation.

1.2 Warnings and safety

1.2.1 Warnings



Read the documentation carefully before use, and retain for future reference. Documentation is available at http://www.deif.com/documentation

It is the responsibility of the user to ensure that the equipment is installed, operated and used for its intended function in the manner specified by DEIF. If this is not the case, then the safety protection provided by the equipment may be impaired.

1.2.2 Alarm LED configuration

MVR 21x

To meet marine class society requirements:

- The MVR must be configured so that the **Trip LED** (⚠ ●) is lit whenever a protection activates a breaker trip.
- For each trip protection, select *Trip ON* in the *NOC EventMask*. In this way, the cause of any trip is shown on the main screen and immediately visible to the operator.

MVR 25x

To meet marine class society requirements:

- The MVR must be configured so that the **Trip LED** () is lit whenever a protection activates a breaker trip.
- For each trip protection, select *Trip ON* in the *NOC EventMask*. In this way, the cause of any trip is shown on the main screen and immediately visible to the operator.
- If any of the 16 configurable LEDs (on the left of the screen) are configured for alarms, then the LED colours must be configured as follows:

Alarm state	Details	LED colour
OK	There is no alarm.	Green
Warning	There is an alert for the operator, but no alarm action.	Yellow (*Orange*)
Trip or Fault	The controller has sent a trip signal the breaker.	Red

1.3 Legal information

1.3.1 Disclaimer

DEIF A/S reserves the right to change any of the contents of this document without prior notice.

The English version of this document always contains the most recent and up-to-date information about the product. DEIF does not take responsibility for the accuracy of translations, and translations might not be updated at the same time as the English document. If there is a discrepancy, the English version prevails.

1.3.2 Copyright

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2. Measurements

2.1 Overview

2.1.1 Measurements for each MVR

The measurements, tracking and calculations that each MVR supports are shown in the following table.

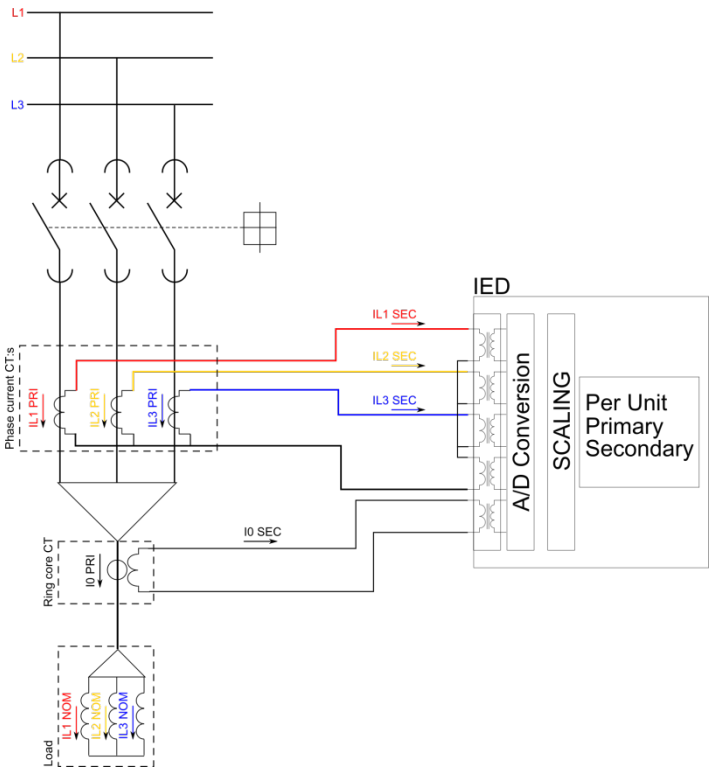
MVR	Current (CT5)	Differential current	Voltage (VT4)	Frequency	Power and energy
F201	•			•	
F205	•		•	•	•
F210	•			•	
F215	•		•	•	•
F255	•		•	•	•
M210	•			•	
M215	•		•	•	•
M255	•		•	•	•
M257	•	•	•	•	•
G215	•		•	•	•
G257	•	•	•	•	•
T215	•		•	•	•
T216	•	•		•	
T256	•	•		•	
T257	•	•	•	•	•
V211			•	•	

2.2 Measured values

2.2.1 Current measurement and scaling

Current measurement module (CT-module) is used for measuring the currents from current transformers and processing the measured values to measurement database and for measurement- and protection functions to use. For the measurements to be correct it is essential to understand the concept of the current measurements.

Figure 2.1 Current measurement terminology



For the measurements to be correct it needs to be made sure that the measurement signals are connected to correct inputs, current direction is connected with correct polarity, and the scaling is set according to current transformer nominal values.

Relay calculates scaling factors based on the set CT primary, secondary and nominal current values. Relay measures secondary current which in this case mean the current output from the current transformer which is installed into the primary circuit of the application. In order the relay to “know” primary and per unit values current transformer rated primary and secondary currents need to be set. In case of motor or any specific electrical apparatus protection application motor nominal current should be set too in order for the values to be per unitized to apparatus nominal and not to CT nominal (This is not absolutely mandatory, in some relays it is still needed to calculate correct settings manually. Setting the relay nominal current makes the motor protection a lot easier and straight forward. In modern protection devices this scaling calculation is done internally after the current transformer primary, secondary and motor nominal currents are given).

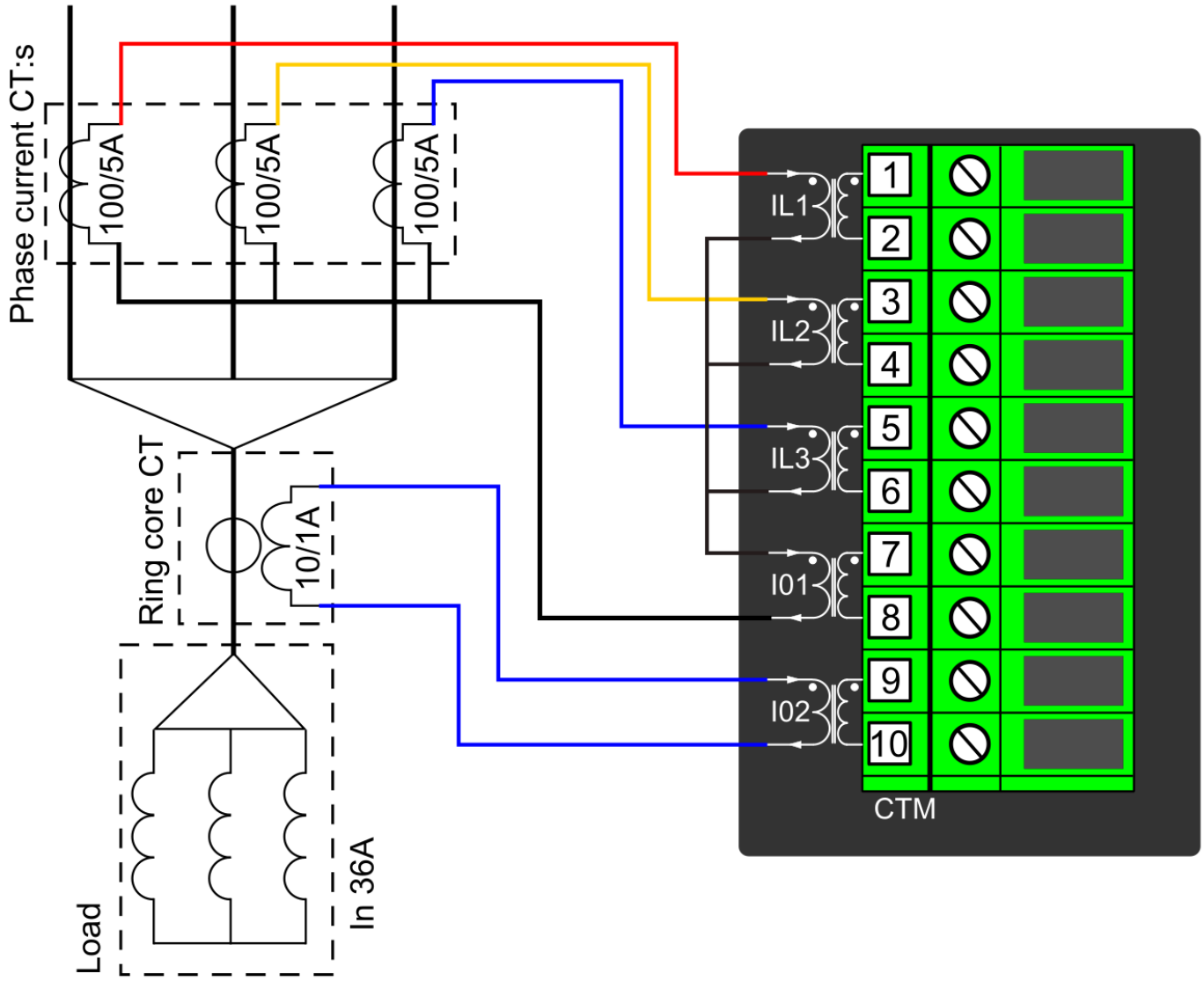
Normally the primary current ratings for phase current transformers are 10A, 12.5A, 15A, 20A, 25A, 30A, 40A, 50A, 60A and 75A and their decimal multiples, while normal secondary current ratings are 1 and 5A. Other, non-standard ratings can be directly connected since the scaling settings are flexible in large ranges. As an example, ring core current transformer ratings may be different. Ring core current transformers are commonly used for sensitive earth fault protection and their rated secondary may be as low as 0.2 A in some cases.

In following chapter is an example for setting the scaling of the current measurements to the example current transformer and system load.

CT scaling example

The connection of CTs to the IED measurement inputs and the ratings of the current transformers and load nominal current are as in following figure.

Figure 2.2 Example connection.



Initial data of the connection and the ratings are presented in following table.

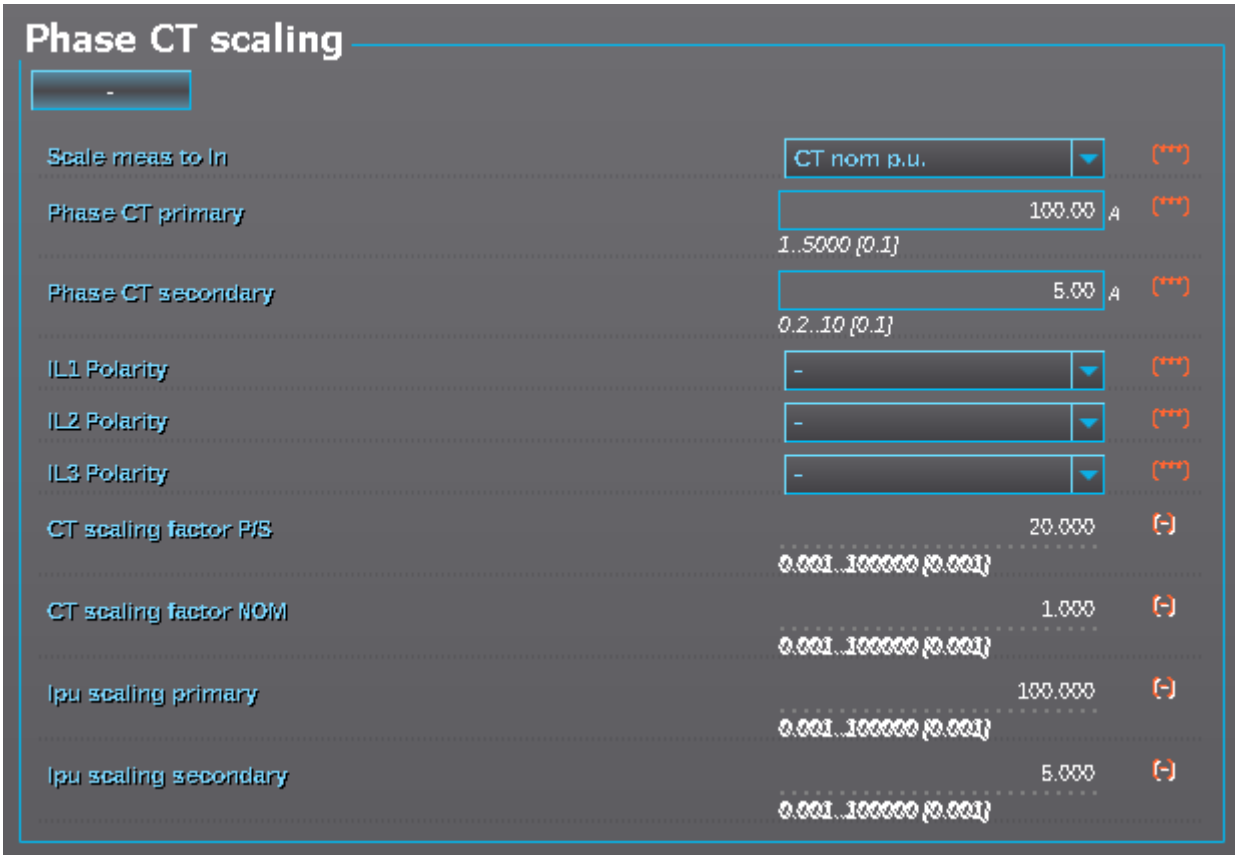
Table 2.1 Initial data from example connection.

Phase current CT: CT primary 100A CT secondary 5A	Ring core CT in Input I02: I0CT primary 10A I0CT secondary 1A	Load nominal 36A
Phase currents are connected to summing “Holmgren” connection into the I01 residual input. Phase current CT secondary currents starpoint is towards the line.		

For the scaling of the currents to per unit values for the protections selection needs to be made now if the protected object nominal current or the CT primary value should be the base for per unitizing.

If the per unit scaling is wanted to be according to the CT values then “Scale meas to In” is set to “CT nom p.u.” As presented in the figure below.

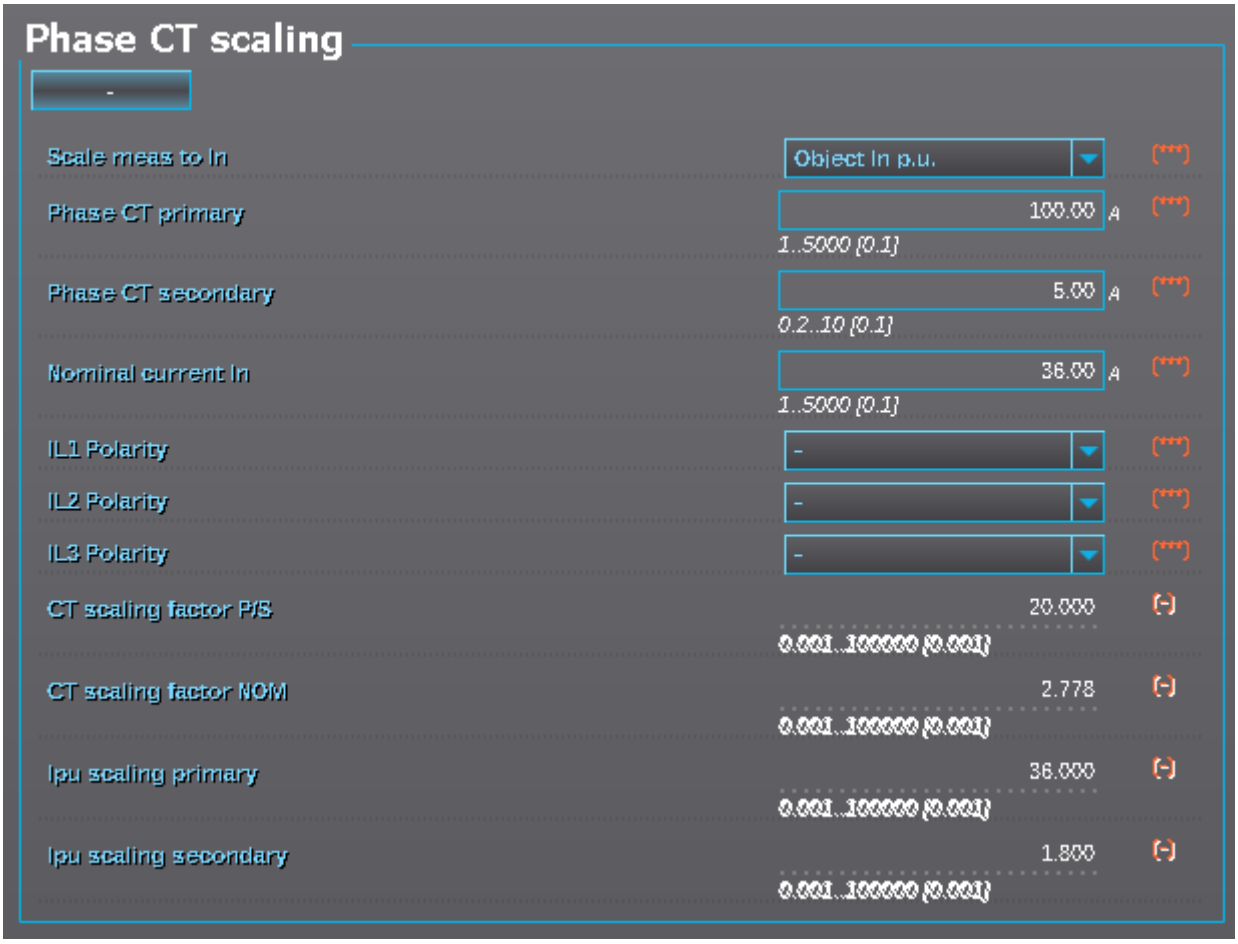
Figure 2.3 Phase current transformer scalings to CT nominal.



After the settings are input to the IED, scaling factors are also calculated and displayed for the user. Scaling factor P/S tells the CT primary to secondary ratio, CT scaling factor to NOM tells the scaling factor to nominal current (in this case it should be 1 since the selected nominal current is the phase CT nominal). Per unit scaling factors to primary and secondary values are also shown. In this case the scaling factors are directly the set primary and secondary currents of the set CT.

If the settings would be wanted to be scaled to load nominal then the selection “Scale meas to In” would be set to “Object In p.u.”

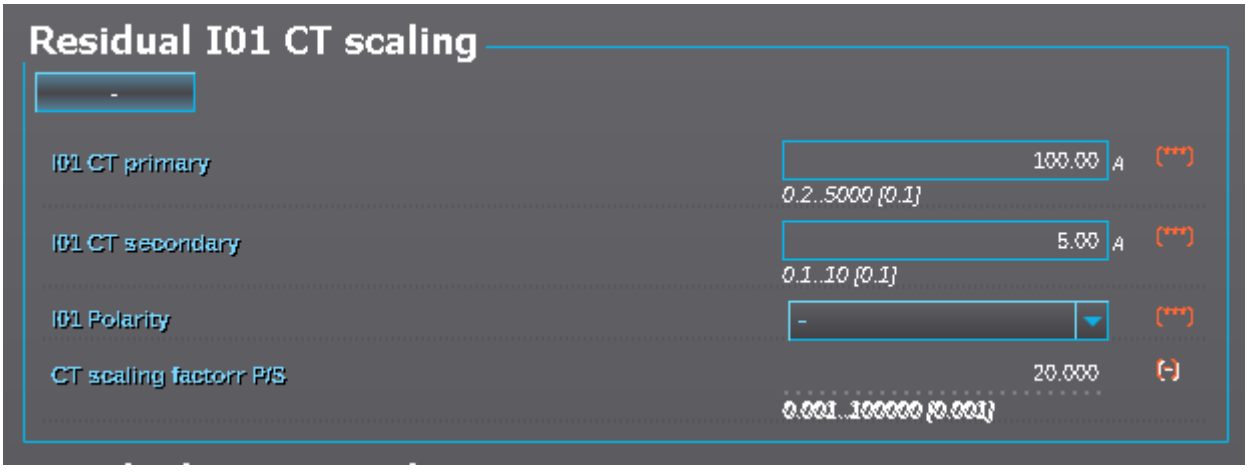
Figure 2.4 Phase current transformer scalings to protected object nominal current.



When measurement scaling is made to the protected object nominal current, the object nominal current needs also to be set into the “Nominal current In” input. The differences in the used scaling factors can now be seen. Primary to secondary ratio is directly the ratio of the set CT ratios, CT scaling factor to nominal is now the set CT primary to nominal current ratio, per unit scalings to primary is changed now to nominal current and the secondary per unit factor is calculated accordingly to the given ratio of CT primary to object nominal current.

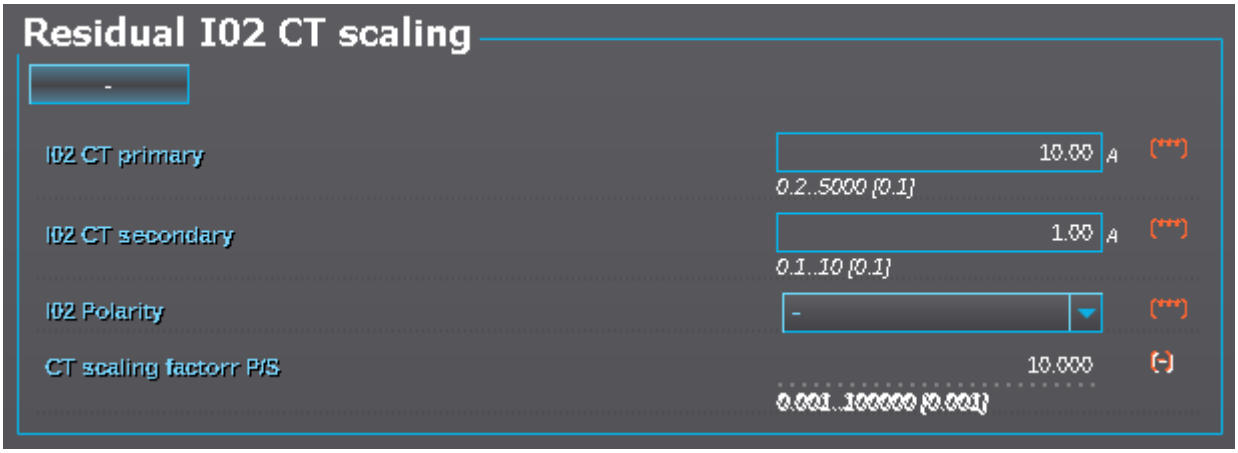
If coarse residual current (I01) is wanted to be used for CT sum (Holmgren) input then it should be set to phase current CT ratings 100/5A.

Figure 2.5 Residual current I01 scaling to summing connection.



For the sensitive residual current (I02) measurement is set directly 10/1A rated currents.

Figure 2.6 Residual current I02 scaling to ring core CT input.



If the scaling was made to CT primary or to object nominal current the measurements will look as follows with nominal current feeding:

Figure 2.7 Scalings to CT nominal.

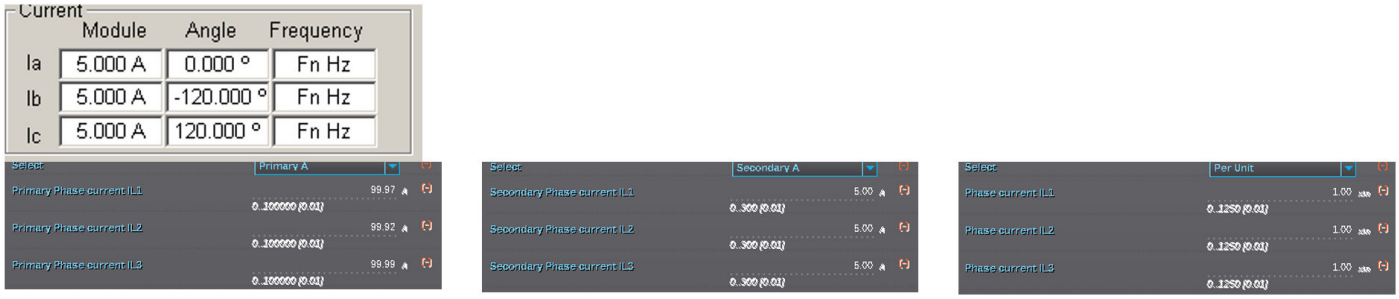
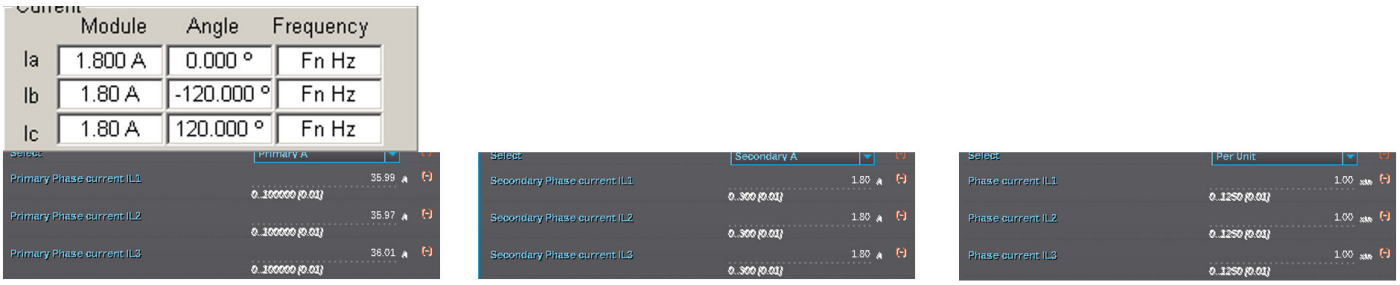


Figure 2.8 Scalings to protected object nominal current.



As seen from the examples the primary and secondary currents will be displayed as actual values so the scaling selection does not have effect to that. Only effect is now that the per unit system in the relay is scaled to either transformer nominal or the protected object nominal and this makes the settings input for the protected object straight forward.

ZCT scaling example

Figure 2.9 If zero sequence current transformer is used it should be connected to I02 channel which has lower CT scaling ranges.

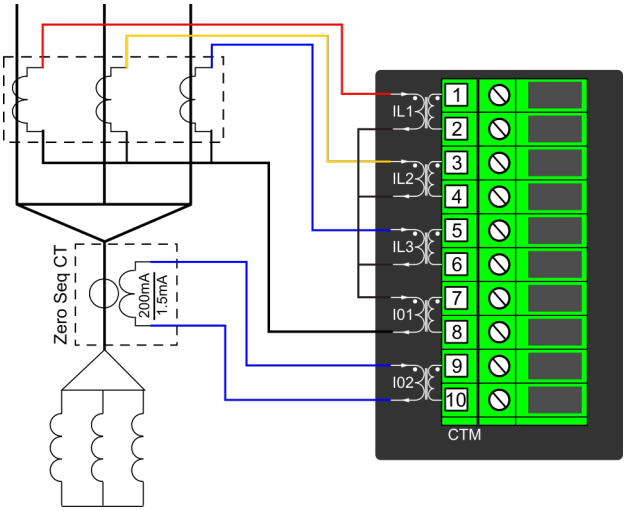


Figure 2.10 Setting example of zero sequence current transformer application.

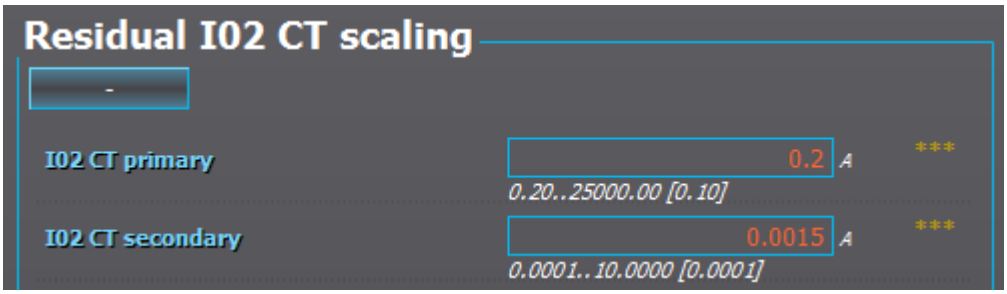
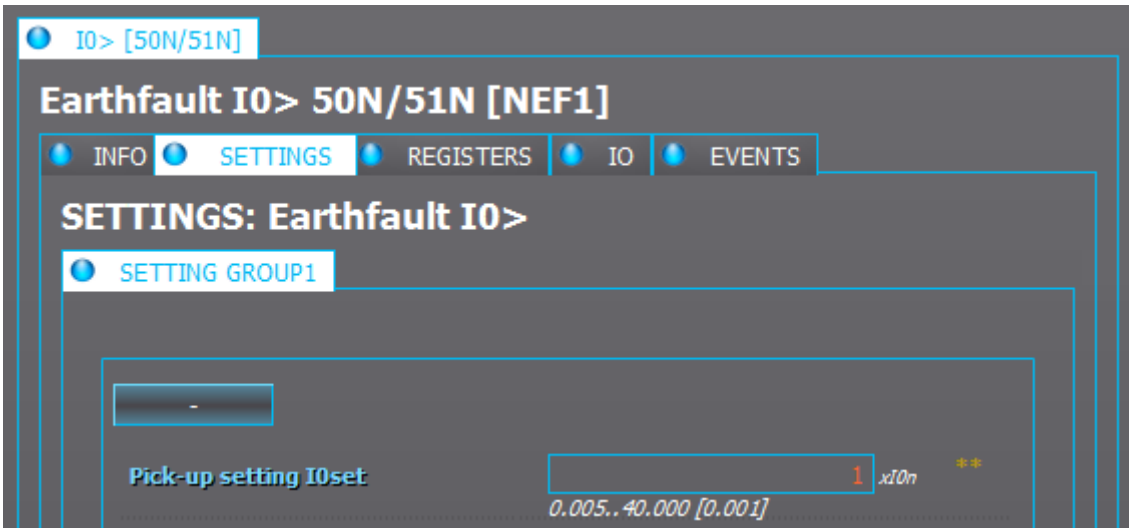


Figure 2.11 With current transformer ratio of 200mA/1.5mA earthfault protection setting 1*I0n will make the function pick-up at 200mA primary current.



Troubleshooting

It is possible that for some reason the measured currents may not be as expected. For these cases following checks may be helpful.

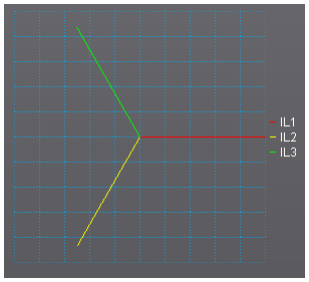
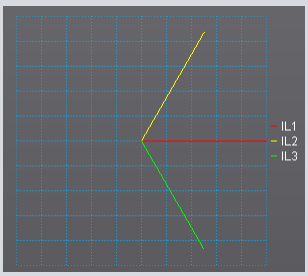
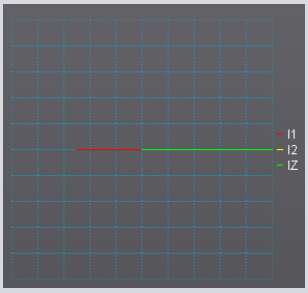
Problem	Check / Resolution
Measured current amplitude in all phases does not match for what is injected.	Scaling settings may be wrong, check from Measurement, Transformers, Phase CT scaling that the settings match for what is expected. Also check that the scaling measurement to In is set accordingly either to “Object In“or CT nominal. If working with CT:s, if possible check the actual ratings from the CT:s as well, since in some cases the actual CT:s may have been changed from the original plan for some reason.
Measured current amplitude does not match for one measured phase or calculated I0 is measured when there should not be any.	Check wiring connections from injection device or CTs to the IED. NOTE: If working with CTs which are in energized system extreme caution should be practiced when checking connections. Opened CT secondary circuit may generate dangerously high voltages. “Buzzing” sound from connector can indicate open circuit.
Measured current amplitudes are all ok and equal but the angles are strange. Phase unbalance protection trips immediately when it is activated. Earth fault protection trips immediately when it is activated.	Phase currents are connected into the measurement module, but the order or polarity of one or all phases is incorrect. Go to Measurement, Phasors and check the current Phasors diagram. When all is correctly connected the diagram should look as below with symmetric feeding:  In following rows few most common cases are presented.

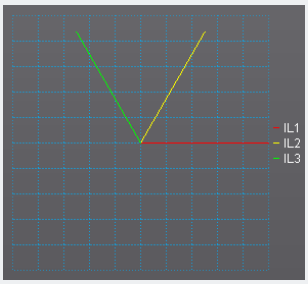
Table 2.2 Phase polarity problems are easy to find since the vector diagram points out the opposite polarity in the wrongly connected phase.

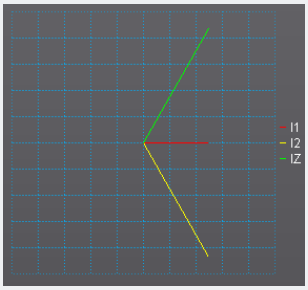


Phase L1 (A) polarity incorrect.
Phase currents
IL1: 1.00 xIn / 0.00 deg
IL2: 1.00 xIn / 60.00 deg
IL3: 1.00 xIn / 300.00 deg
Sequence currents
I1: 0.33 xIn / 180.00 deg
I2: 0.67 xIn / 0.00 deg
I0Calc: 0.67 xIn / 0.00 deg
Resolution:

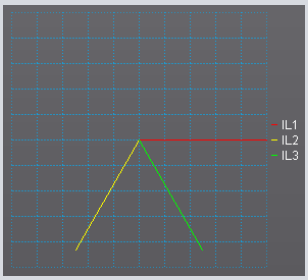


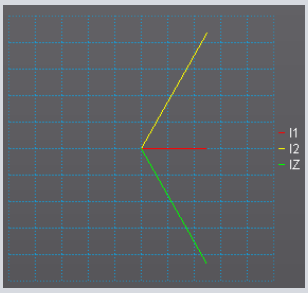
- Change wires to opposite in CT module connectors 1 – 2
- Or from the Transformers, Phase CT scaling select IL1 polarity to “Invert”.





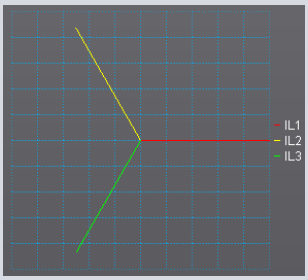
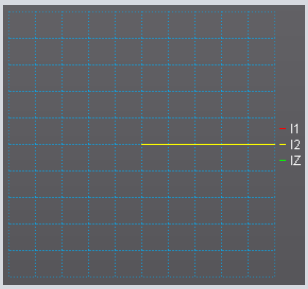
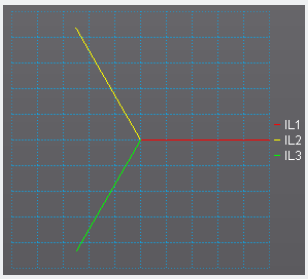
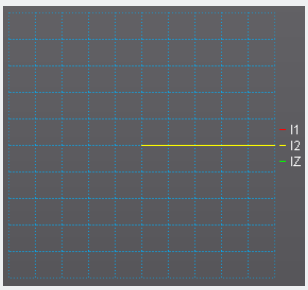
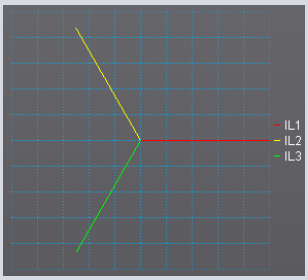
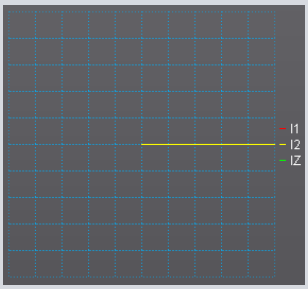
Phase L2 (B) polarity incorrect.
Phase currents
IL1: 1.00 xIn / 0.00 deg
IL2: 1.00 xIn / 60.00 deg
IL3: 1.00 xIn / 120.00 deg
Sequence currents
I1: 0.33 xIn / 0.00 deg
I2: 0.67 xIn / -60.00 deg
I0Calc: 0.67 xIn / 60.00 deg
Resolution:
- Change wires to opposite in CT module connectors 3 – 4
- Or from the Transformers, Phase CT scaling select IL2 polarity to “Invert”.





Phase L3 (C) polarity incorrect.
Phase currents:
IL1: 1.00 xIn / 0.00 deg
IL2: 1.00 xIn / 240.00 deg
IL3: 1.00 xIn / 300.00 deg
Sequence currents:
I1: 0.33 xIn / 0.00 deg
I2: 0.67 xIn / 60.00 deg
I0Calc: 0.67 xIn / -60.00 deg
Resolution:
- Change wires to opposite in CT module connectors 5 – 6
- Or from the Transformers, Phase CT scaling select IL3 polarity to “Invert”.

Table 2.3 Network rotation / mixed phases problem might be difficult to find since the measurement result shall always be the same in the relay. If two phases are mixed together the network rotation shall always look like IL1-IL3-IL2 and the measured negative sequence current shall be always 1.00 per unit if this is the case.

 	Phase L1 (A) and L2 (B) switch place (network rotation wrong). Phase currents IL1: 1.00 xIn / 0.00 deg IL2: 1.00 xIn / 120.00 deg IL3: 1.00 xIn / 240.00 deg Sequence currents I1: 0.00 xIn / 0.00 deg I2: 1.00 xIn / 0.00 deg I0Calc: 0.00 xIn / 0.00 deg Resolution: - Change wires to opposite in CT module connectors 1 - 3
 	Phase L2 (B) and L3 (C) switch place (network rotation wrong). Phase currents IL1: 1.00 xIn / 0.00 deg IL2: 1.00 xIn / 120.00 deg IL3: 1.00 xIn / 240.00 deg Sequence currents I1: 0.00 xIn / 0.00 deg I2: 1.00 xIn / 0.00 deg I0Calc: 0.00 xIn / 0.00 deg Resolution: - Change wires to opposite in CT module connectors 3 - 5
 	Phase L3 (C) and L1 (A) switch place (network rotation wrong). Phase currents IL1: 1.00 xIn / 0.00 deg IL2: 1.00 xIn / 120.00 deg IL3: 1.00 xIn / 240.00 deg Sequence currents I1: 0.00 xIn / 0.00 deg I2: 1.00 xIn / 0.00 deg I0Calc: 0.00 xIn / 0.00 deg Resolution: - Change wires to opposite in CT module connectors 1 - 5

Settings

Table 2.4 Settings of the Phase CT scaling.

Name	Range	Step	Default	Description
Scale meas to In	0:CT nom p.u. 1:Object In p.u.	-	0:CT nom p.u.	Selection of the IED per unit system scaling reference, either the set phase current CT primary or protected object nominal current.
Phase CT primary	1...25000.000A	0.001A	100.000A	Rated primary current of the CT in amperes.
Phase CT secondary	0.200...10.000A	0.001A	5.000A	Rated secondary current of the CT in amperes.
Nominal current In	1...25000.000A	0.001A	100.000A	Protected object nominal current in amperes. (This setting is visible if “Scale meas to In” setting is set to “Object In p.u.”)
IL1 Polarity	0:- 1:Invert	-	0:-	IL1 (first current) measurement channel polarity (direction) selection. Default setting is that positive current flow is from connector 1 to connector 2 and the secondary currents starpoint is towards line.
IL2 Polarity	0:- 1:Invert	-	0:-	IL2 (second current) measurement channel polarity (direction) selection. Default setting is that positive current flow is from connector 3 to connector 4 and the secondary currents starpoint is towards line.
IL3 Polarity	0:- 1:Invert	-	0:-	IL3 (third current) measurement channel polarity (direction) selection. Default setting is that positive current flow is from connector 5 to connector 6 and the secondary currents starpoint is towards line.
CT scaling factor P/S	-	-	-	IED feedback value, this is the calculated scaling factor for primary /secondary current ratio
CT scaling factor NOM	-	-	-	IED feedback value, this is the calculated ratio in between of set primary and nominal currents.
Ipu scaling primary	-	-	-	IED feedback value, scaling factor from p.u. value to primary current.
Ipu scaling secondary	-	-	-	IED feedback value, scaling factor from p.u. value to secondary current.

Figure 2.12 Settings of the residual I01 CT scaling.

Name	Range	Step	Default	Description
I01 CT primary	0.2...25000.000000A	0.00001A	100.0A	Rated primary current of the CT in amperes.
I01 CT secondary	0.1...10.00000A	0.00001A	5.0A	Rated secondary current of the CT in amperes.
I01 Polarity	0:- 1:Invert	-	0:-	I01 (coarse residual) measurement channel polarity (direction) selection. Default setting is that positive current flow is from connector 7 to connector 8.

Name	Range	Step	Default	Description
CT scaling factor P/S	-	-	-	IED feedback value, this is the calculated scaling factor for primary /secondary current ratio

Table 2.5 Settings of the residual I02 CT scaling.

Name	Range	Step	Default	Description
I02 CT primary	0.2...25000.0A	0.00001A	100.0A	Rated primary current of the CT in amperes.
I02 CT secondary	0.001...10.0A	0.00001A	5.0A	Rated secondary current of the CT in amperes.
I02 Polarity	0:- 1:Invert	-	0:-	I02 (fine residual) measurement channel polarity (direction) selection. Default setting is that positive current flow is from connector 9 to connector 10.
CT scaling factor P/S	-	-	-	IED feedback value, this is the calculated scaling factor for primary /secondary current ratio

Measurements

Following measurements are available from the measured current channels.

Table 2.6 Per unit phase current measurements.

Name	Range	Step	Description
Phase current ILx	0.00...1250.0xIn	0.01xIn	Per unit measurement from each phase current channel fundamental frequency RMS current.
Phase current ILx TRMS	0.00...1250.0xIn	0.01xIn	Per unit measurement from each current channel TRMS current including harmonics up to 31st.
Peak to peak current ILx	0.00...500.0xIn	0.01xIn	Per unit measurement peak to peak current from each phase current measurement channel.

Table 2.7 Primary phase current measurements.

Name	Range	Step	Description
Primary Phase current ILx	0.00...1000000.0A	0.01A	Primary measurement from each phase current channel fundamental frequency RMS current.
Phase current ILx TRMS pri	0.00...1000000.0A	0.01A	Primary measurement from each current channel TRMS current including harmonics up to 31st.

Table 2.8 Secondary phase current measurements.

Name	Range	Step	Description
Secondary Phase current ILx	0.00...300.0A	0.01A	Secondary measurement from each phase current channel fundamental frequency RMS current.
Phase current ILx TRMS sec	0.00...300.0A	0.01A	Secondary measurement from each current channel TRMS current including harmonics up to 31st.

Table 2.9 Phase current angles measurements.

Name	Range	Step	Description
Phase angle ILx	0.00...360.00deg	0.01deg	Phase angle measurement of the three phase current inputs.

Table 2.10 Per unit residual current measurements.

Name	Range	Step	Description
Residual current I01	0.00...1250.0xIn	0.01xIn	Per unit measurement from residual current channel I01 fundamental frequency RMS current.
Residual current I02	0.00...1250.0xIn	0.01xIn	Per unit measurement from residual current channel I02 fundamental frequency RMS current.
Calculated I0	0.00...1250.0xIn	0.01xIn	Per unit measurement from calculated I0 current fundamental frequency RMS current.
Phase current I01 TRMS	0.00...1250.0xIn	0.01xIn	Per unit measurement from I01 residual current channel TRMS current including harmonics up to 31st.
Phase current I02 TRMS	0.00...1250.0xIn	0.01xIn	Per unit measurement from I02 residual current channel TRMS current including harmonics up to 31st.
Peak to peak current I01	0.00...500.0xIn	0.01xIn	Per unit measurement peak to peak current from I01 residual current measurement channel.
Peak to peak current I02	0.00...500.0xIn	0.01xIn	Per unit measurement peak to peak current from I02 residual current measurement channel.

Table 2.11 Primary residual current measurements.

Name	Range	Step	Description
Primary residual current I01	0.00...1000000.0A	0.01A	Primary measurement from residual current channel I01 fundamental frequency RMS current.
Primary residual current I02	0.00...1000000.0A	0.01A	Primary measurement from residual current channel I02 fundamental frequency RMS current.
Primary calculated I0	0.00...1000000.0A	0.01A	Primary measurement from calculated I0 fundamental frequency RMS current.
Residual current I01 TRMS pri	0.00...1000000.0A	0.01A	Primary measurement from residual current channel I01 TRMS current including harmonics up to 31st.
Residual current I02 TRMS pri	0.00...1000000.0A	0.01A	Primary measurement from residual current channel I02 TRMS current including harmonics up to 31st.

Table 2.12 Primary residual current measurements.

Name	Range	Step	Description
Secondary residual current I01	0.00...300.0A	0.01A	Secondary measurement from residual current channel I01 fundamental frequency RMS current.
Secondary residual current I02	0.00...300.0A	0.01A	Secondary measurement from residual current channel I02 fundamental frequency RMS current.
Secondary calculated I0	0.00...300.0A	0.01A	Secondary measurement from calculated I0 fundamental frequency RMS current.
Residual current I01 TRMS sec	0.00...300.0A	0.01A	Secondary measurement from residual current channel I01 TRMS current including harmonics up to 31st.
Residual current I02 TRMS sec	0.00...300.0A	0.01A	Secondary measurement from residual current channel I02 TRMS current including harmonics up to 31st.

Table 2.13 Residual current angles measurements.

Name	Range	Step	Description
Residual current angle I01	0.00...360.00deg	0.01deg	Residual current angle measurement of the I01 current input.
Residual current angle I02	0.00...360.00deg	0.01deg	Residual current angle measurement of the I02 current input.
Calculated I0 phase angle	0.00...360.00deg	0.01deg	Calculated residual current angle measurement.

Table 2.14 Per unit sequence current measurements.

Name	Range	Step	Description
Positive sequence current	0.00...1250.0xIn	0.01xIn	Per unit measurement from calculated positive sequence current
Negative sequence current	0.00...1250.0xIn	0.01xIn	Per unit measurement from calculated negative sequence current
Zero sequence current	0.00...1250.0xIn	0.01xIn	Per unit measurement from calculated zero sequence current

Table 2.15 Primary sequence current measurements.

Name	Range	Step	Description
Primary Positive sequence current	0.00...1000000.0A	0.01A	Primary measurement from calculated positive sequence current
Primary Negative sequence current	0.00...1000000.0A	0.01A	Primary measurement from calculated negative sequence current
Primary Zero sequence current	0.00...1000000.0A	0.01A	Primary measurement from calculated zero sequence current

Table 2.16 Secondary sequence current measurements.

Name	Range	Step	Description
Secondary Positive sequence current	0.00...300.0A	0.01A	Secondary measurement from calculated positive sequence current
Secondary Negative sequence current	0.00...300.0A	0.01A	Secondary measurement from calculated negative sequence current
Secondary Zero sequence current	0.00...300.0A	0.01A	Secondary measurement from calculated zero sequence current

Table 2.17 Sequence current angle measurements.

Name	Range	Step	Description
Positive sequence current angle	0.00...360.0deg	0.01deg	Calculated positive sequence current angle
Negative sequence current angle	0.00...360.0deg	0.01deg	Calculated negative sequence current angle
Zero sequence current angle	0.00...360.0deg	0.01deg	Calculated zero sequence current angle

Table 2.18 Harmonic current measurements.

Name	Range	Step	Description
IL1 Harmonics IL1 fund...IL1 31harm	0.00...1000000.0A	0.01A	Per unit, primary and secondary harmonics per component for current input IL1
IL2 Harmonics IL2 fund...IL2 31harm	0.00...1000000.0A	0.01A	Per unit, primary and secondary harmonics per component for current input IL2

Name	Range	Step	Description
IL3 Harmonics IL3 fund...IL3 31harm	0.00...1000000.0A	0.01A	Per unit, primary and secondary harmonics per component for current input IL3
I01 Harmonics I01 fund...I01 31harm	0.00...1000000.0A	0.01A	Per unit, primary and secondary harmonics per component for current input I01
I02 Harmonics I02 fund...I02 31harm	0.00...1000000.0A	0.01A	Per unit, primary and secondary harmonics per component for current input I02

Current component measurements

Current component measurements indicate the resistive (wattmetric cos[φ]) and reactive (varmetric sin[φ]) current values. These are calculated with the following formula:

Wattmetric resistive component = I_X * cosφ

Varmetric reactive component = I_X * sinφ

Where “Ix” is phase or residual current magnitude and “φ” is the angle difference between the phase or residual voltage and current.

Following measurements are available from the measured current channels.

Table 2.19 Per unit phase current component measurements.

Name	Range	Step	Description
ILx Resistive Current p.u.	-1250.00...1250.0xIn	0.01xIn	Per unit measurement from each phase current channel resistive current component.
ILx Reactive Current p.u.	-1250.00...1250.0xIn	0.01xIn	Per unit measurement from each phase current channel reactive current component.
Pos.Seq Resistive Current p.u.	-1250.00...1250.0xIn	0.01xIn	Per unit measurement from each phase current channel resistive current component.
Pos.Seq Reactive Current p.u.	-1250.00...1250.0xIn	0.01xIn	Per unit measurement from each phase current channel reactive current component.
I01 Resistive Current p.u.	-1250.00...1250.0xIn	0.01xIn	Per unit measurement from residual current channel I01 resistive current component.
I01 Reactive Current p.u.	-1250.00...1250.0xIn	0.01xIn	Per unit measurement from residual current channel I01 reactive current component.
I02 Resistive Current p.u.	-1250.00...1250.0xIn	0.01xIn	Per unit measurement from residual current channel I02 resistive current component.
I02 Reactive Current p.u.	-1250.00...1250.0xIn	0.01xIn	Per unit measurement from residual current channel I02 reactive current component.

Table 2.20 Primary phase current component measurements

Name	Range	Step	Description
ILx Resistive Current Pri.	-100000.00 ...100000.00A	0.01A	Primary measurement from each phase current channel resistive current component.
ILx Reactive Current Pri.	-100000.00 ...100000.00A	0.01A	Primary measurement from each phase current channel reactive current component.
Pos.Seq Resistive Current Pri.	-100000.00 ...100000.00A	0.01A	Primary measurement from each phase current channel resistive current component.

Name	Range	Step	Description
Pos.Seq Reactive Current Pri.	-100000.00 ...100000.00A	0.01A	Primary measurement from each phase current channel reactive current component.
I01 Resistive Current Pri.	-100000.00 ...100000.00A	0.01A	Primary measurement from residual current channel I01 resistive current component.
I01 Reactive Current Pri.	-100000.00 ...100000.00A	0.01A	Primary measurement from residual current channel I01 reactive current component.
I02 Resistive Current Pri.	-100000.00 ...100000.00A	0.01A	Primary measurement from residual current channel I02 resistive current component.
I02 Reactive Current Pri.	-100000.00 ...100000.00A	0.01A	Primary measurement from residual current channel I02 reactive current component.

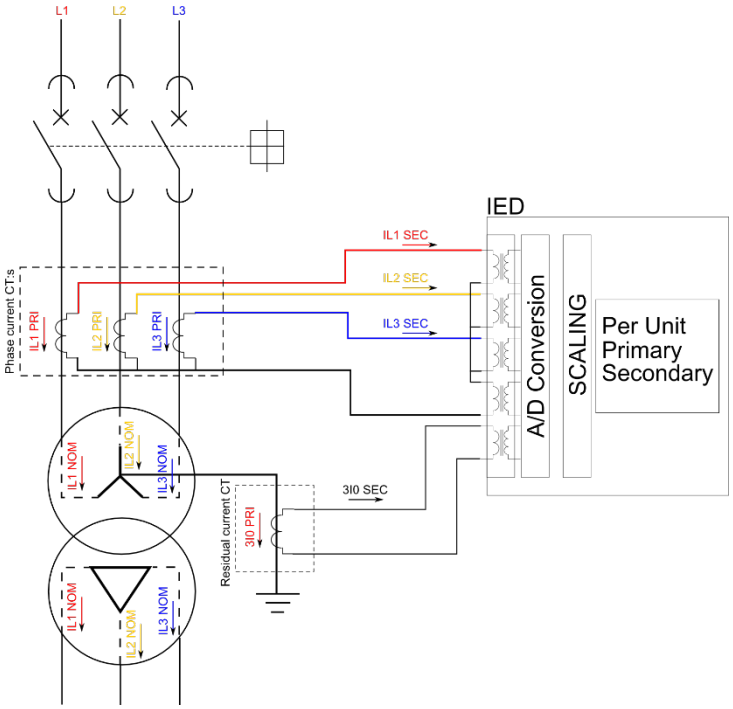
Table 2.21 Secondary phase current component measurements

Name	Range	Step	Description
ILx Resistive Current Sec.	-300.00...300.00A	0.01A	Secondary measurement from each phase current channel resistive current component.
ILx Reactive Current Sec.	-300.00...300.00A	0.01A	Secondary measurement from each phase current channel reactive current component.
Pos.Seq Resistive Current Sec.	-300.00...300.00A	0.01A	Secondary measurement from each phase current channel resistive current component.
Pos.Seq Reactive Current Sec.	-300.00...300.00A	0.01A	Secondary measurement from each phase current channel reactive current component.
I01 Resistive Current Pri.	-300.00...300.00A	0.01A	Secondary measurement from residual current channel I01 resistive current component.
I01 Reactive Current Pri.	-300.00...300.00A	0.01A	Secondary measurement from residual current channel I01 reactive current component.
I02 Resistive Current Pri.	-300.00...300.00A	0.01A	Secondary measurement from residual current channel I02 resistive current component.
I02 Reactive Current Pri.	-300.00...300.00A	0.01A	Secondary measurement from residual current channel I02 reactive current component.

2.2.2 Current measurement and scaling in differential application

Current measurement module (CT-module) is used for measuring the currents from current transformers and processing the measured currents to measurement database and for use of measurement- and protection functions. For the measurements to be correct it is essential to understand the concept of current measurements.

Figure 2.13 Current measurement terminology



PRI: Primary current, the current which flows in the primary circuit and through primary side of the current transformer.

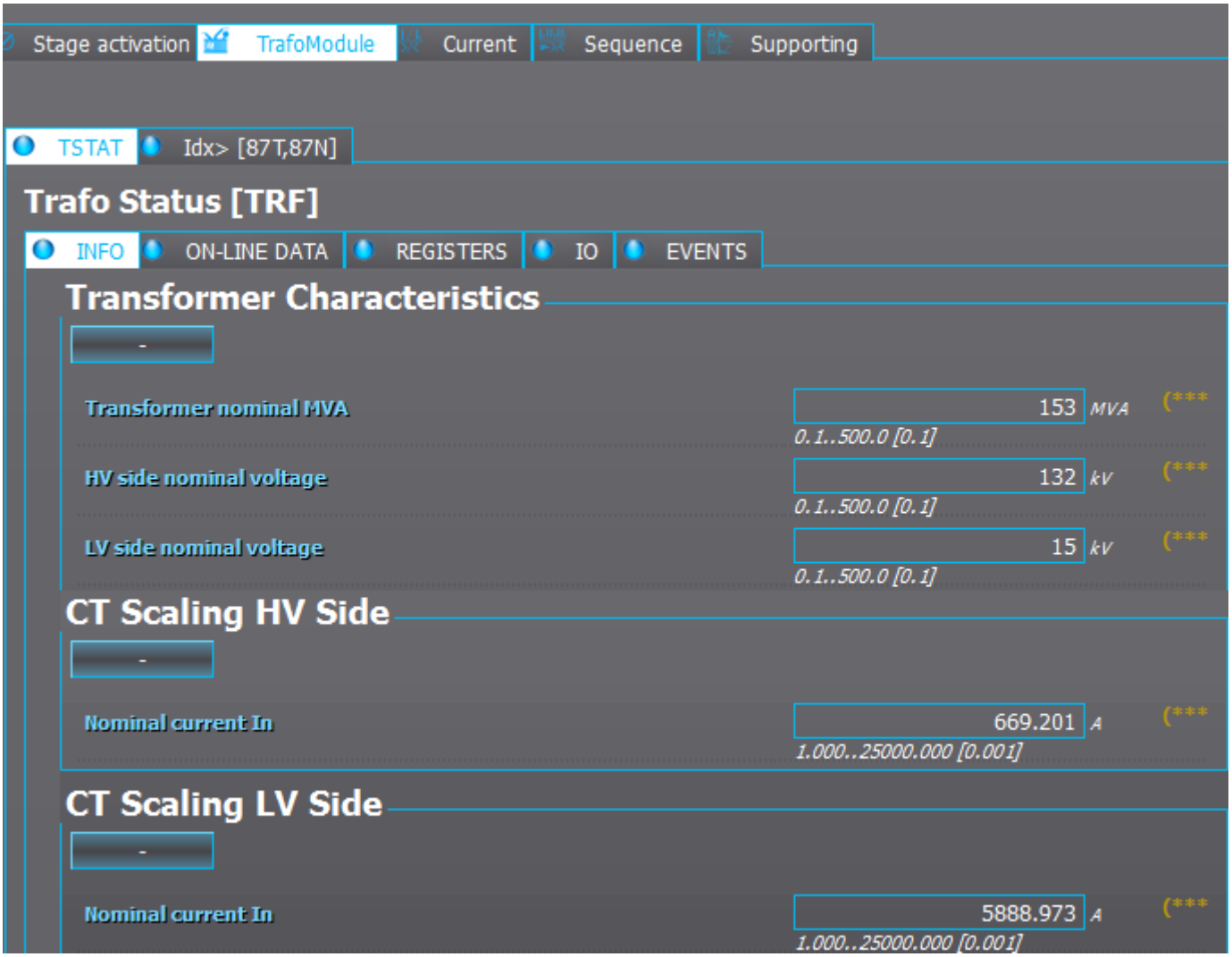
SEC: Secondary current, the current which the current transformer transforms according to its ratios. This current is measured by the protection IED.

NOM: Nominal primary current of the protected transformer. Nominal current differs on the HV and LV side according to the transformer voltage ratio. Nominal current is calculated based on transformers MVA and nominal voltage on each winding.

For the measurements to be correct it needs to be made sure that the measurement signals are connected to correct inputs, current direction is connected correctly and the scaling is set correctly.

For scaling, the relay calculates scaling factors based onto the set CT primary, secondary and nominal current values. Relay measures secondary current which in this case mean the current output from the current transformer which is installed into the primary circuit of the application. In order the relay to “know” primary and per unit values it needs to be told the current transformer rated primary and secondary currents. In case of a power transformer the protected unit nominal current in both windings is calculated based on given nominal power (MVA) and nominal voltage (V), only when the nominal current is known the settings can be per unitized to apparatus nominal. By knowing the transformer nominal current it makes the unit protection a lot easier and straight forward. In modern protection devices this scaling calculation is done internally after the current transformer primary, secondary and machine nominal currents are known.

Figure 2.14 Nominal current calculation in differential protection relay



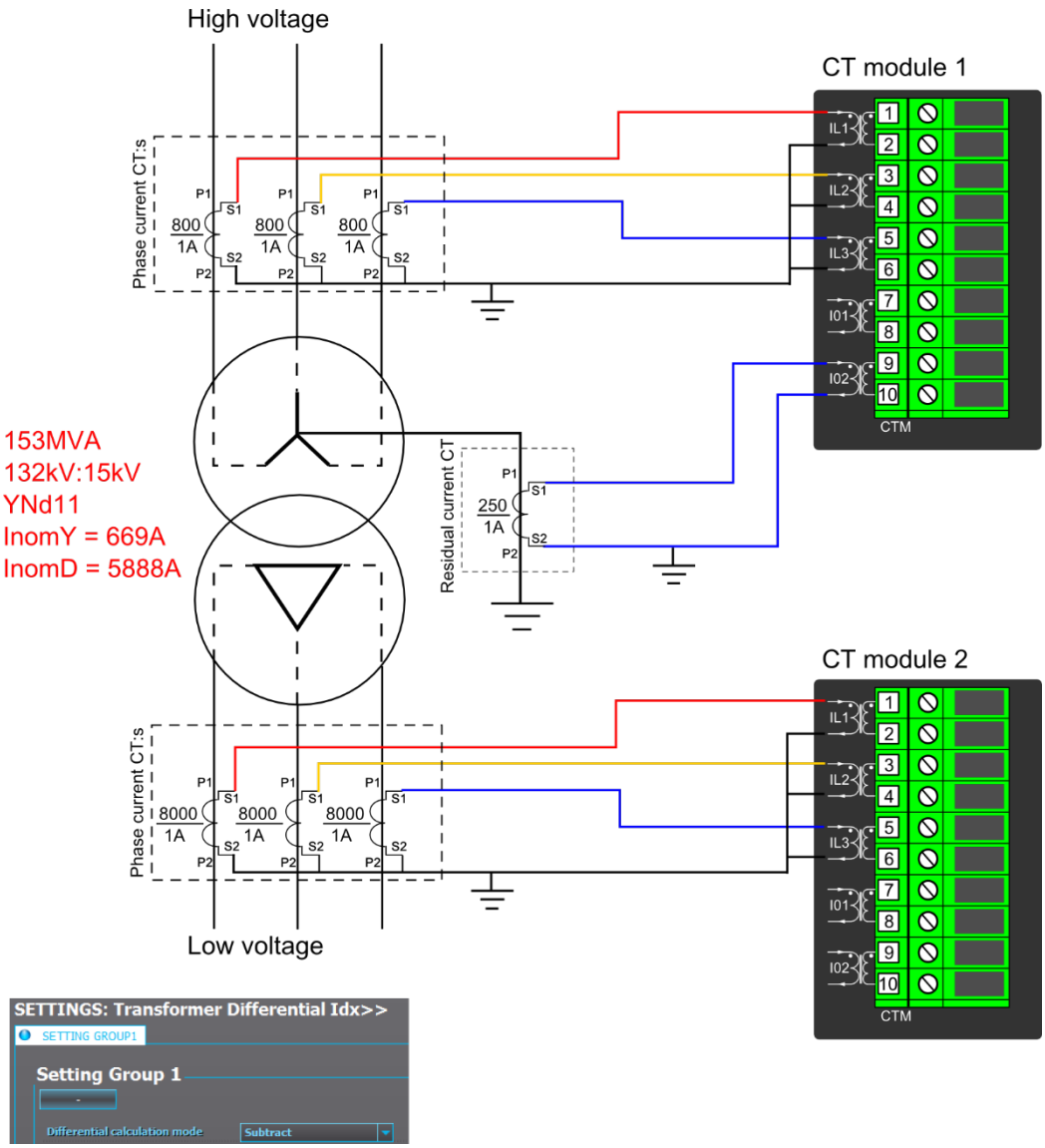
Normally the primary current ratings for phase current transformers are from 10A to thousands of Amps and their decimal multiples, while normal secondary current ratings are 1 and 5A. Other, non-standard ratings can be directly connected too since the scaling settings are flexible in large ranges. For ring core current transformers the ratings may be different. Ring core current transformers are commonly used for sensitive earth fault protection and their rated secondary may be as low as 0.2 A in some cases.

In following chapter is given example for the scaling of the relay measurements to the example current transformers and nominal load.

CT scaling example (application 1)

The connection of CTs to the IED measurement inputs and the ratings of the current transformers and transformer nominal current are as in following figure.

Figure 2.15 Example connection (S1 always to odd connector regardless the CT direction). CT direction is selected under differential function



Please see the above figure, as a result of the direction of the CTs and according to the fact that P1/S1 side of the CTs are always wired to the odd inputs of the relay CT module, the “Differential calculation mode” under the *Protection → TrafoModule → Idx> [87T,87N] → Settings* has to be set as “Subtract”. Due to this the direction of measured currents are checked correctly from the relay perspective.

Initial data of the connection and the ratings are presented in following table.

Table 2.22 Initial data from example connection.

High voltage side CT: CT primary 800A CT secondary 1A HV-side nominal current: 669A	Ring core CT in Input I02: 3I0CT primary 250A 3I0CT secondary 1A	Low voltage side CT: CT primary 8000A CT secondary 1A LV-side nominal current: 5888A
Both CTs are pointing through the transformer (HV-S2 and LV-S2 are pointing to same direction).		

Nominal current for both high voltage and low voltage side of the protected transformer are calculated based on given values under the “Transformer Characteristics” menu, which is located under the protection main menu. CT module 1 and 2

ratio can be set directly under the same menu, or optionally under *Measurement → Transformers* –menu. Per unit (PU) scaling is automatically set as fixed to “Object In p.u.” in all machine protection relays and it cannot be changed.

Figure 2.16 Phase current transformer scaling to machine nominal.



As it can be seen in the figure above, the high voltage side nominal current is calculated to be 669.2A and the low voltage side current is 5888.97A. These nominal currents are calculated as follow:

$$HV\ side\ nominal\ current(pri) = \frac{MVA/3}{U_{HV}/\sqrt{3}} = \frac{153000000/3}{132000/\sqrt{3}} = 669.2A$$

$$LV\ side\ nominal\ current(sec) = \frac{MVA/3}{U_{LV}/\sqrt{3}} = \frac{153000000/3}{15000/\sqrt{3}} = 5888.97A$$

Per unit values for high –and low voltage side nominal currents can be calculated as shown below:

$$HV\ CT\ nom\ to\ TR\ nom\ factor = \frac{HV\ side\ nominal\ current(pri)}{Phase\ CT\ primary} = \frac{669.2A}{800A} = 0.84p.u.$$

$$LV\ CT\ nom\ to\ TR\ nom\ factor = \frac{LV\ side\ nominal\ current(pri)}{Phase\ CT\ primary} = \frac{5888.97A}{8000A} = 0.74p.u.$$

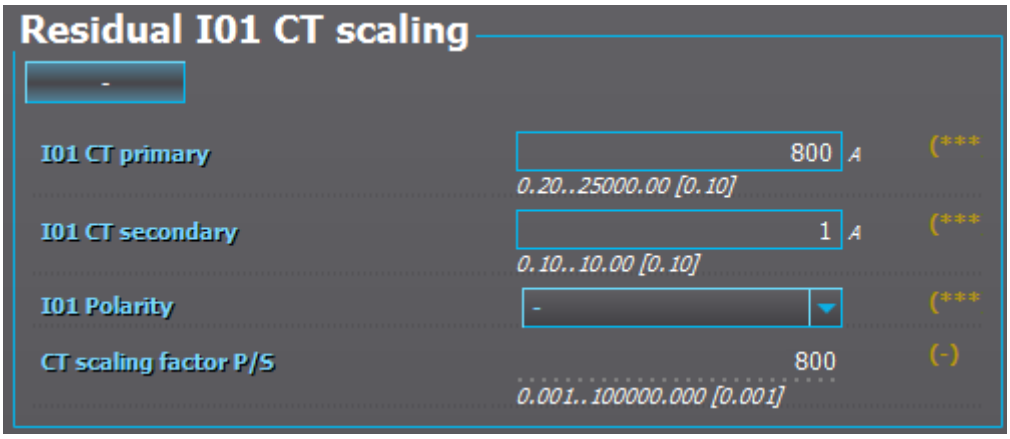
To multiply the per unit value with Phase CT secondary side current, it is possible to get the nominal secondary current of transformer as Amperes. This current can be used when the unit is commissioned and the directions of CTs are checked. See an example calculation below:

$$HV\ side\ nominal\ current(sec) = HV\ CT\ nom\ to\ TR\ nom\ factor\ \times Phase\ CT\ secondary\ = 0.84p.u. \times 1A = 0.84A$$

$$LV\ side\ nominal\ current(sec) = LV\ CT\ nom\ to\ TR\ nom\ factor\ \times Phase\ CT\ secondary\ = 0.74p.u. \times 1A = 0.74A$$

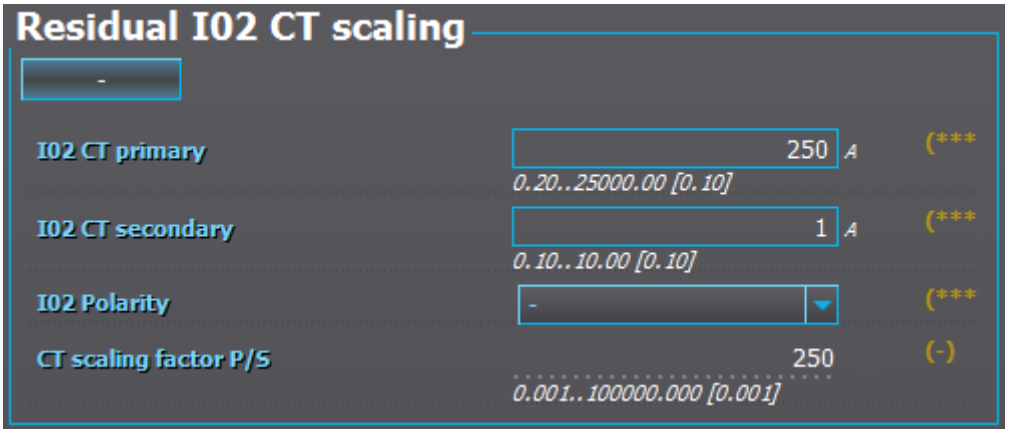
In case coarse residual current (I01) input is used for CT sum (Holmgren) input then it should be set to phase current CT ratings 100/5A.

Figure 2.17 Residual current I01 scaling to summing connection.



For the sensitive residual current (I02) measurement the CT primary and secondary currents are set directly as rated currents 250/1A.

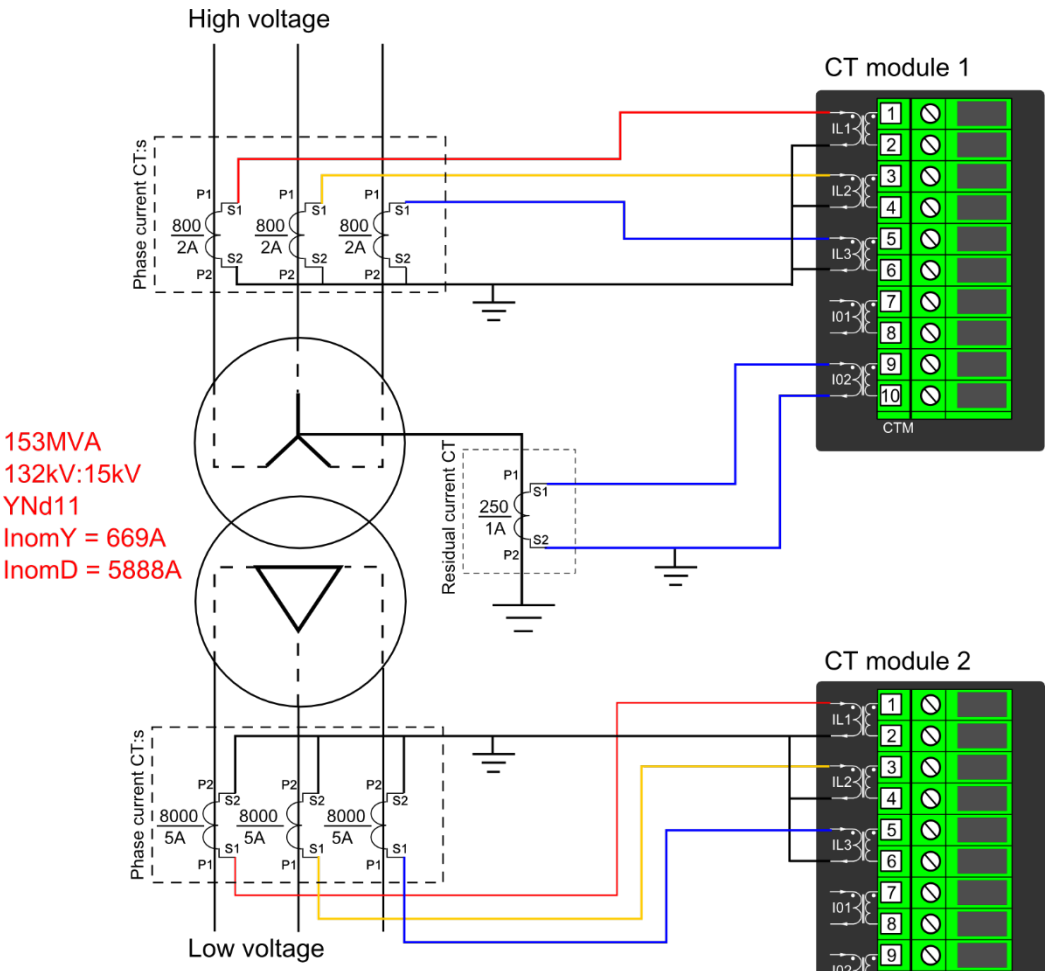
Figure 2.18 Residual current I02 scaling to ring core CT input.

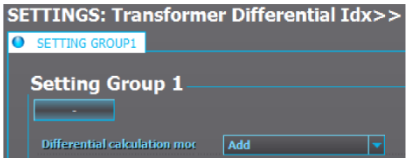


CT scaling example (application 2)

The connection of CTs to the IED measurement inputs and the ratings of the current transformers and transformer nominal current are as in following figure.

Figure 2.19 Example connection (S1 always to odd connector regardless the CT direction). CT direction is selected under differential function





Please see the above figure, as a result of the direction of the CTs and according to the fact that P1/S1 side of the CTs are always wired to the odd inputs of the relay CT module, the “Differential calculation mode” under the *Protection → TrafoModule → Idx> [87T,87N] → Settings* has to be set as “Add”. The difference to the first application is that here the CTs are pointing towards the protected object instead of pointing through it.

Initial data of the connection and the ratings are presented in following table.

Table 2.23 Initial data from example connection.

Machine nominal power: 153MVA Machine high voltage side nominal amplitude: 132kV Machine low voltage side nominal amplitude: 15kV		
High voltage side CT: CT primary 800A CT secondary 2A HV-side nominal current: 669A	Ring core CT in Input I02: 3I0CT primary 250A 3I0CT secondary 1A	Low voltage side CT: CT primary 8000A CT secondary 5A LV-side nominal current: 5888A
Both CTs are pointing through the transformer (HV-S2 and LV-S2 are pointing to same direction).		

The nominal currents on high voltage and low voltage side are exactly the same as in application 1. The only difference is that the secondary current level of the CTs have been changed to 2A on high voltage side and to 5A on low voltage side. Nominal currents are still calculated the same way:

$$HV\ side\ nominal\ current(pri) = \frac{MVA/3}{U_{HV}/\sqrt{3}} = \frac{153000000/3}{132000/\sqrt{3}} = 669.2A$$

$$LV\ side\ nominal\ current(sec) = \frac{MVA/3}{U_{LV}/\sqrt{3}} = \frac{153000000/3}{15000/\sqrt{3}} = 5888.97A$$

Per unit values for high –and low voltage side nominal currents can be calculated as shown below:

$$HV\ CT\ nom\ to\ TR\ nom\ factor = \frac{HV\ side\ nominal\ current(pri)}{Phase\ CT\ primary} = \frac{669.2A}{800A} = 0.84p.u.$$

$$LV\ CT\ nom\ to\ TR\ nom\ factor = \frac{LV\ side\ nominal\ current(pri)}{Phase\ CT\ primary} = \frac{5888.97A}{8000A} = 0.74p.u.$$

To multiply the per unit value with Phase CT secondary side current, it is possible to get the nominal secondary current of transformer as Amperes. This current can be used when the unit is commissioned and the directions of CTs are checked. In application 2 it is necessary to inject higher amplitudes to the CTs via secondary injection tool to reach the nominal currents. See an example calculation below:

$$HV\ side\ nominal\ current(sec) = HV\ CT\ nom\ to\ TR\ nom\ factor \times Phase\ CT\ secondary = 0.84p.u. \times 2A = 1.68A$$

$$LV\ side\ nominal\ current(sec) = LV\ CT\ nom\ to\ TR\ nom\ factor \times Phase\ CT\ secondary = 0.74p.u. \times 1A = 3.74A$$

Settings

Table 2.24 Settings of the Phase CT scaling

Name	Range	Step	Default	Description
Scale meas to In	0:CT nom p.u. 1:Object In p.u.	-	0:CT nom p.u.	Selection of the IED per unit system scaling reference, either the set phase current CT primary or protected object nominal current. (NOT APPLICABLE IN MACHINE PROTECTION).
Phase CT primary	1...5000.0A	0.1A	100.0A	Rated primary current of the CT in amperes.
Phase CT secondary	0.2...10.0A	0.1A	5.0A	Rated secondary current of the CT in amperes.
Nominal current In	1...5000A	0.01A	100.00A	Protected object nominal current in amperes. (This setting is visible if “Scale meas to In” setting is set to “Object In p.u.”)

Name	Range	Step	Default	Description
IL1 Polarity	0:- 1:Invert	-	0:-	IL1 (first current) measurement channel polarity (direction) selection. Default setting is that positive current flow is from connector 1 to connector 2 and the secondary currents starpoint is towards line.
IL2 Polarity	0:- 1:Invert	-	0:-	IL2 (second current) measurement channel polarity (direction) selection. Default setting is that positive current flow is from connector 3 to connector 4 and the secondary currents starpoint is towards line.
IL3 Polarity	0:- 1:Invert	-	0:-	IL3 (third current) measurement channel polarity (direction) selection. Default setting is that positive current flow is from connector 5 to connector 6 and the secondary currents starpoint is towards line.
CT scaling factor P/S	-	-	-	IED feedback value, this is the calculated scaling factor for primary /secondary current ratio
CT scaling factor NOM	-	-	-	IED feedback value, this is the calculated ratio in between of set primary and nominal currents.
Ipu scaling primary	-	-	-	IED feedback value, scaling factor from p.u. value to primary current.
Ipu scaling secondary	-	-	-	IED feedback value, scaling factor from p.u. value to secondary current.

Table 2.25 Settings of the residual I01 CT scaling

Name	Range	Step	Default	Description
I01 CT primary	1...5000.0A	0.1A	100.0A	Rated primary current of the CT in amperes.
I01 CT secondary	0.2...10.0A	0.1A	5.0A	Rated secondary current of the CT in amperes.
I01 Polarity	0:- 1:Invert	-	0:-	I01 (coarse residual) measurement channel polarity (direction) selection. Default setting is that positive current flow is from connector 7 to connector 8.
CT scaling factor P/S	-	-	-	IED feedback value, this is the calculated scaling factor for primary / secondary current ratio

Table 2.26 Settings of the residual I02 CT scaling

Name	Range	Step	Default	Description
I02 CT primary	1...5000.0A	0.1A	100.0A	Rated primary current of the CT in amperes.
I02 CT secondary	0.1...10.0A	0.1A	5.0A	Rated secondary current of the CT in amperes.
I02 Polarity	0:- 1:Invert	-	0:-	I02 (fine residual) measurement channel polarity (direction) selection. Default setting is that positive current flow is from connector 9 to connector 10.
CT scaling factor P/S	-	-	-	IED feedback value, this is the calculated scaling factor for primary / secondary current ratio

Measurements

Following measurements are available from the measured current channels.

Table 2.27 Per unit phase current measurements

Name	Range	Step	Description
Phase current ILx	0.00...1250.0xIn	0.01xIn	Per unit measurement from each phase current channel fundamental frequency RMS current.
Phase current ILx TRMS	0.00...1250.0xIn	0.01xIn	Per unit measurement from each current channel TRMS current including harmonics up to 31st.
Peak to peak current ILx	0.00...500.0xIn	0.01xIn	Per unit measurement peak to peak current from each phase current measurement channel.

Table 2.28 Primary phase current measurements

Name	Range	Step	Description
Primary Phase current ILx	0.00...1000000.0A	0.01A	Primary measurement from each phase current channel fundamental frequency RMS current.
Phase current ILx TRMS pri	0.00...1000000.0A	0.01A	Primary measurement from each current channel TRMS current including harmonics up to 31st.

Table 2.29 Secondary phase current measurements

Name	Range	Step	Description
Secondary Phase current ILx	0.00...300.0A	0.01A	Secondary measurement from each phase current channel fundamental frequency RMS current.
Phase current ILx TRMS sec	0.00...300.0A	0.01A	Secondary measurement from each current channel TRMS current including harmonics up to 31st.

Table 2.30 Phase current angles measurements

Name	Range	Step	Description
Phase angle ILx	0.00...360.00deg	0.01deg	Phase angle measurement of the three phase current inputs.

Table 2.31 Per unit residual current measurements

Name	Range	Step	Description
Residual current I01	0.00...1250.0xIn	0.01xIn	Per unit measurement from residual current channel I01 fundamental frequency RMS current.
Residual current I02	0.00...1250.0xIn	0.01xIn	Per unit measurement from residual current channel I02 fundamental frequency RMS current.
Calculated I0	0.00...1250.0xIn	0.01xIn	Per unit measurement from calculated I0 current fundamental frequency RMS current.
Phase current I01 TRMS	0.00...1250.0xIn	0.01xIn	Per unit measurement from I01 residual current channel TRMS current including harmonics up to 31st.
Phase current I02 TRMS	0.00...1250.0xIn	0.01xIn	Per unit measurement from I02 residual current channel TRMS current including harmonics up to 31st.
Peak to peak current I01	0.00...500.0xIn	0.01xIn	Per unit measurement peak to peak current from I01 residual current measurement channel.
Peak to peak current I02	0.00...500.0xIn	0.01xIn	Per unit measurement peak to peak current from I02 residual current measurement channel.

Table 2.32 Primary residual current measurements

Name	Range	Step	Description
Primary residual current I01	0.00...1000000.0A	0.01A	Primary measurement from residual current channel I01 fundamental frequency RMS current.
Primary residual current I02	0.00...1000000.0A	0.01A	Primary measurement from residual current channel I02 fundamental frequency RMS current.
Primary calculated I0	0.00...1000000.0A	0.01A	Primary measurement from calculated I0 fundamental frequency RMS current.
Residual current I01 TRMS pri	0.00...1000000.0A	0.01A	Primary measurement from residual current channel I01 TRMS current including harmonics up to 31st.
Residual current I02 TRMS pri	0.00...1000000.0A	0.01A	Primary measurement from residual current channel I02 TRMS current including harmonics up to 31st.

Table 2.33 Primary residual current measurements

Name	Range	Step	Description
Secondary residual current I01	0.00...300.0A	0.01A	Secondary measurement from residual current channel I01 fundamental frequency RMS current.
Secondary residual current I02	0.00...300.0A	0.01A	Secondary measurement from residual current channel I02 fundamental frequency RMS current.
Secondary calculated I0	0.00...300.0A	0.01A	Secondary measurement from calculated I0 fundamental frequency RMS current.
Residual current I01 TRMS sec	0.00...300.0A	0.01A	Secondary measurement from residual current channel I01 TRMS current including harmonics up to 31st.
Residual current I02 TRMS sec	0.00...300.0A	0.01A	Secondary measurement from residual current channel I02 TRMS current including harmonics up to 31st.

Table 2.34 Residual current angles measurements

Name	Range	Step	Description
Residual current angle I01	0.00...360.00deg	0.01deg	Residual current angle measurement of the I01 current input.
Residual current angle I02	0.00...360.00deg	0.01deg	Residual current angle measurement of the I02 current input.
Calculated I0 phase angle	0.00...360.00deg	0.01deg	Calculated residual current angle measurement.

Table 2.35 Per unit sequence current measurements

Name	Range	Step	Description
Positive sequence current	0.00...1250.0xIn	0.01xIn	Per unit measurement from calculated positive sequence current
Negative sequence current	0.00...1250.0xIn	0.01xIn	Per unit measurement from calculated negative sequence current
Zero sequence current	0.00...1250.0xIn	0.01xIn	Per unit measurement from calculated zero sequence current

Table 2.36 Primary sequence current measurements

Name	Range	Step	Description
Primary Positive sequence current	0.00...1000000.0A	0.01A	Primary measurement from calculated positive sequence current
Primary Negative sequence current	0.00...1000000.0A	0.01A	Primary measurement from calculated negative sequence current
Primary Zero sequence current	0.00...1000000.0A	0.01A	Primary measurement from calculated zero sequence current

Table 2.37 Secondary sequence current measurements

Name	Range	Step	Description
Secondary Positive sequence current	0.00...300.0A	0.01A	Secondary measurement from calculated positive sequence current
Secondary Negative sequence current	0.00...300.0A	0.01A	Secondary measurement from calculated negative sequence current
Secondary Zero sequence current	0.00...300.0A	0.01A	Secondary measurement from calculated zero sequence current

Table 2.38 Sequence current angle measurements

Name	Range	Step	Description
Positive sequence current angle	0.00...360.0deg	0.01deg	Calculated positive sequence current angle
Negative sequence current angle	0.00...360.0deg	0.01deg	Calculated negative sequence current angle
Zero sequence current angle	0.00...360.0deg	0.01deg	Calculated zero sequence current angle

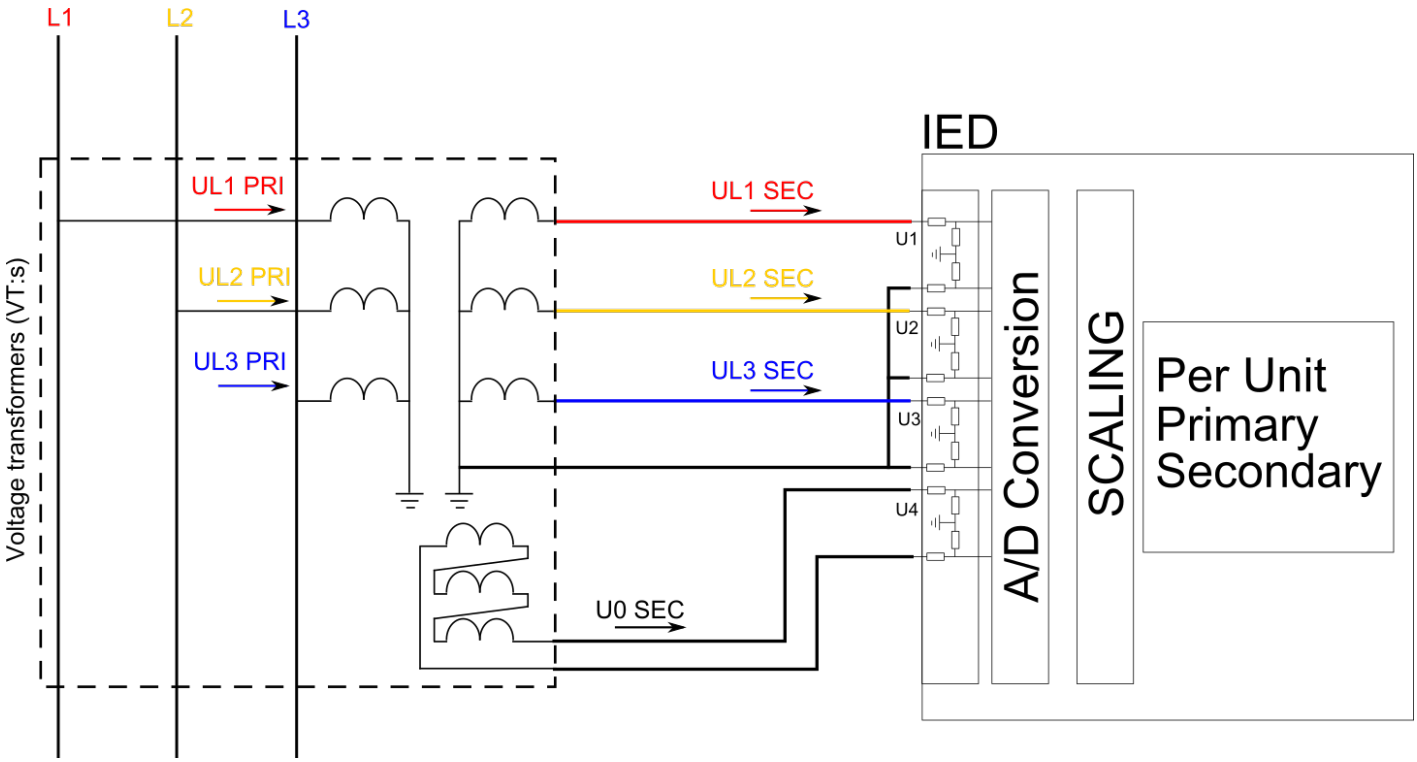
Table 2.39 Harmonic current measurements

Name	Range	Step	Description
IL1 Harmonics IL1 fund...IL1 31harm	0.00...1000000.0A	0.01A	Per unit, primary and secondary harmonics per component for current input IL1
IL2 Harmonics IL2 fund...IL2 31harm	0.00...1000000.0A	0.01A	Per unit, primary and secondary harmonics per component for current input IL2
IL3 Harmonics IL3 fund...IL3 31harm	0.00...1000000.0A	0.01A	Per unit, primary and secondary harmonics per component for current input IL3
I01 Harmonics I01 fund...I01 31harm	0.00...1000000.0A	0.01A	Per unit, primary and secondary harmonics per component for current input I01
I02 Harmonics I02 fund...I02 31harm	0.00...1000000.0A	0.01A	Per unit, primary and secondary harmonics per component for current input I02

2.2.3 Voltage measurement and scaling

Voltage measurement module (VT-module) is used for measuring the voltages from voltage transformers and processing the measured voltages to measurement database and for use of measurement- and protection functions (protection function availability depends on IED type). For the measurements to be correct it is essential to understand the concept of the IEDs voltage measurements.

Figure 2.20 Voltage measurement terminology



For the measurements to be correct it is important to make sure that the measurement signals are connected to correct inputs and direction of voltages are connected right and the scaling is set correctly.

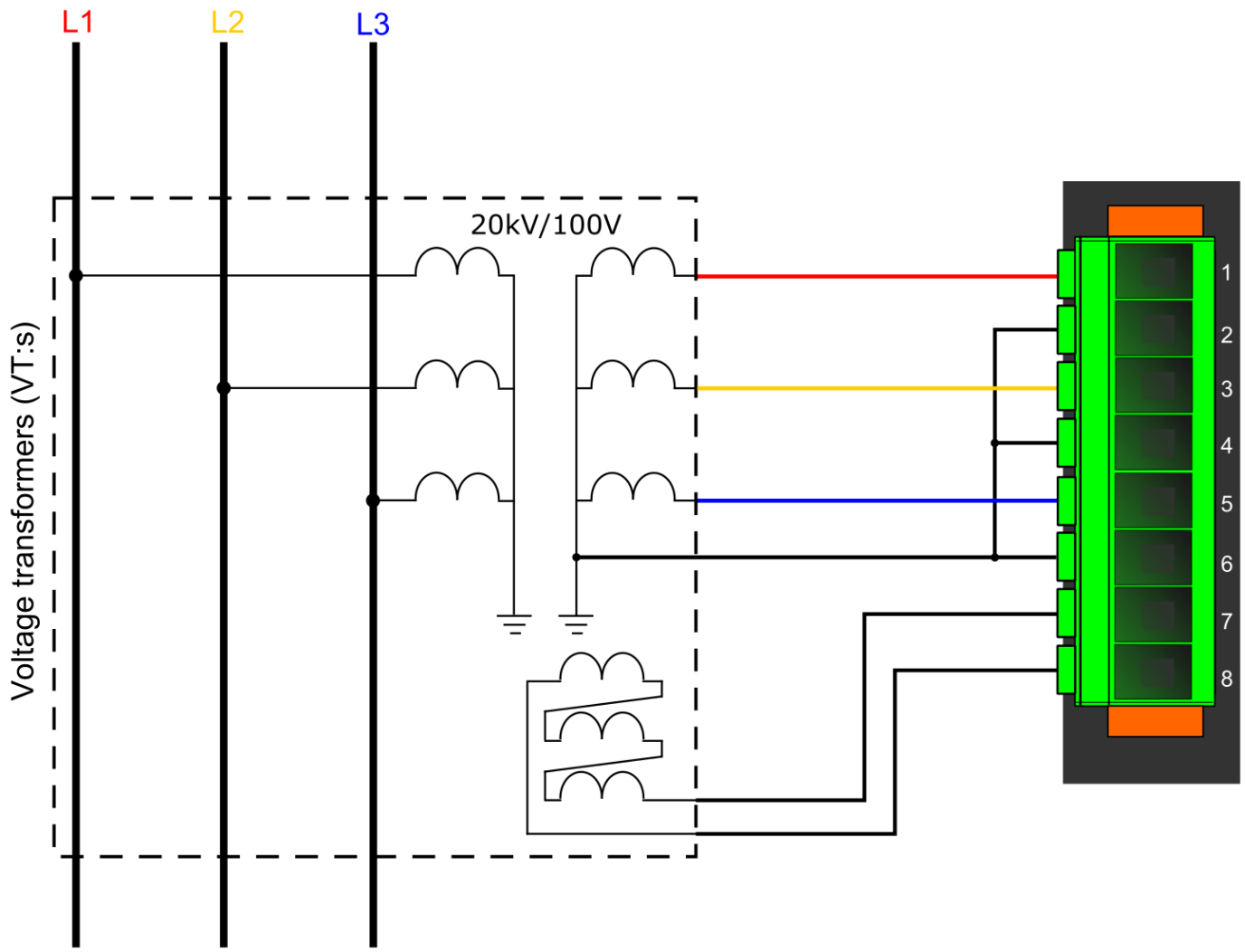
Relay calculates scaling factors based on the set VT primary and secondary voltage values. Relay measures secondary voltages which in this case mean the voltage outputs from the voltage transformer that is installed into the primary circuit of the application. Voltage can be measured up to 400V system directly as well. For the relay to “know” primary and per unit values the voltage transformer rated primary and secondary voltages need to be set. In modern IEDs like the scaling calculation is done internally after the voltage transformer primary and secondary voltages are given.

Normally the primary line to line voltage rating for voltage transformers between 400V and 600kV while normally secondary voltage ratings are 100-120V. Non-standard ratings can also be directly connected since the scaling settings are flexible in large ranges.

VT scaling example

The connection of VTs to the IED measurement inputs and the ratings of the voltage transformers are as in following figure. In figure below line to neutral voltages are connected among with zero sequence voltage. Other connection possibilities are presented in this chapter.

Figure 2.21 Example connection with three line to neutral voltages and zero sequence voltage connected. 3LN+U4 mode has to be selected. U4 channel has to be set as U0.



Initial data of the connection and the ratings are presented in following table.

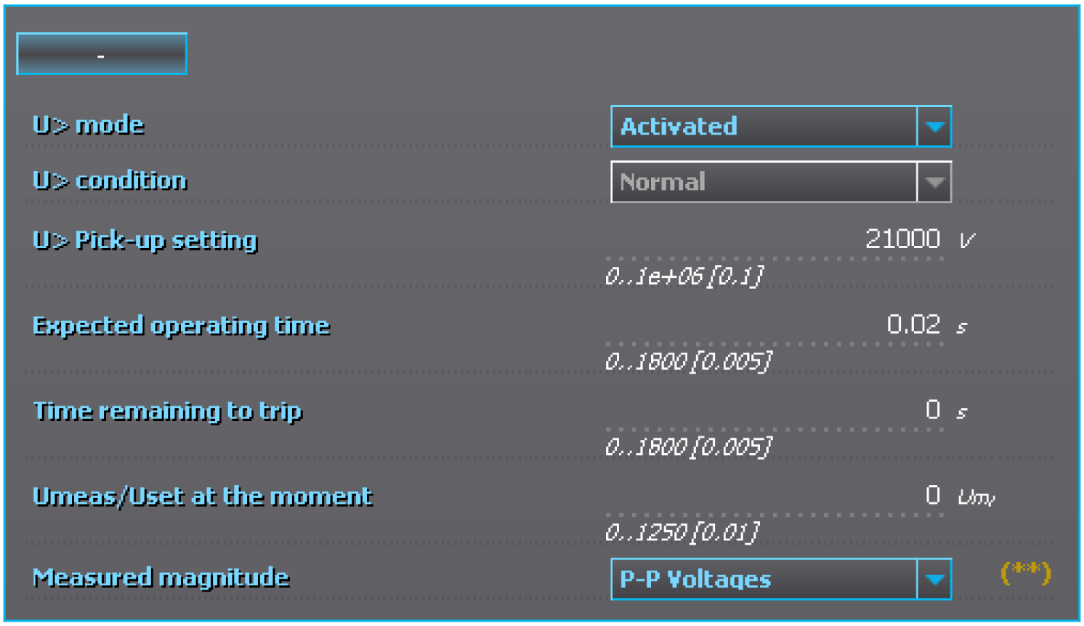
Table 2.40 Initial data of previous example connection.

Phase voltage VT: VT primary 20000V VT secondary 100V	Zero sequence voltage VT: U4 VT primary 20000V U4 VT secondary 100V
Zero sequence voltage is connected similar way with Line to neutral voltages (+U0). In case of incorrect wiring all polarities can be switched individually by 180 degrees in IED.	

If voltage based protection is used the supervised voltage may be based on line to line –or line to earth voltages. This selection is completed in each protection stage menu separately.

Voltage protection is based on nominal voltage. If 20000V is set to be the nominal voltage this equals 100% setting in voltage based protection functions. 120% trip setting in overvoltage stage equals to 24000V on primary level so 20% increase in this case would be 4000V.

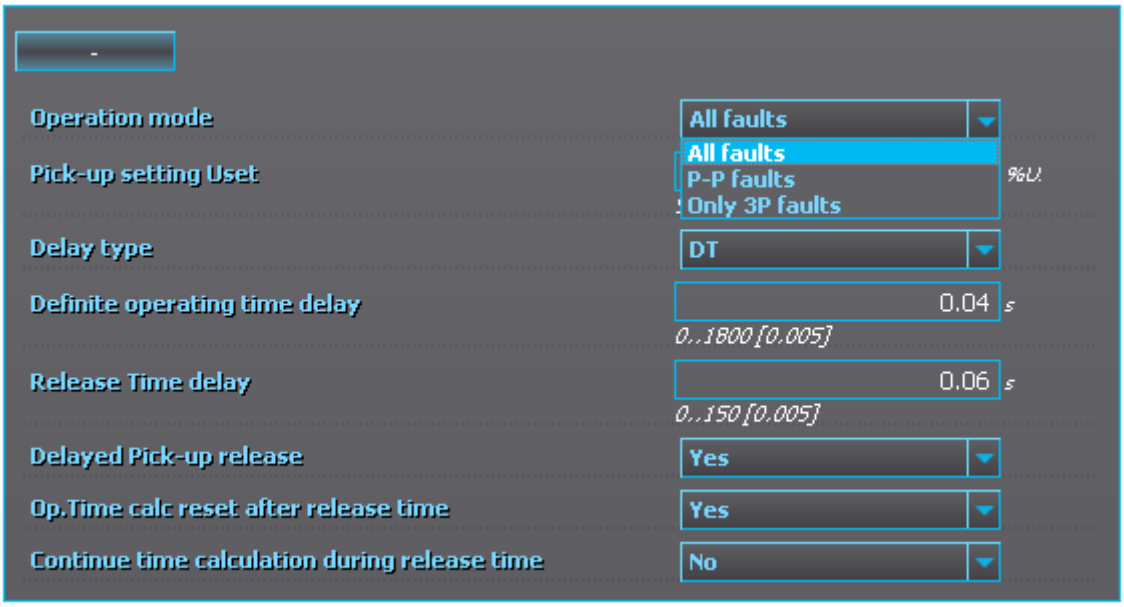
Figure 2.22 Voltage may be based on line to line voltage or line to neutral voltage. This selection is completed in “Measured magnitude” –menu under each voltage protection stage separately. Availability of protection functions depends on IED type.



After the settings are input to the IED scaling factors are also calculated and displayed for the user. Scaling factor P/S tells the VT primary to secondary ratio. Per unit scaling factors to primary and secondary values are also shown.

Triggering of voltage protection stage can be based on single, dual or all three fault loops. Fault loops are either line to line or line to neutral according the “Measured magnitude” setting.

Figure 2.23 Activation of one fault loop will trip the voltage protection stage as a default.



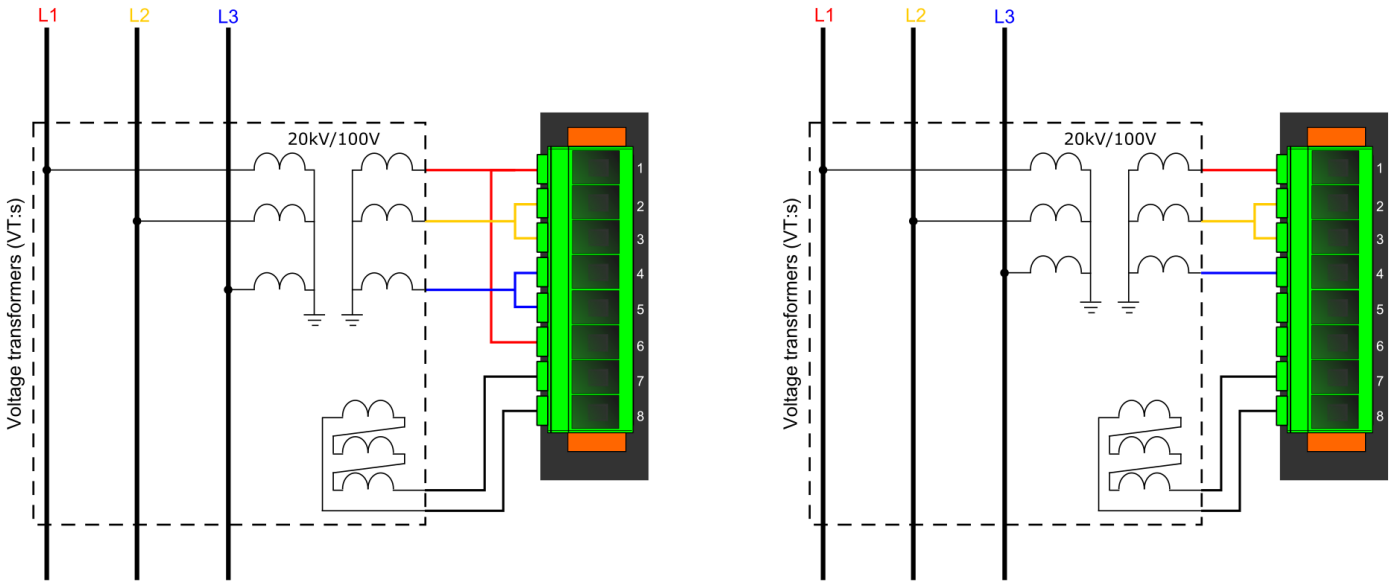
There are several different ways to use all four voltage channels. Most common voltage measurement mode is the three from line to neutral voltages and measured zero sequence voltage 3LN+U0. For further information see different voltage measurement mode examples below:

- 3LN+U4
- 3LL+U4

- 2LL+U3+U4

See below connection wirings for 3LL and 2LL connections.

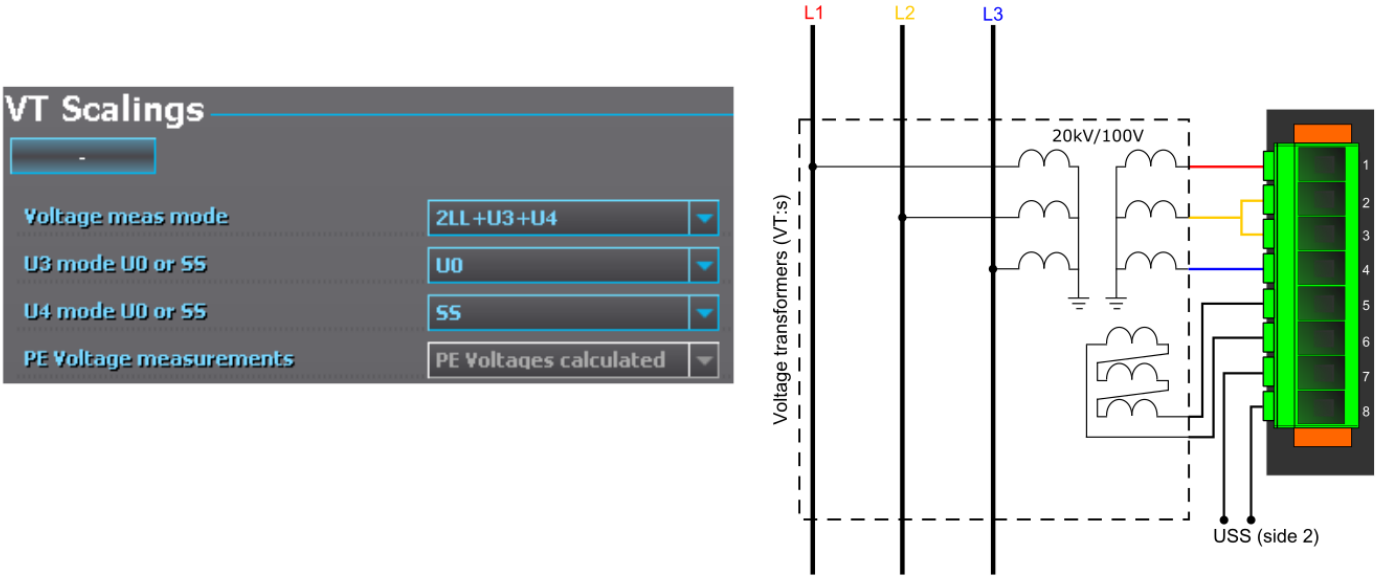
Figure 2.24 Example connections for voltage line to line measurement. Three line- to line voltages on the left and two on the right.



In case only two line to line voltages are measured the third one is calculated based on U12 and U23 vectors. When measuring line to line voltages the line to neutral voltages can be calculated if U0 is measured and known.

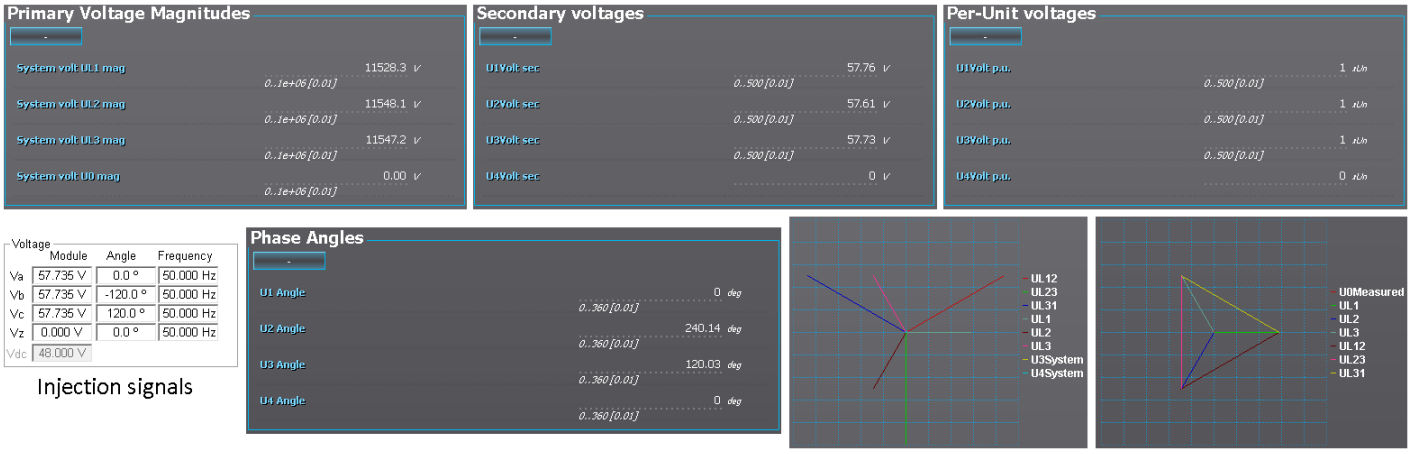
Voltage measurement channel U4 can always be used for either zero sequence voltage U0 or side 2 voltage measurement (Synchro-check). In case 2LL+U3+U4 mode is selected the third channel U3 can be used to similar purpose. Be noticed that U0 can be measured only by using one channel.

Figure 2.25 Two line to line measurements with zero sequence voltage and voltage from side 2 for Synchro-check 2LL +U0+SS. Line to neutral voltages can be calculated since U0 is available.



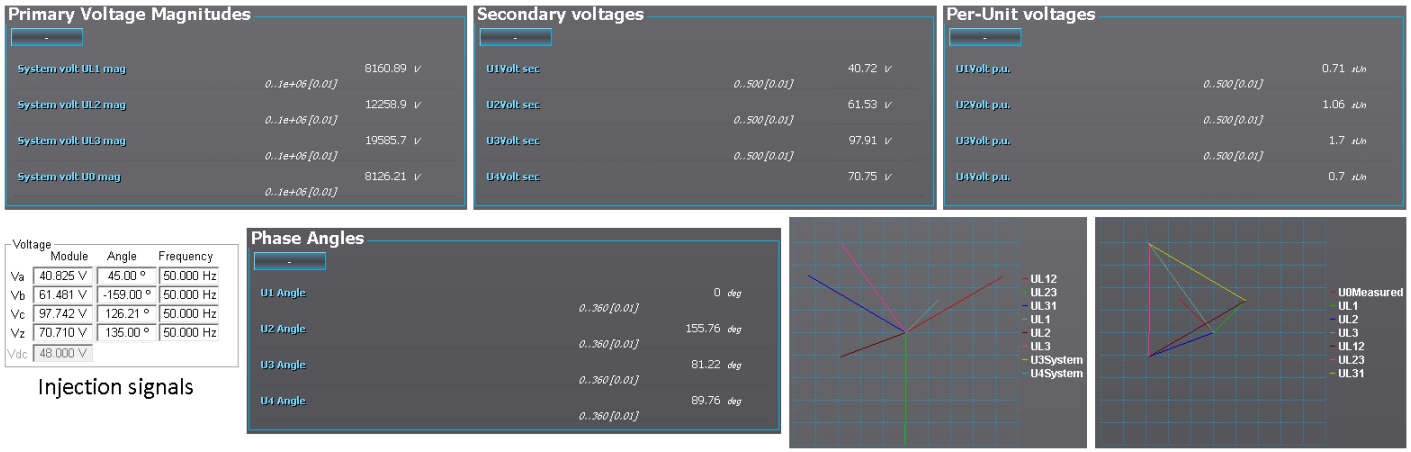
In the next figure is presented relay behavior when nominal voltage is injected to the relay and the IED is measuring line to neutral voltages. Part of the available information from the IED is presented as well:

Figure 2.26 Nominal voltage injection to the IED by using secondary test equipment. Voltage transformer scaling is set to 20000:100 V. Voltage measurement mode is 3LN+U4 and U4 channel is measuring zero sequence voltage which has same ratio 20000:100 V.



Injection signals

Figure 2.27 Voltage injection during earth fault to the IED by using secondary test equipment. Voltage transformer scaling is set to 20000:100 V. Voltage measurement mode is 3LN+U4 and U4 channel is measuring zero sequence voltage which has same ratio 20000:100 V.

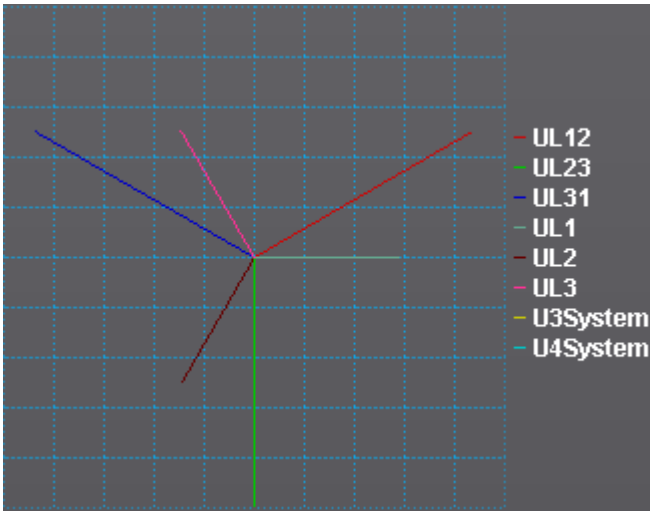


Injection signals

Troubleshooting

It is possible that for some reason the measured voltages may not be as expected. For these cases following checks may be helpful.

Problem	**Check / Resolution**
Measured voltage amplitude in all phases does not match for what is injected.	Scaling settings or voltage measurement mode may be wrong, check from *Measurement → Transformers → VT Module* that the settings match for what is expected.
Measured voltage amplitude does not match for one measured phase or calculated U0 is	Wiring connections from injection device or VT:s to the IED.

Problem	Check / Resolution
measured when there should not be any.	
Measured voltage amplitudes are all ok and equal but the angles are strange. Voltage unbalance protection trips immediately when it is activated. Earth fault protection trips immediately when it is activated and voltage is calculated.	Voltages are connected into the measurement module, but the order or polarity of one or all phases is incorrect. Go to *Measurement → Phasors* and check the voltage vector diagram. When all is correctly connected the diagram should look as below with symmetric feeding: 

Settings

Table 2.41 Settings of the VT scaling.

Name	Range	Step	Default	Description
Voltage meas mode	0:3LN+U4 1:3LL+U4 2:2LL+U3+U4	-	0:3LN+U4	Voltage wiring method to the IED. Voltages are scaled according the set voltage measurement mode.
U3 mode U0 or SS	0:NotUsed 1:U0 2:SS	-	0:NotUsed	Voltage channel U3 can be used to measure zero sequence voltage U0 or Synchro-check voltage SS. In case these are not needed the default setting “NotUsed” should be active. (Valid only in 2LL+U3+U4 mode)
U0 (U3) Measured from	0:Broken Delta 1:Neutral point 2:Open delta	-	0:Broken delta	Defines how secondary voltage is scaled to primary. Does not affect to how protection operates – only affects to displayed primary voltages. Parameter visible when U3 channel has been set to “U0” mode.
U4 mode U0 or SS	0:NotUsed 1:U0 2:SS	-	0:NotUsed	Voltage channel U3 can be used to measure zero sequence voltage U0 or Synchro-check voltage SS. In

Name	Range	Step	Default	Description
				case these are not needed the default setting “NotUsed” should be active.
U0 (U4) Measured from	0:Broken Delta 1:Neutral point 2:Open delta	-	0:Broken delta	Connected U0 voltage. Defines how secondary voltage is scaled to primary. Does not affect to how protection operates – only affects to displayed primary voltages. Parameter visible when U3 channel has been set to “U0” mode.
PE Voltage measurements	0=NO PE voltages avail. 1=PE Voltages calculated 2=PE Voltages measured	-	-	Indicates if phase to earth voltages are available or not and if the voltages are measured from the voltage channels directly or if they are calculated from line to line and neutral voltages.
VT primary	1...1000000.0 V	0.1V	20000.0V	Rated primary voltage of the VT in volts.
VT secondary	0.2...400.0 V	0.1V	100.0V	Rated secondary voltage of the VT in volts.
U3 Res/SS VT primary	1...1000000V	0.1V	20000.0V	Primary nominal voltage of connected U0 –or SS VT. (Valid only in 2LL+U3+U4 mode)
U3 Res/SS VT secondary	0.2...400V	0.1V	100.0V	Secondary nominal voltage of connected U0 –or SS VT. (Valid only in 2LL+U3+U4 mode)
U4 Res/SS VT primary	1...1000000V	0.1V	20000.0V	Primary nominal voltage of connected U0 –or SS VT.
U4 Res/SS VT secondary	0.2...400V	0.1V	100.0V	Secondary nominal voltage of connected U0 –or SS VT.
U1 Polarity	0:- 1:Invert	-	0:-	U1 (first voltage) measurement channel polarity (direction) selection. Default setting is that positive voltage flow is from connector 1 to connector 2 and the secondary voltage star point is towards line.
U2 Polarity	0:- 1:Invert	-	0:-	U2 (second voltage) measurement channel polarity (direction) selection. Default setting is that positive voltage flow is from connector 1 to connector 2 and the secondary voltage star point is towards line.
U3 Polarity	0:- 1:Invert	-	0:-	U3 (third voltage) measurement channel polarity (direction) selection. Default setting is that positive voltage flow is from connector 1 to connector 2 and the secondary voltage star point is towards line.
U4 Polarity	0:- 1:Invert	-	0:-	U4 (fourth voltage) measurement channel polarity (direction) selection. Default setting is that positive voltage flow is from connector 1 to connector 2 and the secondary voltage star point is towards line.
VT scaling factor P/S	-	-	-	IED feedback value, this is the calculated scaling factor for primary /secondary voltage ratio
VT scaling factor p.u. Pri	-	-	-	IED feedback value, scaling factor from p.u. value to primary voltage.
VT scaling factor p.u. Sec	-	-	-	IED feedback value, scaling factor from p.u. value to secondary voltage.
U3 VT scaling factor P/S U0/SS	-	-	-	IED feedback value, this is the calculated scaling factor for primary /secondary voltage ratio of voltage channel U3. (Valid only in 2LL+U3+U4 mode)
U3 scaling factor p.u. Pri	-	-	-	IED voltage channel U3 feedback value, scaling factor from p.u. value to primary voltage. (Valid only in 2LL +U3+U4 mode)

Name	Range	Step	Default	Description
U3 scaling factor p.u. Sec	-	-	-	IED voltage channel U3 feedback value, scaling factor from p.u. value to secondary voltage. (Valid only in 2LL +U3+U4 mode)
U4 VT scaling factor P/S U0/SS	-	-	-	IED feedback value, this is the calculated scaling factor for primary /secondary voltage ratio of voltage channel U4.
U4 scaling factor p.u. Pri	-	-	-	IED voltage channel U4 feedback value, scaling factor from p.u. value to primary voltage.
U4 scaling factor p.u. Sec	-	-	-	IED voltage channel U4 feedback value, scaling factor from p.u. value to secondary voltage.

Measurements

Following measurements are available from the measured voltage channels.

Table 2.42 Per unit voltage measurements.

Name	Range	Step	Description
Ux Volt p.u.	0.00...500.0xUn	0.01V	Per unit measurement from each voltage channel fundamental frequency RMS voltage.
UxVolt TRMS p.u.	0.00...500.0xUn	0.01V	Per unit measurement from each voltage channel TRMS voltage including harmonics up to 31st.

Table 2.43 Secondary voltage measurements.

Name	Range	Step	Description
Ux Volt sec	0.00...500.0xUn	0.01V	Secondary measurement from each voltage channel fundamental frequency RMS voltage.
UxVolt TRMS sec	0.00...500.0xUn	0.01V	Secondary measurement from each voltage channel TRMS voltage including harmonics up to 31st.

Table 2.44 Voltage phase angle measurements.

Name	Range	Step	Description
Ux Angle	0.00...360.00deg	0.01deg	Phase angle measurement of the four voltage inputs.

Table 2.45 Per unit sequence voltage measurements.

Name	Range	Step	Description
Pos.seq.Volt.p.u.	0.00...500.0xUn	0.01xUn	Per unit measurement from calculated positive sequence voltage
Neg.seq.Volt.p.u.	0.00...500.0xUn	0.01xUn	Per unit measurement from calculated negative sequence voltage
Zero.seq.Volt.p.u.	0.00...500.0xUn	0.01xUn	Per unit measurement from calculated zero sequence voltage
U0 Calc.Volt p.u.	0.00...500.0xUn	0.01xUn	Per unit measurement from calculated residual voltage

Table 2.46 Primary sequence voltage measurements.

Name	Range	Step	Description
Pos.seq.Volt.pri	0.00...1000000.00xUn	0.01V	Primary measurement from calculated positive sequence voltage
Neg.seq.Volt.pri	0.00...1000000.00xUn	0.01V	Primary measurement from calculated negative sequence voltage
Zero.seq.Volt.pri	0.00...1000000.00xUn	0.01V	Primary measurement from calculated zero sequence voltage
U0 Calc. pri	0.00...1000000.00xUn	0.01V	Primary measurement from calculated residual voltage

Table 2.47 Secondary sequence voltage measurements.

Name	Range	Step	Description
Pos.seq.Volt.sec	0.00...4800.0V	0.01V	Secondary measurement from calculated positive sequence voltage
Neg.seq.Volt.sec	0.00...4800.0V	0.01V	Secondary measurement from calculated negative sequence voltage
Zero.seq.Volt.sec	0.00...4800.0V	0.01V	Secondary measurement from calculated zero sequence voltage
U0 Calc. sec	0.00...4800.0V	0.01V	Secondary measurement from calculated residual voltage

Table 2.48 Sequence voltage angle measurements.

Name	Range	Step	Description
Pos.seq.Volt.Angle	0.00...360.0deg	0.01deg	Calculated positive sequence voltage angle
Neg.seq.Volt.Angle	0.00...360.0deg	0.01deg	Calculated negative sequence voltage angle
Zero.seq.Volt.Angle	0.00...360.0deg	0.01deg	Calculated zero sequence voltage angle

Table 2.49 Primary voltage measurements.

Name	Range	Step	Description
System volt UL12 mag	0.00...1000000.00V	0.01V	Primary measured or calculated fundamental frequency RMS line to line UL12 voltage.
System volt UL23 mag	0.00...1000000.00V	0.01V	Primary measured or calculated fundamental frequency RMS line to line UL23 voltage.
System volt UL31 mag	0.00...1000000.00V	0.01V	Primary measured or calculated fundamental frequency RMS line to line UL31 voltage.
System volt UL1 mag	0.00...1000000.00V	0.01V	Primary measured or calculated fundamental frequency RMS line to neutral UL1 voltage.
System volt UL2 mag	0.00...1000000.00V	0.01V	Primary measured or calculated fundamental frequency RMS line to neutral UL2 voltage.
System volt UL3 mag	0.00...1000000.00V	0.01V	Primary measured or calculated fundamental frequency RMS line to neutral UL3 voltage.
System volt U0 mag	0.00...1000000.00V	0.01V	Primary measured or calculated fundamental frequency RMS zero sequence U0 voltage.
System volt U3 mag	0.00...1000000.00V	0.01V	Primary measured fundamental frequency RMS Synchro-check SS voltage. (Valid only in 2LL+U3+U4 mode)
System volt U4 mag	0.00...1000000.00V	0.01V	Primary measured fundamental frequency RMS Synchro-check SS voltage.

Table 2.50 Voltage measurement angles.

Name	Range	Step	Description
System volt UL12 ang	0.00...360.0deg	0.01deg	Primary measured or calculated line to line UL12 angle.
System volt UL23 ang	0.00...360.0deg	0.01deg	Primary measured or calculated line to line UL23 angle.
System volt UL31 ang	0.00...360.0deg	0.01deg	Primary measured or calculated line to line UL31 angle.
System volt UL1 ang	0.00...360.0deg	0.01deg	Primary measured or calculated line to neutral UL1 angle.
System volt UL2 ang	0.00...360.0deg	0.01deg	Primary measured or calculated line to neutral UL2 angle.
System volt UL3 ang	0.00...360.0deg	0.01deg	Primary measured or calculated line to neutral UL3 angle.
System volt U0 ang	0.00...360.0deg	0.01deg	Primary measured or calculated zero sequence U0 angle.
System volt U3 ang	0.00...360.0deg	0.01deg	Primary measured Synchro-check SS angle. (Valid only in 2LL+U3+U4 mode)
System volt U4 ang	0.00...360.0deg	0.01deg	Primary measured Synchro-check SS angle.

Table 2.51 Harmonic voltage measurements.

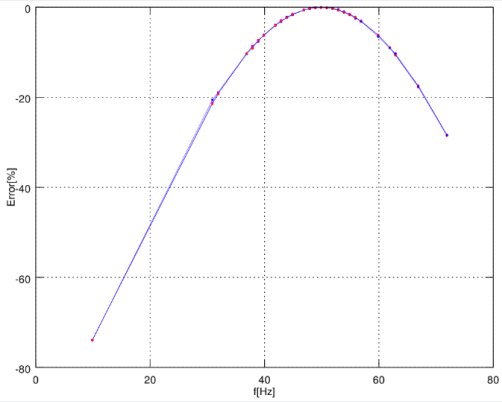
Name	Range	Step	Description
U1 Harmonics U1 fund...U1 31harm	0.00...100000.0V	0.01V	Selectable per unit, primary and secondary harmonics per component for voltage input U1
U2 Harmonics U2 fund...U2 31harm	0.00...100000.0V	0.01V	Selectable per unit, primary and secondary harmonics per component for voltage input U2
U3 Harmonics U3 fund...U3 31harm	0.00...100000.0V	0.01V	Selectable per unit, primary and secondary harmonics per component for voltage input U3
U4 Harmonics U4 fund...U4 31harm	0.00...100000.0V	0.01V	Selectable per unit, primary and secondary harmonics per component for voltage input U4

2.3 Tracked values

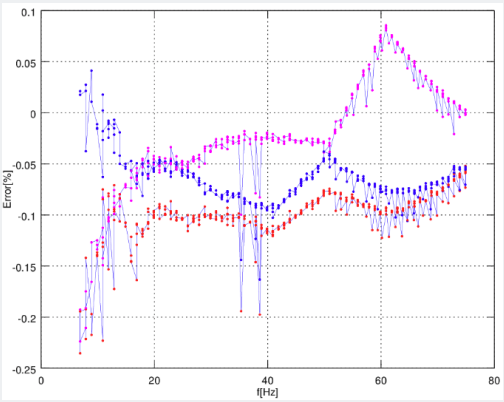
2.3.1 Frequency tracking and scaling

Measurement sampling can be set to frequency tracking mode or fixed user given frequency sampling mode. Benefit of the frequency tracking is that the measurements are in given accuracy range even when the fundamental frequency of the power system changes.

Table 2.52 Frequency tracking effect when the fundamental frequency is changing from 6 Hz to 75 Hz.



Measurement error with fixed 50Hz sampling frequency when frequency changes. Constant current of 5A, frequency sweep from 6 Hz to 75 Hz



Measurement error with frequency tracking when frequency changes. Constant current of 5A, frequency sweep from 6 Hz to 75 Hz

As can be seen in the figure above the sampling frequency has major effect to the measurement accuracy of the IED. If the sampling is not tracked to the system frequency it can be seen that even a change from set 50Hz to measured system frequency 60Hz (most common system frequencies) already gives measurement error of roughly over 5% in the measured phase currents. From the figure can also be seen that when the frequency is tracked the measurement accuracy is about -0.2% - 0.1% error in the whole frequency range when the sampling is adjusted according to the detected system frequency.

The system frequency independent measurement accuracy has been achieved in MVR-2xx series devices by adjusting the samplerate of the measurement channels according to the measured system frequency so that the FFT calculation has always whole power cycle in the buffer. Further improvement for the achieved measurement accuracy is the patented method of calibrating of the analog channels against 8 system frequency points for both, magnitude and angle. This frequency dependent correction compensates the used measurement hardware frequency dependencies. These two mentioned methods combined shall give the result of accurate system frequency independent measurement.

As can be noted generally that the frequency dependent sampling improves the measurement accuracy significantly also there can be seen that the measurement hardware is not linear considering the measured analog signal frequency. For this reason the magnitude and angle measurements need to be calibrated against frequency. For this purpose measured channels FFT result fundamental frequency component is corrected for magnitude and angle errors by MVR-2xx series patented calibration algorithms.

Troubleshooting

It is possible that for some reason the measured currents may not be as expected. For these cases following checks may be helpful.

Problem	Check / Resolution
Measured current or voltage amplitude is too low compared to what it should be. Values are “jumping” and are not stable.	Set system frequency may be wrong. Check the set frequency and that it matches to your local system frequency or change the measurement mode to “Tracking” and the IED will adjust the frequency by itself.
Frequency readings are wrong.	In tracking mode frequency interpreted by the relay may be wrong if there is no current/voltage injected to the CT or VT. Check the frequency measurement settings.

Settings

Table 2.53 Settings of the frequency tracking

Name	Range	Step	Default	Description
Sampling mode	0:Fixed 1:Tracking	-	0:Fixed	Selection of the IED measurement sampling mode either fixed user settable frequency or tracked system frequency
System nominal frequency	5...75Hz	1Hz	50Hz	User settable system nominal frequency when Sampling mode has been set to Fixed.
Tracked system frequency	5...75.0Hz	0.1Hz	-	Display of rough measured system frequency
Sampl.freq. used	5...75.0Hz	0.1Hz	-	Display of used tracking frequency at the moment
Freq.Reference 1	0:None 1:CT1IL1 2:CT2IL1 3:VT1U1 4:VT2U1	-	CT1IL1	Frequency tracking reference source 1

Name	Range	Step	Default	Description
Freq.Reference 2	0:None 1:CT1IL2 2:CT2IL2 3:VT1U2 4:VT2U2	-	CT1IL2	Frequency tracking reference source 2
Freq.Reference 3	0:None 1:CT1IL3 2:CT2IL3 3:VT1U3 4:VT2U3	-	CT1IL3	Frequency tracking reference source 3
Freq tracker quality	0:No trackable channels 1:Reference 1 Trackable 2:Reference 2 Trackable 3:Reference 1&2 Trackable 4:Reference 3 Trackable 5:Reference 1&3 Trackable 6:Reference 2&3 Trackable 7:All References Trackable	-	-	Frequency tracker quality. If the current or voltage measured amplitude is below the threshold channel tracking quality is 0 and cannot be used for frequency tracking. If all channels magnitudes are below threshold there will be no trackable channels.
Start behavior	0:Start tracking immediately 1:Use nom or tracked	-	0:Start tracking immediately	Start behavior of the frequency tracked. Can be set so that the tracking is started after set delay from the receiving of first trackable channel or tracking start immediately.
Start sampling with	0:Use track freq 1:Use nom freq	-	0:Use track freq.	Start of sampling selection, can be either previously tracked frequency or user set nominal frequency.
Use nom. freq. until	0...1800.000s	0.005s	0.100s	Setting how long nominal frequency is used when starting tracking. Setting is valid if tracking mode is active and start behavior is “Use nom or tracked”
Tracked F CHA	5...75.0Hz	0.1Hz	-	Display of the channel A tracked frequency, rough value.
Tracked F CHB	5...75.0Hz	0.1Hz	-	Display of the channel B tracked frequency, rough value.
Tracked F CHC	5...75.0Hz	0.1Hz	-	Display of the channel C tracked frequency, rough value.

2.4 Calculated values

2.4.1 Power and energy calculation

IEDs with both voltage –and current cards can calculate power and have power based protection and monitoring functions depending on the IED type. When power calculation is possible also the energy magnitudes are calculated.

Power is divided into three magnitudes, apparent power S, active power P and reactive power Q. Energy measurement is calculating magnitude for active and reactive energy. Energy can be flowing to forward (exported) or reverse (imported) direction.

If unit has more than one CT measurement module it is possible to choose which side modules current measurement is used by power calculation.

Line to neutral voltages available

Power is calculated from line to neutral voltages and phase currents. In case line to line voltages are connected the line to neutral voltages can be calculated based on measured zero sequence voltage. In line to neutral mode and in line to line voltage measurement mode when U0 is connected and measured the following equations apply for power calculation:

Below is presented formula for three phase apparent power (S) calculation:

$$S_{L1} = U_{L1} \times I_{L1}$$

$$S_{L2} = U_{L2} \times I_{L2}$$

$$S_{L3} = U_{L3} \times I_{L3}$$

$$S = S_{L1} + S_{L2} + S_{L3}$$

Below is presented formula for three phase active power (P) calculation:

$$P_{L1} = U_{L1} \times I_{L1} \cos \varphi$$

$$P_{L2} = U_{L2} \times I_{L2} \cos \varphi$$

$$P_{L3} = U_{L3} \times I_{L3} \cos \varphi$$

$$P = P_{L1} + P_{L2} + P_{L3}$$

Where phi is the angle difference between voltage and current.

Below is presented formula for three phase reactive power (Q) calculation:

$$Q_{L1} = U_{L1} \times I_{L1} \sin \varphi$$

$$Q_{L2} = U_{L2} \times I_{L2} \sin \varphi$$

$$Q_{L3} = U_{L3} \times I_{L3} \sin \varphi$$

$$Q = Q_{L1} + Q_{L2} + Q_{L3}$$

Active power direction can be to forward or reverse direction. Active power direction can be indicated simply by using Cos (φ). Cosine phi is calculated according the following formula:

$$3PH\ Cos(phi) = {}^{P}/_{S}$$

$$L1\ Cos(phi) = {}^{P_{L1}}/_{S_{L1}}$$

$$L2\ Cos(phi) = {}^{P_{L2}}/_{S_{L2}}$$

$$L3\ Cos(phi) = {}^{P_{L3}}/_{S_{L3}}$$

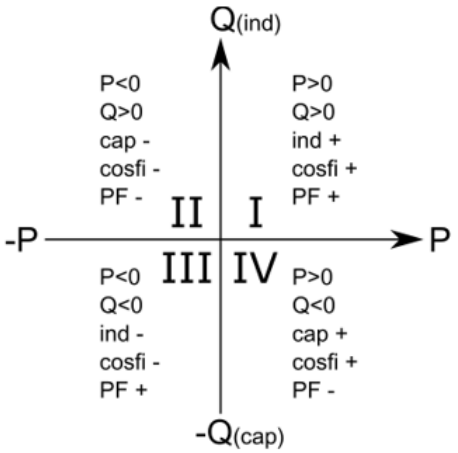
Direction of reactive power is divided in to four quadrants. Reactive power may be inductive or capacitive on both forward and reverse direction. Reactive power quadrant can be indicated simply by using Tan (φ) together with Cos(φ). Tangent phi is calculated according the following formula:

$$3PH\ Tan(phi) = {}^{Q}/_{P}$$

$$L1\ Tan(phi) = {}^{Q_{L1}}/_{P_{L1}}$$

$$L2\ Tan(phi) = {}^{Q_{L2}}/_{P_{L2}}$$

$$L3\ Tan(phi) = {}^{Q_{L3}}/_{P_{L3}}$$



Power factor calculation is done similarly to cosine phi but the polarity is defined by reactive power direction. Therefore power factor is calculated with the following formula:

$$3PH\ PF = {}^{P}/_{S} * {}^{Q}/_{|Q|}$$

$$L1\ PF = {}^{P_{L1}}/_{S_{L1}} * {}^{Q_{L1}}/_{|Q_{L1}|}$$

$$L2\ PF = {}^{P_{L2}}/_{S_{L2}} * {}^{Q_{L2}}/_{|Q_{L2}|}$$

$$L3\ PF = {}^{P_{L3}}/_{S_{L3}} * {}^{Q_{L3}}/_{|Q_{L3}|}$$

Only line to line voltages available

In case the line to line voltages are measured and zero sequence voltage is not measured and known the three phase power calculation is based on Aaron's theorem:

$$S = U_{23} \times I_{L1} \cos(30) + U_{31} \times I_{L2} \cos(30)$$

$$P = U_{23} \times I_{L1} \cos(30 - \varphi) + U_{31} \times I_{L2} \cos(30 + \varphi)$$

$$Q = U_{23} \times I_{L1} + \sin(30 - \varphi) + U_{31} \times I_{L2} \sin(30 + \varphi)$$

Cosine and tangent phi is calculated similar way with line to neutral mode.

Troubleshooting

Check troubleshooting section in chapters "Current measurement and scaling" and "Voltage measurement and scaling". Faulty power and energy measurement is normally related to same issues (wiring errors, wrong voltage measurement mode, faulty frequency settings etc.).

Settings

Table 2.54 Power and Energy meas. settings

Name	Range	Step	Default	Description
EP meas 3ph	0:Disabled 1:Enabled	-	0:Disabled	Enable active energy measurement.
EQ meas 3ph	0:Disabled	-	0:Disabled	Enable reactive energy measurement.

Name	Range	Step	Default	Description
	1:Enabled			
E 3ph M or k	0:Mega 1:Kilo	-	0:Mega	Measured energy in kilo –or mega values.
Enable editing energy values	0:Disabled 1:Enabled	-	0:Disabled	Enables user to set the energy value by hand. Please note that E 3ph M or k has to be set to kilo for this parameter to take effect.
PQ Quadrant	0=Undefined; 1:Q1 Fwd Ind; 2:Q2 Rev Cap; 3:Q3 Rev Ind; 4:Q4 Fwd Cap	-	0:Undefined	Indication of the power PQ quadrant at the moment.
VA Quadrant	0:Undefined; 1:Q1 Fwd Cap, AV; 2:Q2 Rev Ind AV; 3:Q3 Rev Cap VA; 4:Q4 Fwd Ind VA	-	0:Undefined	Indication of the power VA quadrant at the moment.
Reset 3ph Energies	0:- 1:Reset	-	0:-	Resets the memory of each 3 phase energy calculator. Goes back to “-“ -state automatically after reset.
EP meas per phase	0:Disabled 1:Enabled	-	0:Disabled	Enable active energy per phase measurement.
EQ meas per phase	0:Disabled 1:Enabled	-	0:Disabled	Enable reactive energy per phase measurement.
E phs M or k	0:Mega 1:Kilo	-	0:Mega	Measured energy per phase in kilo –or mega values.
Reset E per phase	0:- 1:Reset	-	0:-	Resets the memory of each phase energy calculator. Goes back to “-“ -state automatically after reset.

Table 2.55 Energy Dose Counter 1 settings

Name	Range	Step	Default	Description
Energy dose counter mode	0:Disabled 1:Activated	-	0:Disabled	Enable energy dose counters generally.
DC 1...4 enable	0:Disabled 1:Enabled	-	0:Disabled	Enable energy dose counter 1...4 individually.
DC 1...4 Input signal select	0:3PH.Fwd.Act.EP 1:3PH.Rev.Avt.EP 2:3PH.Fwd.Eact.EQ.CAP 3: 3PH.Fwd.Eact.EQ.IND 4:3PH.Rev.Eact.EQ.CAP 5: 3PH.Rev.Eact.EQ.IND	-	0:3PH.Fwd.Act.EP	Choose forward or reverse direction active or reactive energy magnitudes.
DC 1...4 Input signal	-1×10^{6}...1×10^{6}	0.01	-	Total amount of consumed energy.
DC 1...4 Pulse magnitude	0...1800	0.005	1 kW/Var	Set pulse size. Energy pulse is given every time when set magnitude exceeds.
DC 1...4 Pulse Length	0...1800	0.005	1 s	Total length of control pulse.

Table 2.56 DC 1...4 Pulse out settings

Name	Range	Step	Default	Description
DC 1...4 Pulse out	OUT1...OUTx	-	None selected	Controlled physical outputs selection.

Power measurements

Following power calculations are available when voltage and current cards are available.

Table 2.57 Three phase power calculation

Name	Range	Step	Description
3PH Apparent power (S)	$-1\times10^6...1\times10^6$ kVA	0.01kVA	Total 3 phase apparent power
3PH Active power (P)	$-1\times10^6...1\times10^6$ kW	0.01kW	Total 3 phase active power
3PH Reactive power (Q)	$-1\times10^6...1\times10^6$ kVar	0.01kVar	Total 3 phase reactive power
3PH Tan(phi)	$-1\times10^6...1\times10^6$	0.0001	3 phase active power direction
3PH Cos(phi)	$-1\times10^6...1\times10^6$	0.0001	3 phase reactive power direction
3PH PF	$-1\times10^6...1\times10^6$	0.0001	3 phase power factor

Table 2.58 Phase L1 power calculation

Name	Range	Step	Description
L1 Apparent power (S)	$-1\times10^6...1\times10^6$ kVA	0.01kVA	Phase L1 apparent power
L1 Active power (P)	$-1\times10^6...1\times10^6$ kW	0.01kW	Phase L1 active power
L1 Reactive power (Q)	$-1\times10^6...1\times10^6$ kVar	0.01kVar	Phase L1 reactive power
L1 Tan(phi)	$-1\times10^6...1\times10^6$	0.0001	Phase L1 active power direction
L1 Cos(phi)	$-1\times10^6...1\times10^6$	0.0001	Phase L1 reactive power direction
L1 PF	$-1\times10^6...1\times10^6$	0.0001	Phase L1 power factor

Table 2.59 Phase L2 power calculation

Name	Range	Step	Description
L2 Apparent power (S)	$-1\times10^6...1\times10^6$ kVA	0.01kVA	Phase L2 apparent power
L2 Active power (P)	$-1\times10^6...1\times10^6$ kW	0.01kW	Phase L2 active power
L2 Reactive power (Q)	$-1\times10^6...1\times10^6$ kVar	0.01kVar	Phase L2 reactive power
L2 Tan(phi)	$-1\times10^6...1\times10^6$	0.0001	Phase L2 active power direction
L2 Cos(phi)	$-1\times10^6...1\times10^6$	0.0001	Phase L2 reactive power direction
L2 PF	$-1\times10^6...1\times10^6$	0.0001	Phase L2 power factor

Table 2.60 Phase L3 power calculation

Name	Range	Step	Description
L3 Apparent power (S)	$-1\times10^6...1\times10^6$ kVA	0.01kVA	Phase L3 apparent power
L3 Active power (P)	$-1\times10^6...1\times10^6$ kW	0.01kW	Phase L3 active power
L3 Reactive power (Q)	$-1\times10^6...1\times10^6$ kVar	0.01kVar	Phase L3 reactive power

Name	Range	Step	Description
L3 Tan(phi)	$-1\times10^{6}...1\times10^{6}$	0.0001	Phase L3 active power direction
L3 Cos(phi)	$-1\times10^{6}...1\times10^{6}$	0.0001	Phase L3 reactive power direction
L3 PF	$-1\times10^{6}...1\times10^{6}$	0.0001	Phase L3 power factor

Energy measurements

Following energy calculations are available when voltage and current cards are available.

Table 2.61 Three phase energy calculation

Name	Range	Step	Description
Exp.Active Energy Mwh	-999999995904.000 ... 999999995904.000kWh/MWh	0.01 kWh/MWh	Total exported active energy
Imp.Active Energy Mwh	-999999995904.000 ... 999999995904.000kWh/MWh	0.01 kWh/MWh	Total imported active energy
Exp/Imp.Act.E balance Mwh	-999999995904.000 ... 999999995904.000kWh/MWh	0.01 kWh/MWh	Sum of imported and exported active energy
Exp.React.Cap.E.Mvarh	-999999995904.000 ... 999999995904.000kVarh/MVarh	0.01 kVarh/ MVarh	Total exported reactive capacitive energy
Imp.React.Cap.E.Mvarh	-999999995904.000 ... 999999995904.000kVarh/MVarh	0.01 kVarh/ MVarh	Total imported reactive capacitive energy
Exp/Imp React.Cap.E.bal.MVarh	-999999995904.000 ... 999999995904.000kVarh/MVarh	0.01 kVarh/ MVarh	Sum of imported and exported reactive capacitive energy
Exp.React.Ind.E.Mvarh	-999999995904.000 ... 999999995904.000kVarh/MVarh	0.01 kVarh/ MVarh	Total exported reactive inductive energy
Imp.React.Ind.E.Mvarh	-999999995904.000 ... 999999995904.000kVarh/MVarh	0.01 kVarh/ MVarh	Total imported reactive inductive energy
Exp/Imp React.Ind.E.bal.MVarh	-999999995904.000 ... 999999995904.000kVarh/MVarh	0.01 kVarh/ MVarh	Sum of imported and exported reactive inductive energy

Table 2.62 Phase L1 energy calculation

Name	Range	Step	Description
L1 Exp.Active Energy Mwh	$-1\times10^{9}...1\times10^{9}$ kWh/MWh	0.01MWh	Phase L1 exported active energy
L1 Imp.Active Energy Mwh	$-1\times10^{9}...1\times10^{9}$ kWh/MWh	0.01MWh	Phase L1 imported active energy
L1 Exp/Imp.Act.E balance Mwh	$-1\times10^{9}...1\times10^{9}$ kWh/MWh	0.01MWh	Sum of imported and exported phase L1 active energy
L1 Exp.React.Cap.E.Mvarh	$-1\times10^{9}...1\times10^{9}$ kVarh/ MVarh	0.01 kVarh/MVarh	Phase L1total exported reactive capacitive energy
L1 Imp.React.Cap.E.Mvarh	$-1\times10^{9}...1\times10^{9}$ kVarh/ MVarh	0.01 kVarh/MVarh	Phase L1 total imported reactive capacitive energy
L1 Exp/Imp React.Cap.E.bal.MVarh	$-1\times10^{9}...1\times10^{9}$ kVarh/ MVarh	0.01 kVarh/MVarh	Sum of imported and exported phase L1 reactive capacitive energy
L1 Exp.React.Ind.E.Mvarh	$-1\times10^{9}...1\times10^{9}$ kVarh/ MVarh	0.01 kVarh/MVarh	Phase L1 total exported reactive inductive energy

Name	Range	Step	Description
L1 Imp.React.Ind.E.Mvarh	-1×10^9...1×10^9 kVarh/ MVarh	0.01 kVarh/MVarh	Phase L1 total imported reactive inductive energy
L1 Exp/Imp React.Ind.E.bal.MVarh	-1×10^9...1×10^9 kVarh/ MVarh	0.01 kVarh/MVarh	Sum of imported and exported phase L1 reactive inductive energy

Table 2.63 Phase L2 energy calculation

Name	Range	Step	Description
L2 Exp.Active Energy Mwh	-1×10^9...1×10^9 kWh/MWh	0.01 kWh/MWh	Phase L2 exported active energy
L2 Imp.Active Energy Mwh	-1×10^9...1×10^9 kWh/MWh	0.01 kWh/MWh	Phase L2 imported active energy
L2 Exp/Imp.Act.E balance Mwh	-1×10^9...1×10^9 kWh/MWh	0.01 kWh/MWh	Sum of imported and exported phase L2 active energy
L2 Exp.React.Cap.E.Mvarh	-1×10^9...1×10^9 kVarh/ MVarh	0.01 kVarh/MVarh	Phase L2total exported reactive capacitive energy
L2 Imp.React.Cap.E.Mvarh	-1×10^9...1×10^9 kVarh/ MVarh	0.01 kVarh/MVarh	Phase L2 total imported reactive capacitive energy
L2 Exp/Imp React.Cap.E.bal.MVarh	-1×10^9...1×10^9 kVarh/ MVarh	0.01 kVarh/MVarh	Sum of imported and exported phase L2 reactive capacitive energy
L2 Exp.React.Ind.E.Mvarh	-1×10^9...1×10^9 kVarh/ MVarh	0.01 kVarh/MVarh	Phase L2 total exported reactive inductive energy
L2 Imp.React.Ind.E.Mvarh	-1×10^9...1×10^9 kVarh/ MVarh	0.01 kVarh/MVarh	Phase L2 total imported reactive inductive energy
L2 Exp/Imp React.Ind.E.bal.MVarh	kVarh/MVarh	0.01 kVarh/MVarh	Sum of imported and exported phase L2 reactive inductive energy

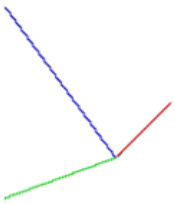
Table 2.64 Phase L3 energy calculation

Name	Range	Step	Description
L3 Exp.Active Energy Mwh	-1×10^6...1×10^6 MWh	0.01 kWh/MWh	Phase L3 exported active energy
L3 Imp.Active Energy Mwh	-1×10^6...1×10^6 MWh	0.01 kWh/MWh	Phase L3 imported active energy
L3 Exp/Imp.Act.E balance Mwh	-1×10^6...1×10^6 MWh	0.01 kWh/MWh	Sum of imported and exported phase L3 active energy
L3 Exp.React.Cap.E.Mvarh	-1×10^6...1×10^6 MVarh	0.01 kVarh/MVarh	Phase L3total exported reactive capacitive energy
L3 Imp.React.Cap.E.Mvarh	-1×10^6...1×10^6 MVarh	0.01 kVarh/MVarh	Phase L3 total imported reactive capacitive energy
L3 Exp/Imp React.Cap.E.bal.MVarh	-1×10^6...1×10^6 MVarh	0.01 kVarh/MVarh	Sum of imported and exported phase L3 reactive capacitive energy
L3 Exp.React.Ind.E.Mvarh	-1×10^6...1×10^6 MVarh	0.01 kVarh/MVarh	Phase L3 total exported reactive inductive energy
L3 Imp.React.Ind.E.Mvarh	-1×10^6...1×10^6 MVarh	0.01 kVarh/MVarh	Phase L3 total imported reactive inductive energy
L3 Exp/Imp React.Ind.E.bal.MVarh	-1×10^6...1×10^6 MVarh	0.01 kVarh/MVarh	Sum of imported and exported phase L3 reactive inductive energy

Calculation examples

Example for power calculation is represented here. Both wiring methods line to line –and line to neutral are checked with same signal injection. Voltage scaling is set to 20000:100V and current scaling is set to 1000:5A.

Voltages (Line to neutral):	**Currents:**
V_A=40.825V, 45.00°	I_{L1}=2.500V, 0.00°
V_B=61.481V, -159.90°	I_{L2}=2.500V, -120.00°
V_C=97.742V, 126.21°	I_{L3}=2.500V, 120.00°





$$S_{L1} = U_{L1} \times I_{L1} = 40.825V \times 2.5A = 102\ VA\ (secondary)\ 4.08\ MVA\ (primary)$$

$$P_{L1} = U_{L1} \times I_{L1} \cos\varphi = 40.825V \times 2.5A \cos(45° - 0°) = 72.2\ W\ (secondary)\ 2.89\ MW\ (primary)$$

$$Q_{L1} = U_{L1} \times I_{L1} \sin\varphi = 40.825V \times 2.5A \sin(45° - 0°) = 72.2\ W\ (secondary)\ 2.89\ MVar\ (primary)$$

$$L1\ Tan(phi) = {}^{Q_{L1}}/_{P_{L1}} = {}^{2.89}/_{2.89} = 1.00 \qquad L1\ Cos(phi) = {}^{P_{L1}}/_{S_{L1}} = {}^{2.89}/_{4.08} = 0.71$$

Name	**k#**	**Name**	**k#**	**Name**	**k#**	**Name**	**M#**
L1 (S)	4.08	**L2 (S)**	6.15	**L3 (S)**	9.77	**3PH (S)**	20.00
L1 (P)	2.89	**L2 (P)**	4.72	**L3 (P)**	9.71	**3PH (P)**	17.32
L1 (Q)	2.89	**L2 (Q)**	-3.94	**L3 (Q)**	1.06	**3PH (Q)**	0.01
L1 Tan	1.00	**L2 Tan**	-0.83	**L3 Tan**	0.11	**3PH Tan**	0.00

Name	k#	Name	k#	Name	k#	Name	M#
L1 Cos	0.71	**L2 Cos**	0.77	**L3 Cos**	0.99	**3PH Cos**	0.87

Voltages (Line to line):	**Currents:**
V_A=100.00V, 30.00°	I_{L1}=2.500V, 0.00°
V_B=100.00V, -90.00°	I_{L2}=2.500V, -120.00°
	I_{L3}=2.500V, 120.00°





$$S = U_{12} \times I_{L1} + U_{23} \times I_{L2}$$

$$S = 100 \times 2.5 + 100 \times 2.5 = 500\,VA\,(secondary) 20.00\,MVA\,(primary)$$

$$P = U_{12} \times I_{L1} \cos(-\varphi) + U_{23} \times I_{L2} \cos(\varphi)$$

$$P = 100 \times 2.5 \cos -(30° - 0°) + 100 \times 2.5 \cos(270° - 240°) = 433W(sec) 17.32\,MW(pri)$$

$$Q = U_{12} \times I_{L1} + \sin(-\varphi) + U_{23} \times I_{L2} \sin(\varphi)$$

$$Q = 100 \times 2.5 + \sin -(30° - 0°) + 100 \times 2.5 \sin(270° - 240°) = 0\,Var(sec) 0\,MVar(pri)$$

$$3PH\ Tan(phi) = {}^{Q}/_{P} = {}^{0.01}/_{17.32} = 0.00 \qquad 3PH\ Cos(phi) = {}^{P}/_{S} = {}^{17.32}/_{20.00} = 0.87$$

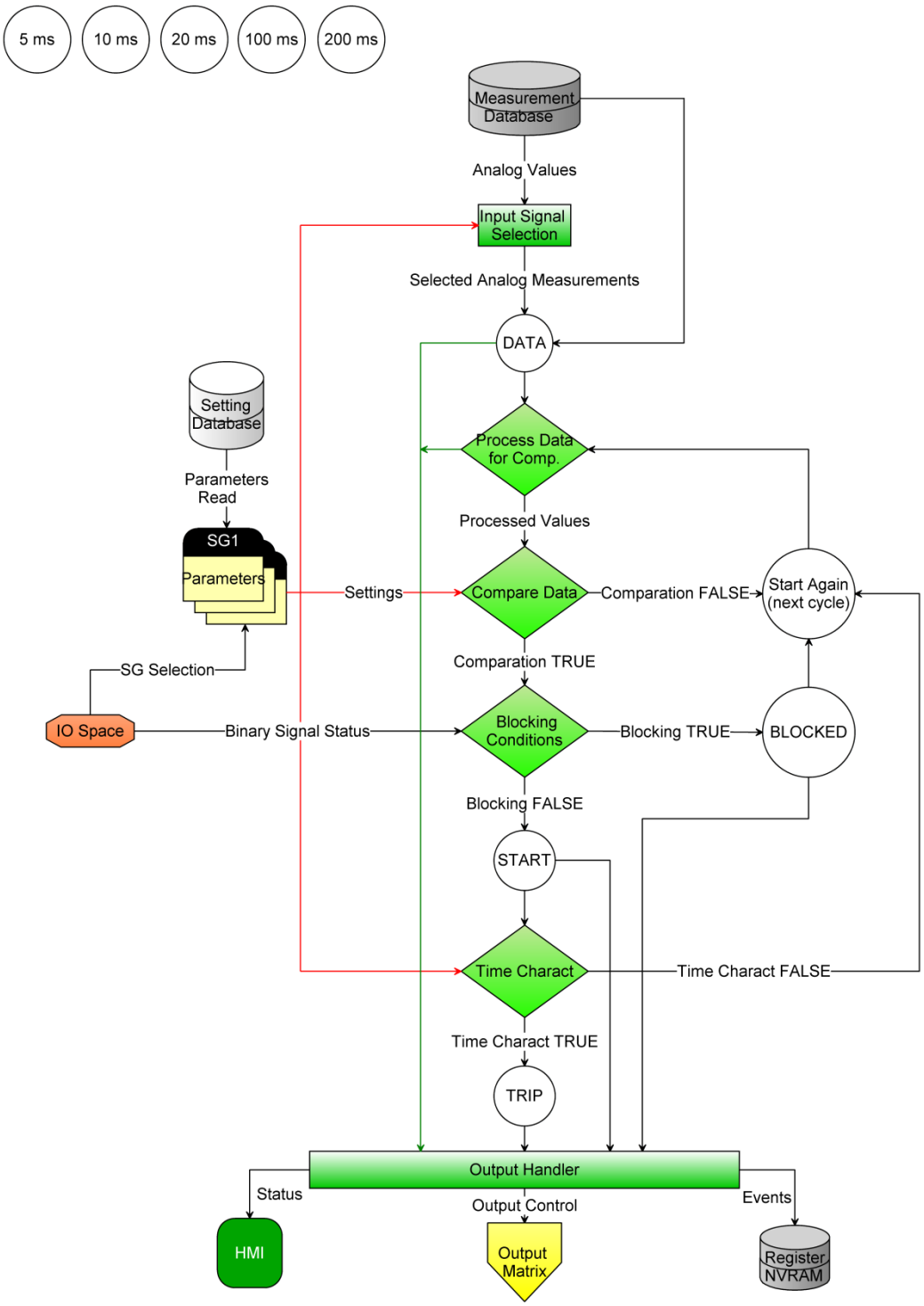
Name	M#
3PH (S)	20.00
3PH (P)	17.32
3PH (Q)	0.00
3PH Tan	0.00
3PH Cos	0.87

3. Protections

3.1 General

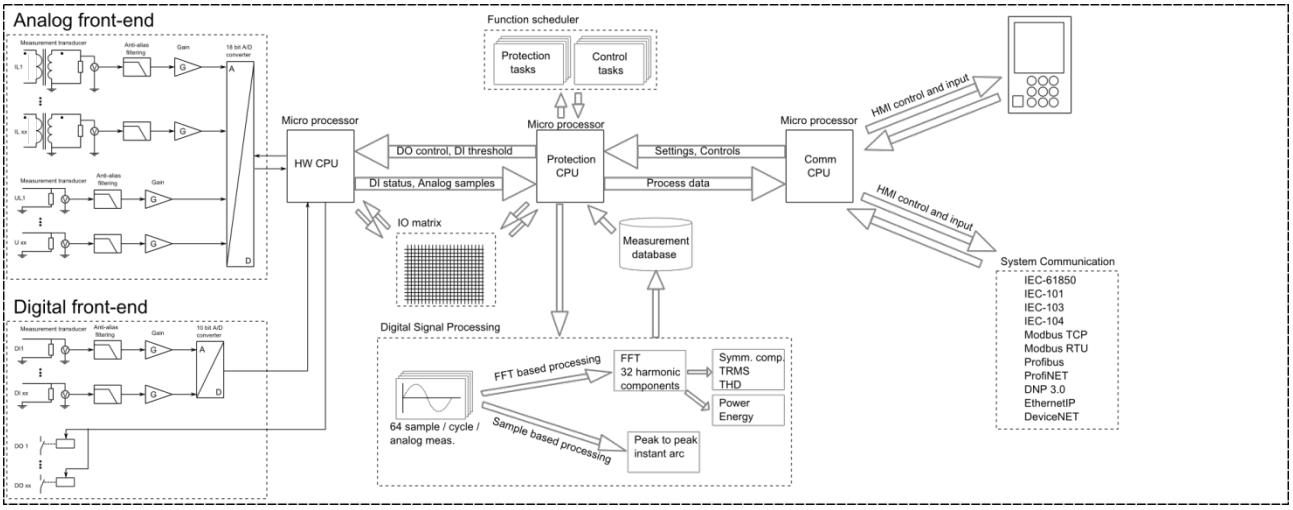
3.1.1 General properties of a protection function

Following flowchart is describes the basic structure of any protection function. Basic structure is composed of analog measurement value comparison to the pick-up values and operating time characteristics.



Protection function is run in a completely digital environment with protection CPU microprocessor which also processes the analog signals transferred to digital form.

Figure 3.1 Principle diagram of protection relay platform.

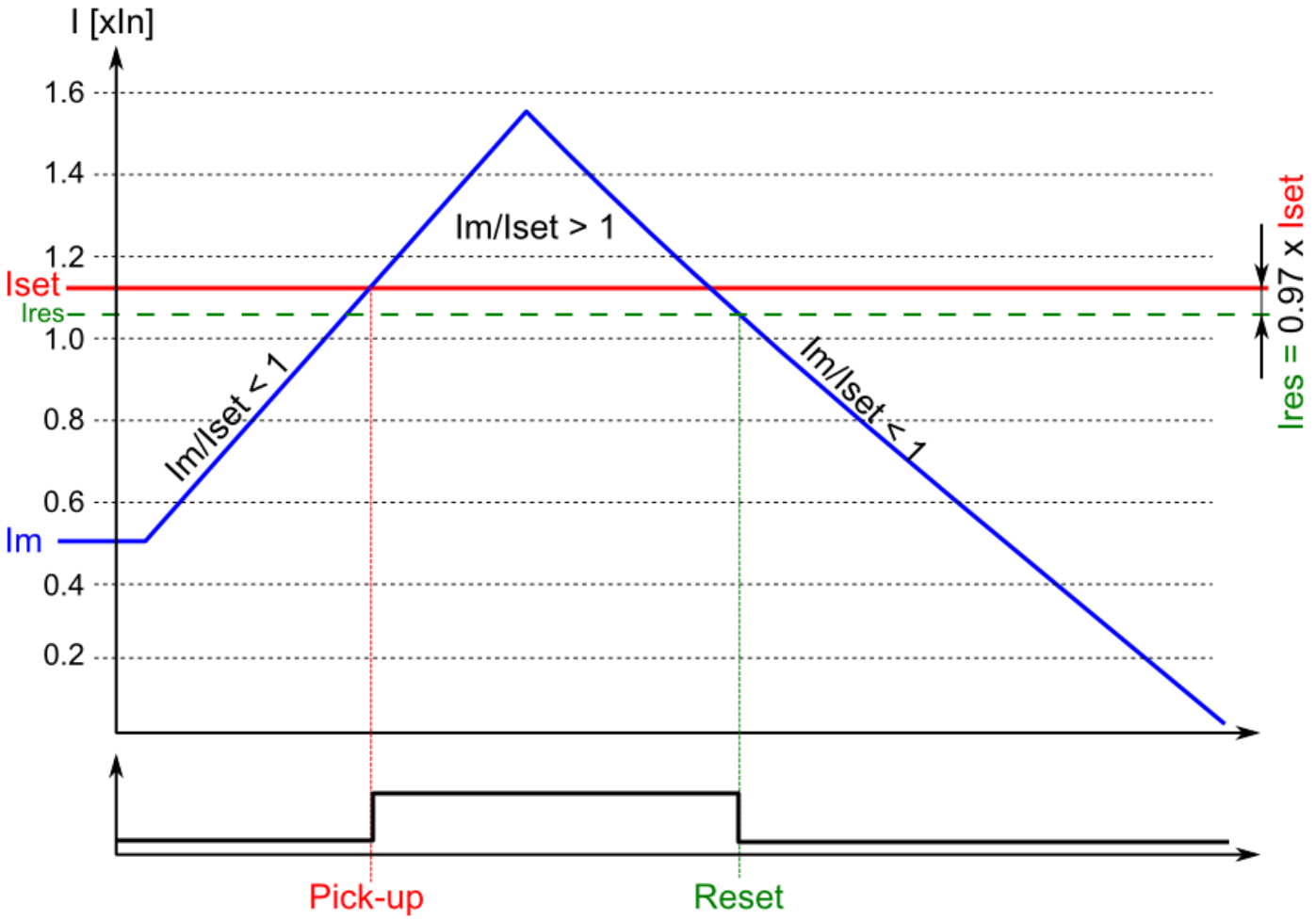


In following chapters common functionalities of protection functions are described. If some protection function deviates from this basic structure the difference is described in the corresponding chapter of the manual.

Pick-up characteristics

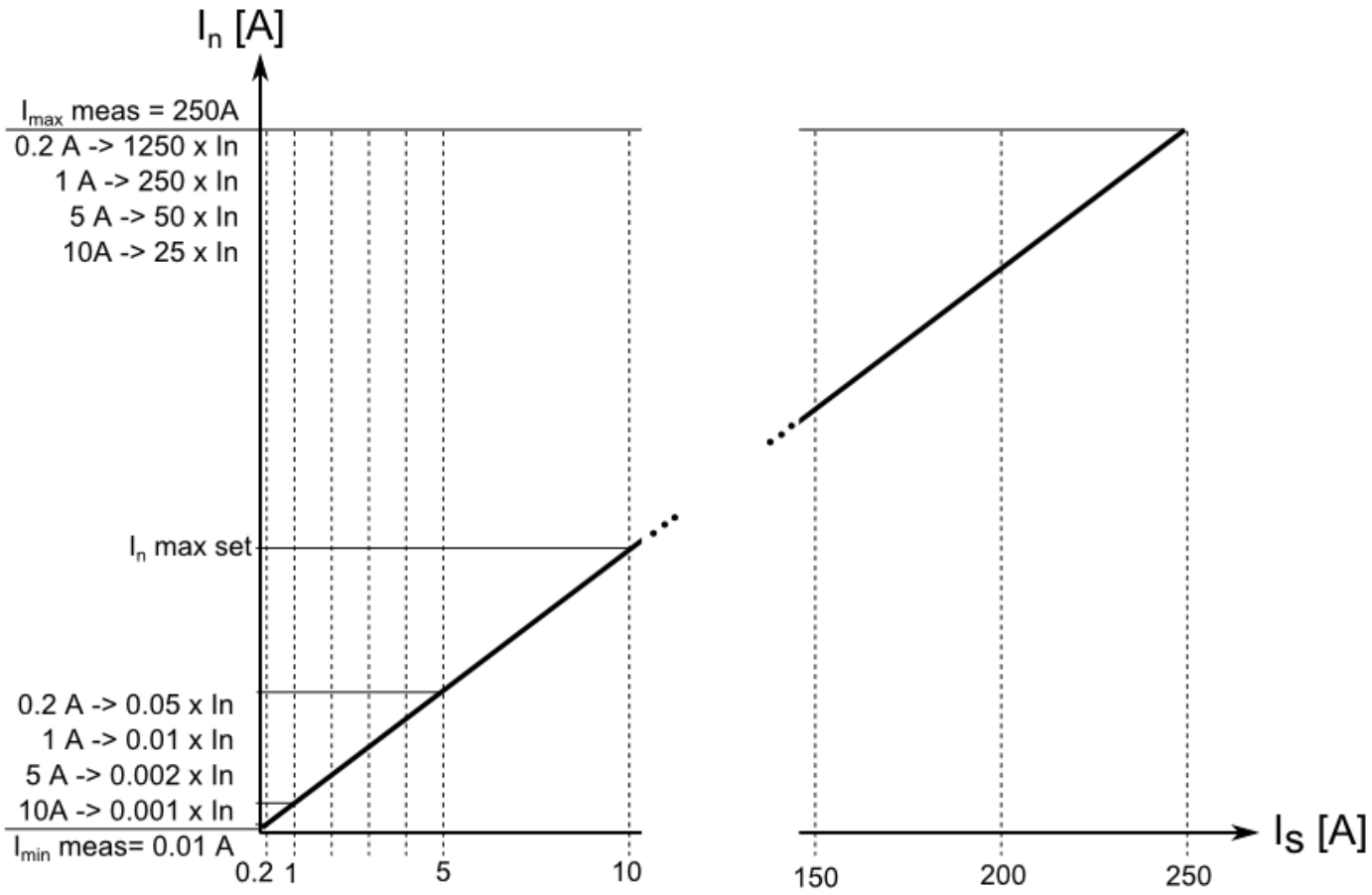
Pick-up of the function is controlled by Xset setting parameter, which defines the maximum or minimum allowed measured magnitude in per unit, absolute or percentage value before function takes action. The function constantly calculates the ratio between the user set pick-up parameter and measured magnitude (Im). Reset ratio of 97 % is inbuilt in the function and is always related to the Xset value. If function pick-up characteristics vary from this description, it is defined in the function part of the manual.

Figure 3.2 Pick up and reset characteristics of the function.



The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Figure 3.3 Measurement range in relation to the nominal current.



The “In” magnitude refers to user set nominal current which can be in range of 0.2...10A, typically 0.2A, 1A or 5A. With its own current measurement card, the IED will measure secondary currents from 0.001A up to 250A. To this relation the pick-up setting in secondary amperes will vary.

Function blocking

In the blocking element the blocking signals are checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function, an HMI display event as well as time stamped blocking event with information of the startup current values and fault type are issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Operating time characteristics for trip and reset

The operating timers’ behavior of the function can be set for trip signal and for the release of the function in case the pick-up element is reset before the trip time has been reached. There are three basic operating modes available for the function. Instant operation gives the trip signal with no additional time delay simultaneously with start signal. Definite time operation

(DT) will give trip signal with user given time delay regardless of the measured current for as long as the current is above/ below the Xset value and thus pick-up element is active (independent time characteristics).

Inverse definite minimum time (IDMT) will give the trip signal in time which is in relation of the set pick-up value Xset and measured value Xm (dependent time characteristics). For the IDMT operation is available IEC and IEEE/ANSI standard characteristics as well as user settable parameters. Please note that in IDMT mode Definite (Min) operating time delay is also in use defining the minimum time for protection tripping. If this function is not desired this parameter should be set to 0 seconds.

Figure 3.4 Definite (Min) Operating Time Delay determines the minimum operating time delay. When using only IDMT it is possible to disable minimum operating time delay by setting this parameter to zero.

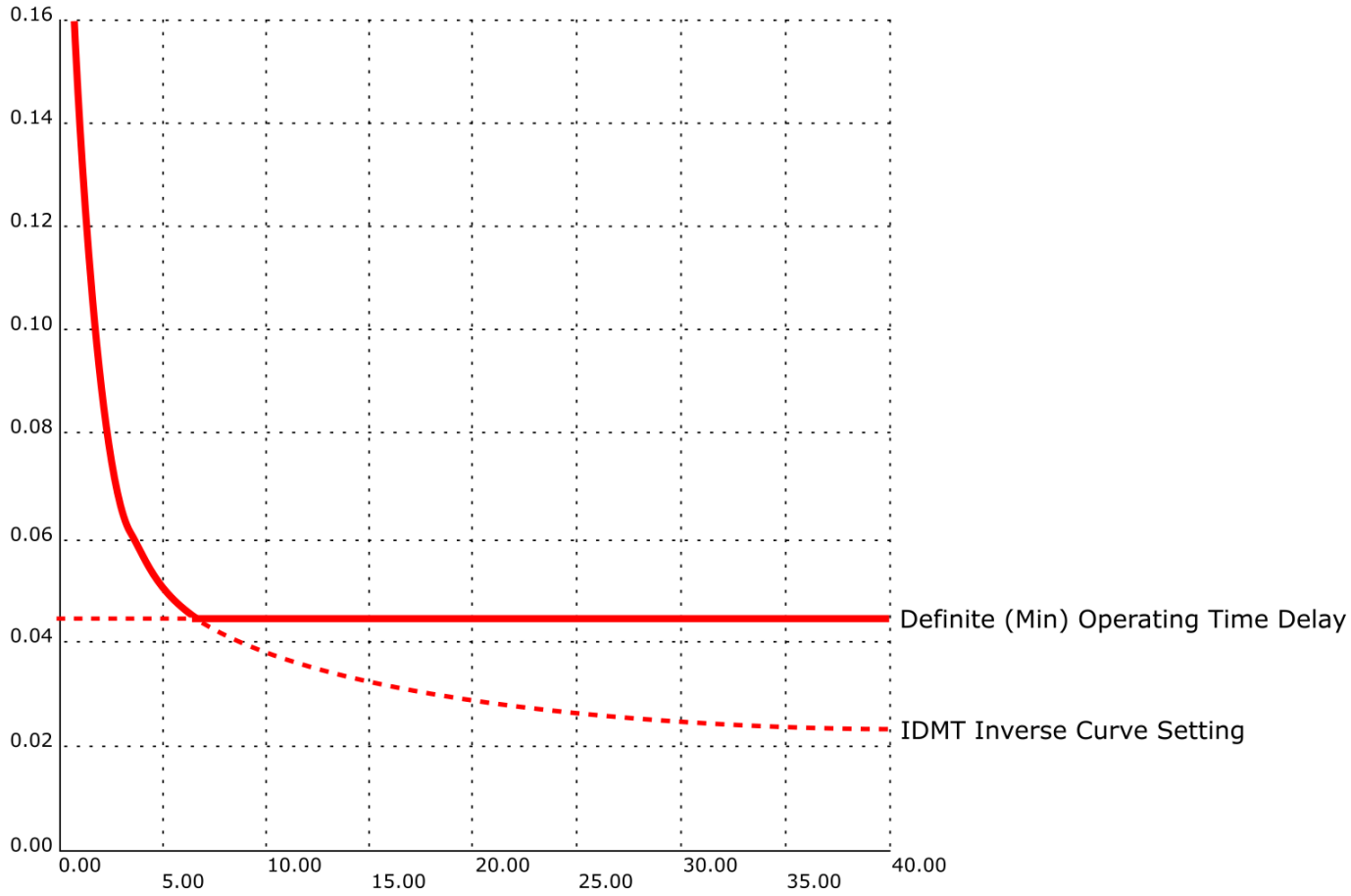


Table 3.1 Operating time characteristics setting parameters (general).

Name	Range	Step	Default	Description
Delay Type	DT IDMT	-	DT	Selection of the delay type time counter. Selection possibilities are dependent (IDMT, Inverse Definite Minimum Time) and independent (DT, Definite Time) characteristics.
Definite (Min) operating time delay	0.000... 1800.000s	0.005s	0.040s	When Delay Type is set to DT this parameter acts as the expected operating time for the protection function. When set to 0.000 s the stage operates as instant (PIOC, 50) stage without added delay. When the parameter is set to 0.005 – 1800 s the stage operates as independent delayed (PTOC, 51). When Delay Type has been set to IDMT this parameter can be used to determine the minimum operating time for the protection function. Example of this is presented in figure above.

Name	Range	Step	Default	Description
Delay curve series	IEC IEEE	-	IEC	Setting is active and visible when Delay Type is selected to IDMT. Delay curve series for IDMT operation following either IEC or IEEE/ ANSI standard defined characteristics.
Delay characteristics IEC	NI EI VI LTI Param	-	NI	Setting is active and visible when Delay Type is selected to IDMT. IEC standard delay characteristics. Normally Inverse, Extremely Inverse, Very Inverse and Long Time Inverse characteristics. Param selection allows the tuning of the constants A and B which allows setting of characteristics following the same formula as the IEC curves mentioned here.
Delay characteristics IEEE	ANSI NI ANSI VI ANSI EI ANSI LI IEEE MI IEEE VI IEEE EI Param	-	LTI	Setting is active and visible when Delay Type is selected to IDMT. IEEE and ANSI standard delay characteristics. ANSI: Normal Inverse, Very Inverse, Extremely inverse, Long time inverse characteristics. IEEE: Moderately Inverse, Very Inverse, Extremely Inverse characteristics. Param selection allows the tuning of the constants A, B and C which allows setting of characteristics following the same formula as the IEEE curves mentioned here.
Time dial setting k	0.01...25.00s	0.01s	0.05s	Setting is active and visible when Delay Type is selected to IDMT. Time dial / multiplier setting for IDMT characteristics.
A	0.0000... 250.0000	0.0001	0.0860	Setting is active and visible when Delay Type is selected to IDMT. Constant A for IEC/IEEE characteristics.
B	0.0000...5.0000	0.0001	0.1850	Setting is active and visible when Delay Type is selected to IDMT. Constant B for IEC/IEEE characteristics.
C	0.0000... 250.0000	0.0001	0.0200	Setting is active and visible when Delay Type is selected to IDMT. Constant C for IEEE characteristics.

Figure 3.5 Inverse operating time formulas for IEC and IEEE standards.

<table>
<tr><th>IEC</th><th>IEEE/ANSI</th></tr>
<tr><td>$$t = \frac{kA}{\left(\frac{I_m}{I_{set}}\right)^B - 1}$$</td><td>$$t = k\left(\frac{A}{\left(\frac{I_m}{I_{set}}\right)^C - 1} + B\right)$$</td></tr>
<tr><td>t = Operating delay (s)
k = Time dial setting
Im = Measured maximum current
Iset = Pick up setting
A = Operating characteristics constant
B = Operating characteristics constant</td><td>t = Operating delay (s)
k = Time dial setting
Im = Measured maximum current
Iset = Pick up setting
A = Operating characteristics constant
B = Operating characteristics constant
C = Operating characteristics constant</td></tr>
<tr><td>Standard delays IEC constants
<table>
<tr><th>Type</th><th>A</th><th>B</th></tr>
<tr><td>Normally Inverse (NI)</td><td>0,14</td><td>0,02</td></tr>
<tr><td>Extremely Inverse (EI)</td><td>80</td><td>2</td></tr>
<tr><td>Very Inverse (VI)</td><td>13,5</td><td>1</td></tr>
<tr><td>Long Time Inverse (LTI)</td><td>120</td><td>1</td></tr>
</table></td><td>Standard delays ANSI constants
<table>
<tr><th>Type</th><th>A</th><th>B</th><th>C</th></tr>
<tr><td>Normally Inverse (NI)</td><td>8,934</td><td>0,1797</td><td>2,094</td></tr>
<tr><td>Very Inverse (VI)</td><td>3,922</td><td>0,0982</td><td>2</td></tr>
<tr><td>Extremely Inverse (EI)</td><td>5,64</td><td>0,02434</td><td>2</td></tr>
<tr><td>Long Time Inverse (LTI)</td><td>5,614</td><td>2,186</td><td>1</td></tr>
</table>
Standard delays IEEE constants
<table>
<tr><th>Type</th><th>A</th><th>B</th><th>C</th></tr>
<tr><td>Moderately Inverse (MI)</td><td>0,0515</td><td>0,114</td><td>0,02</td></tr>
<tr><td>Very Inverse (VI)</td><td>19,61</td><td>0,491</td><td>2</td></tr>
<tr><td>Extremely Inverse (EI)</td><td>28,2</td><td>0,1217</td><td>2</td></tr>
</table></td></tr>
</table>

Figure 3.6 Definite time operating characteristics.

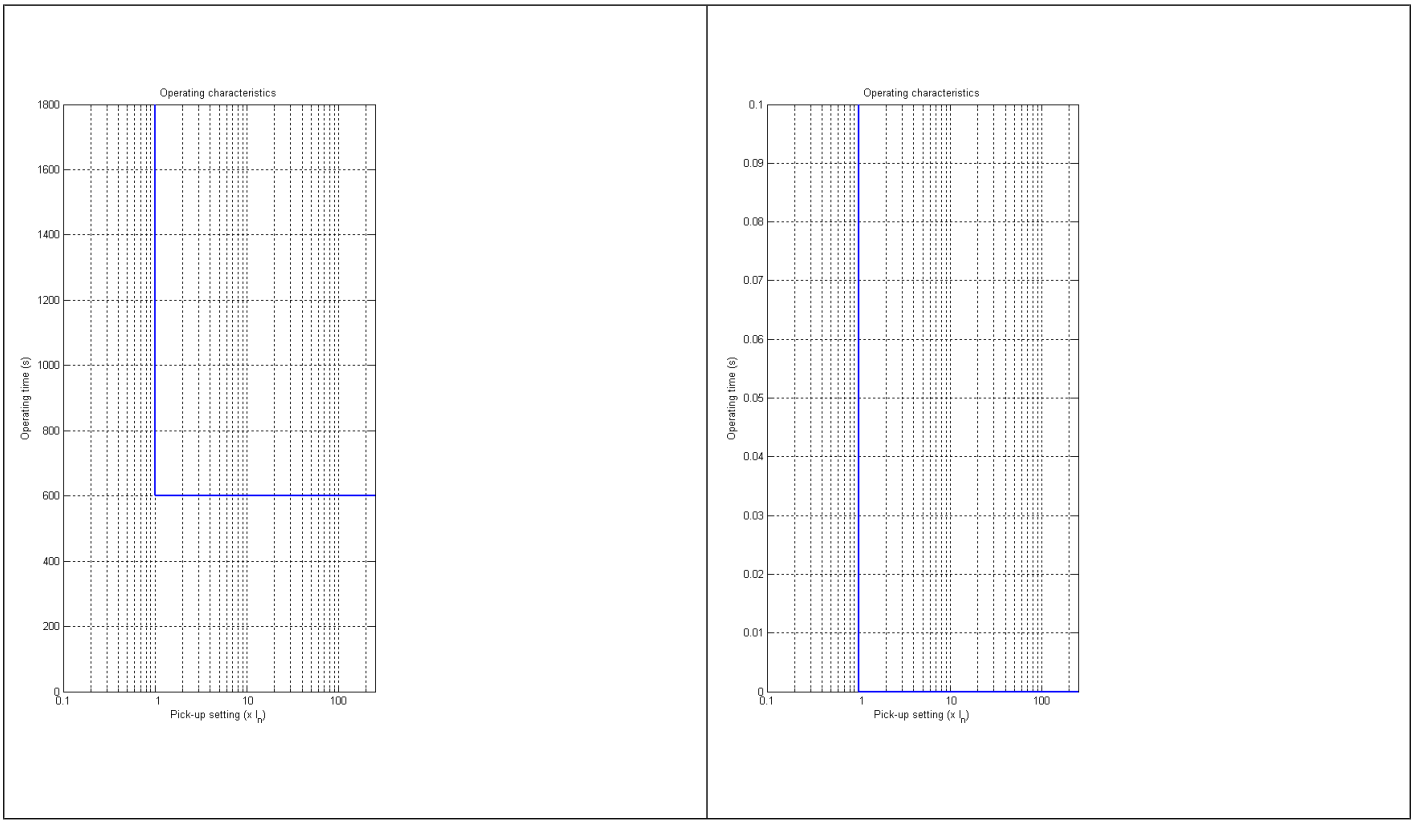
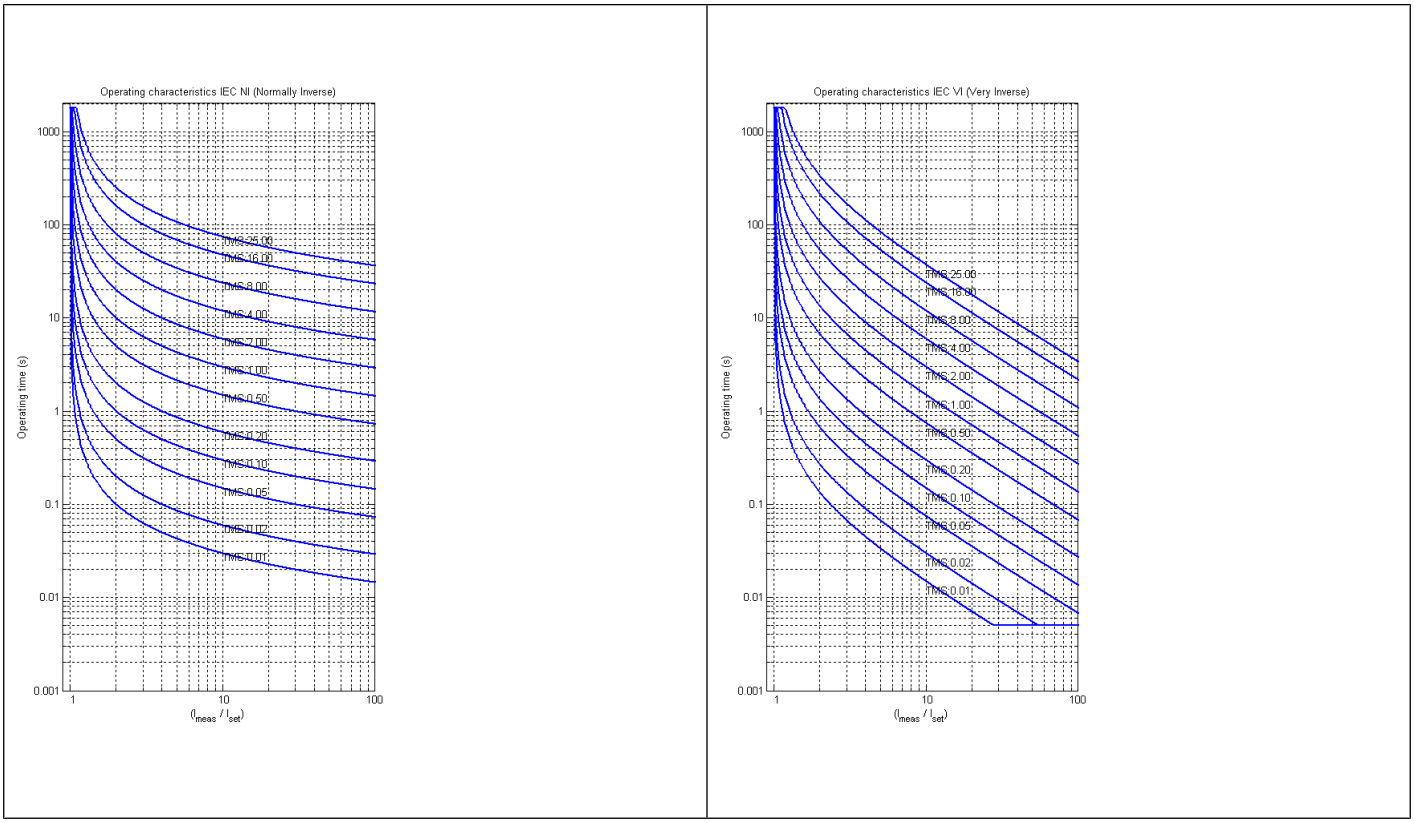
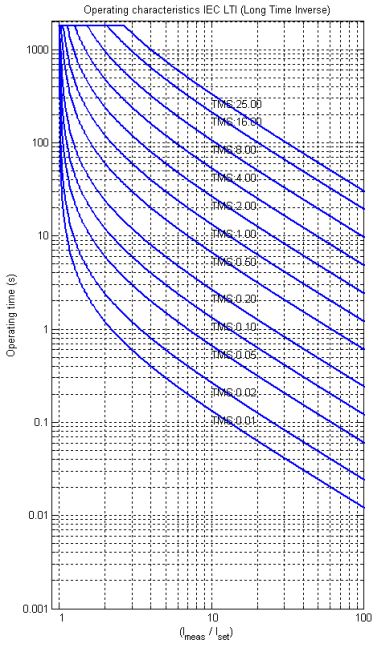


Figure 3.7 IEC predefined characteristics NI, VI, LTI and EI




Operating characteristics IEC LTI (Long Time Inverse)
Operating time (s)
1000
100
10
1
0.1
0.01
0.001
1
10
100
(Imeas / Iset)
TMS 25.00
TMS 16.00
TMS 8.00
TMS 4.00
TMS 2.00
TMS 1.00
TMS 0.60
TMS 0.20
TMS 0.10
TMS 0.05
TMS 0.02
TMS 0.01

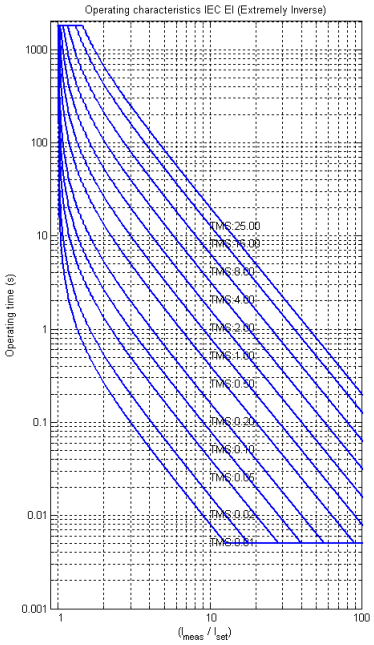

Operating characteristics IEC EI (Extremely Inverse)
Operating time (s)
1000
100
10
1
0.1
0.01
0.001
1
10
100
(Imeas / Iset)
TMS 25.00
TMS 16.00
TMS 8.00
TMS 4.00
TMS 2.00
TMS 1.00
TMS 0.60
TMS 0.20
TMS 0.10
TMS 0.05
TMS 0.02
TMS 0.01

Figure 3.8 IEEE ANSI predefined characteristics EI, LTI, NI and VI

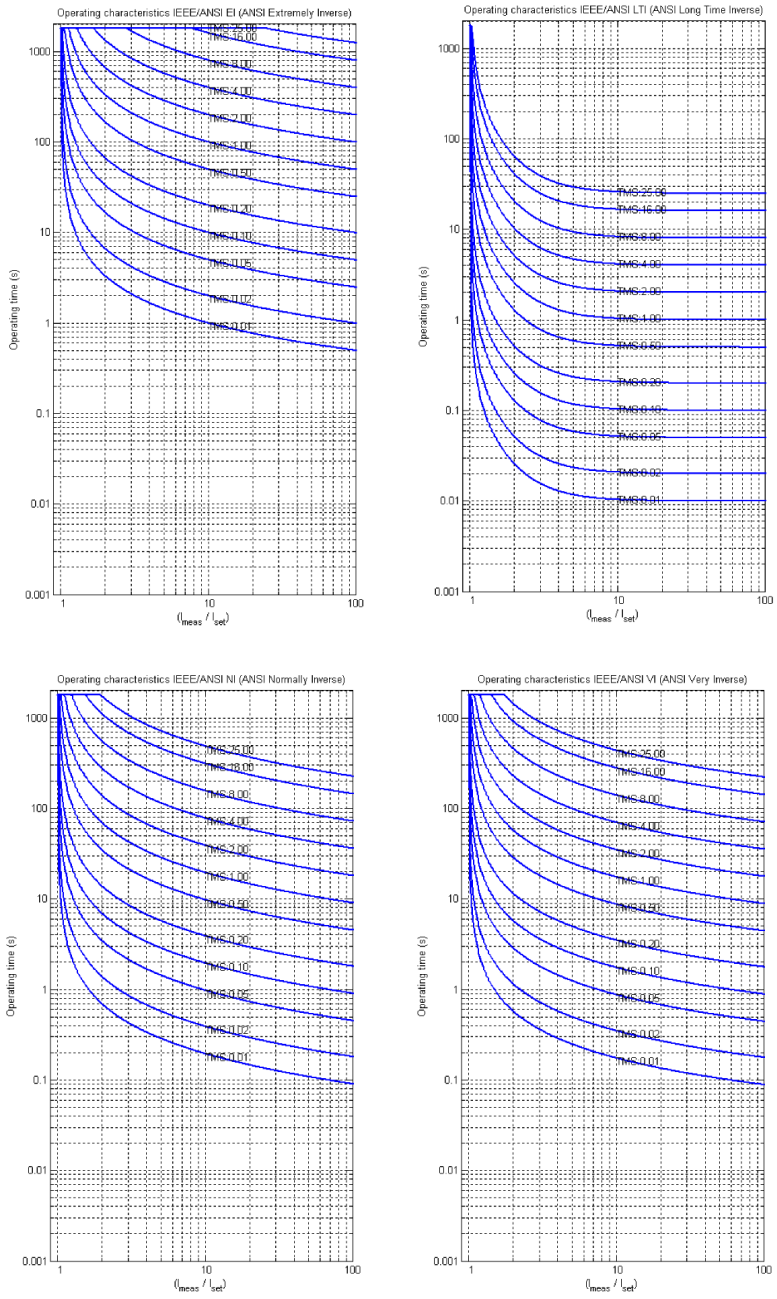


Figure 3.9 IEEE predefined characteristics EI, MI and VI

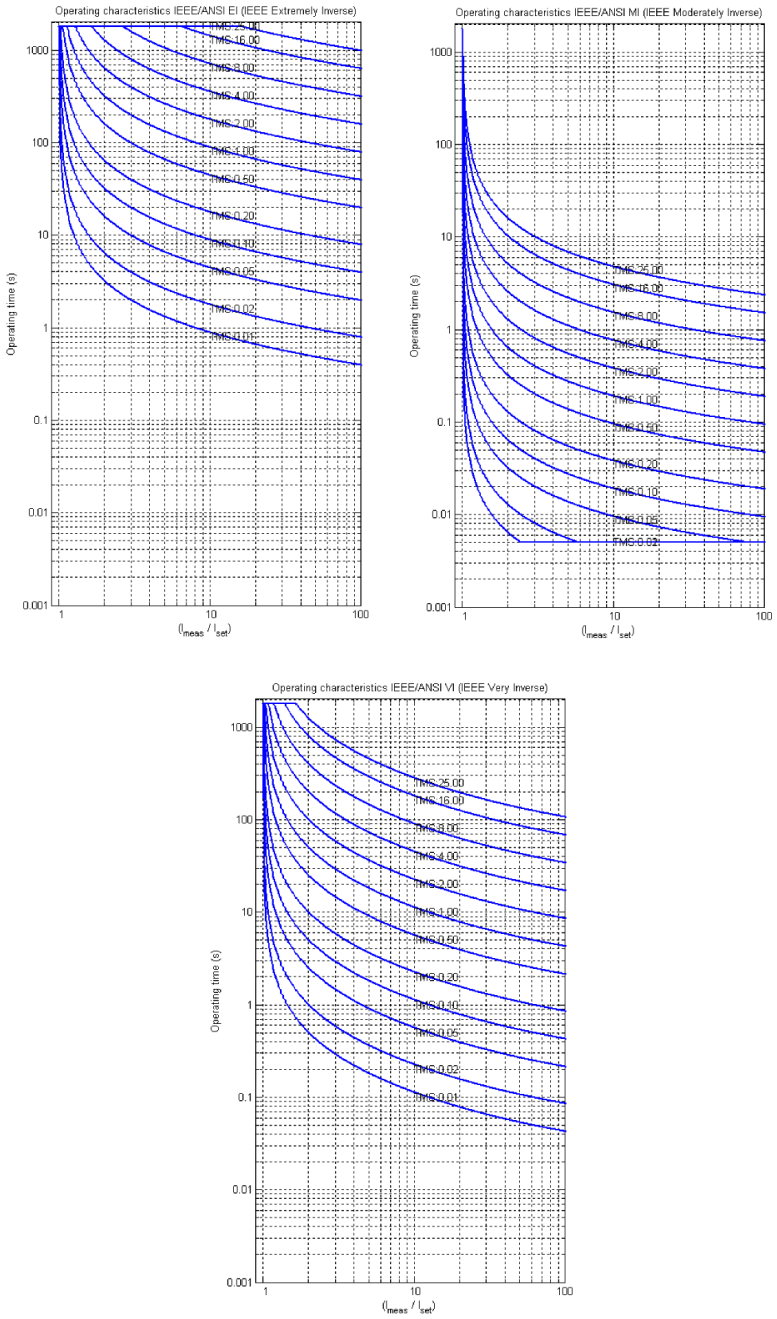
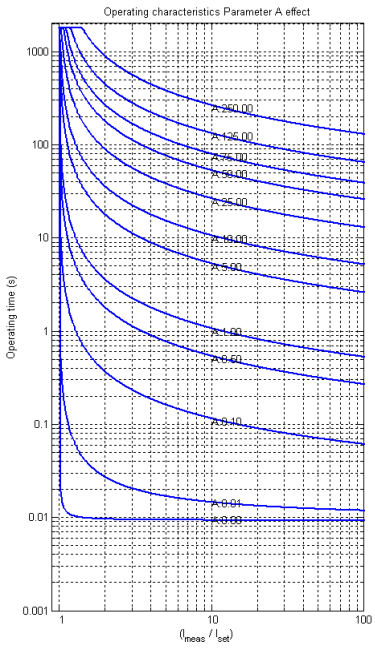
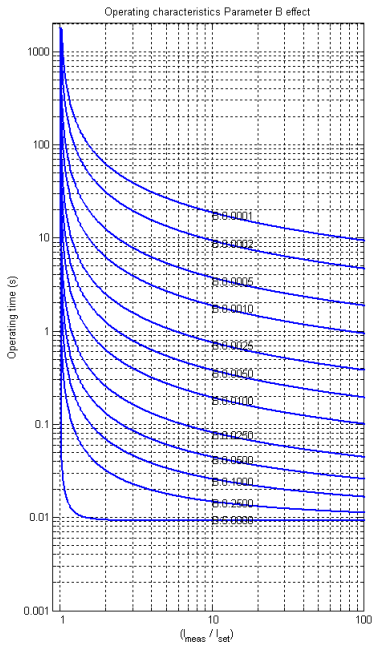
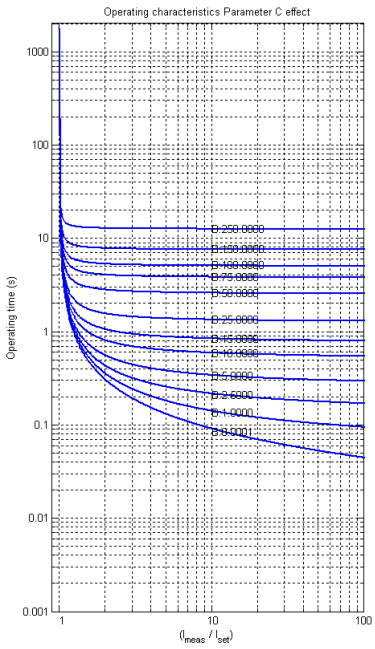


Figure 3.10 Parameters A, B and C effect to the characteristics.







Non-standard delay characteristics

Additionally, to previously mentioned delay characteristics some functions also have delay characteristics that deviate from the IEC or IEEE standards. These functions are Overcurrent stages, Residual overcurrent stages, Directional overcurrent stages and Directional residual overcurrent stages. The setting parameters and their ranges are documented in the function blocks respective chapters.

Table 3.2 Inverse operating time formulas for nonstandard characteristics.

RI-type	RD-type
Used to get time grading with mechanical relays	Mostly used in earth-fault protection which grants selective tripping even in non-directional protection
$t = \frac{k}{0.339 - 0.236 * \frac{I_{set}}{I_m}}$	$t = 5.8 - 1.35 * \ln\left(\frac{I_m}{k * I_{set}}\right)$
t = Operating delay (s) k = Time dial setting Im = Measured maximum current Iset = Pick up setting	t = Operating delay (s) k = Time dial setting Im = Measured maximum current Iset = Pick up setting

Table 3.3 Reset time characteristics setting parameters.

Name	Range	Step	Default	Description
Release Time delay	0.000... 150.000s	0.005s	0.06s	Resetting time. Time allowed in between of pick-ups if the pick-up has not lead into trip operation. During this time the start signal is held on for the timers if delayed pick-up release is active.
Delayed Pick-up release	No Yes	-	Yes	Resetting characteristics selection either time delayed or instant after pick-up element is released. If activated the start signal is reset after set release time delay.
Time calc reset after release time	No Yes	-	Yes	Operating timer resetting characteristics selection. When active the operating time counter is reset after set release time if pick-up element is not activated during this time. When disabled the operating time counter is reset directly after the pick-up element reset.
Continue time calculation during release time	No Yes	-	No	Time calculation characteristics selection. If activated the operating time counter is continuing until set release time even the pick-up element is reset.

Behavior of stages with different release time configurations are presented in the following figures.

Figure 3.11 No delayed pick-up release.

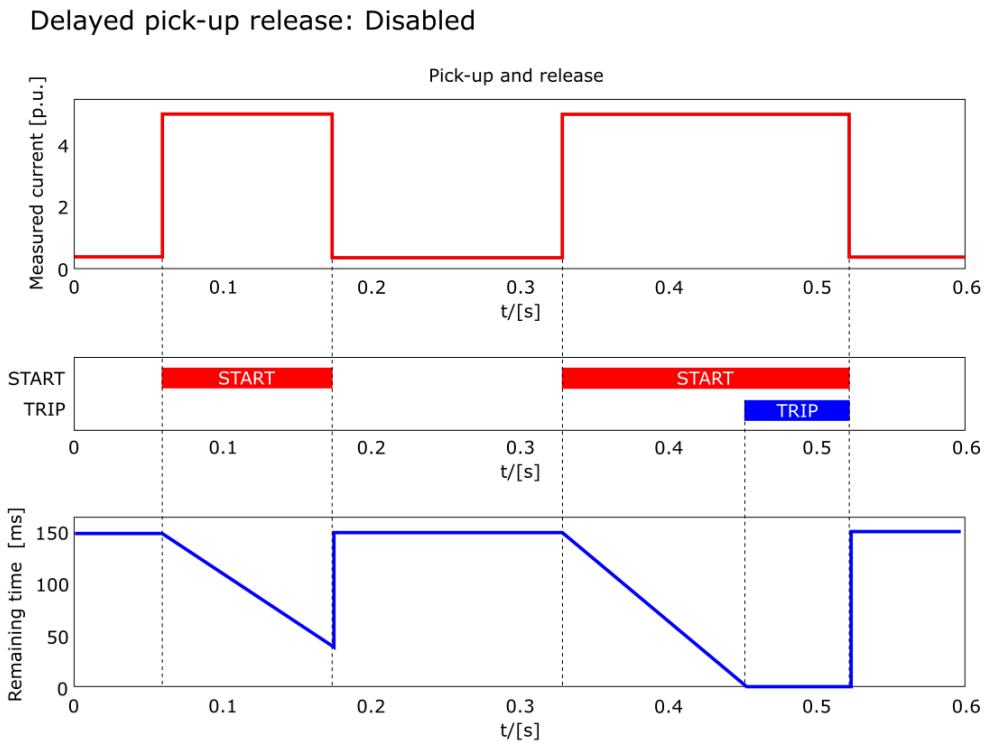


Figure 3.12 Delayed pick-up release, delay counter is reset at signal drop-off.

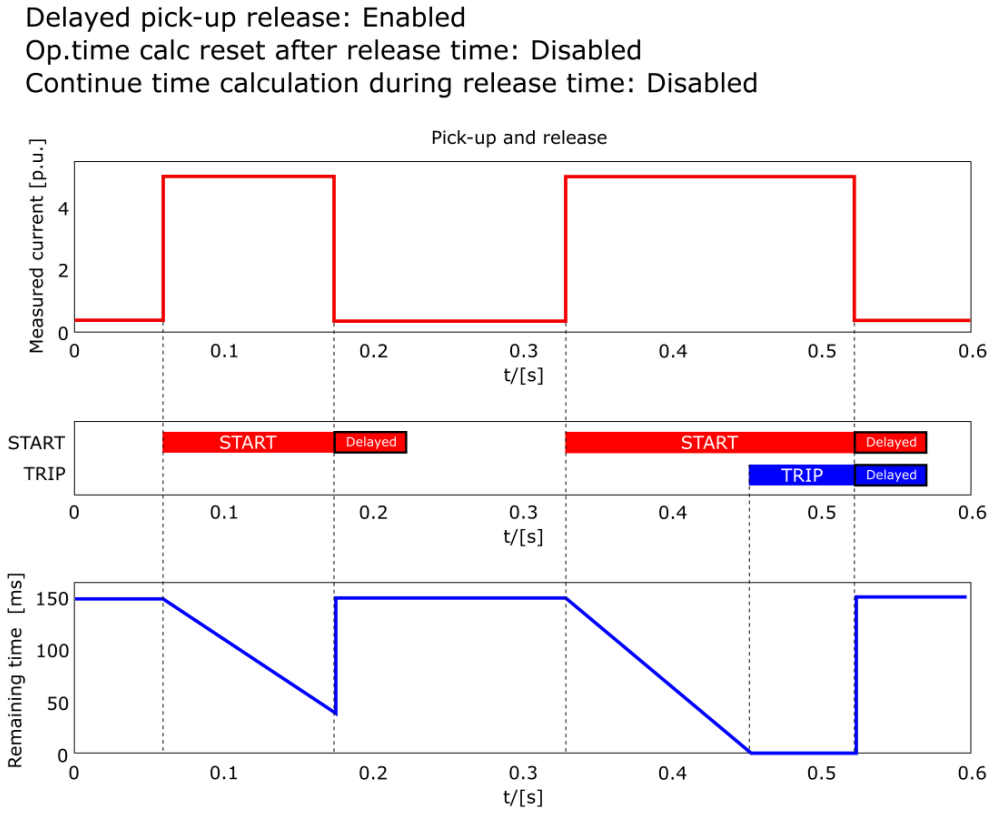


Figure 3.13 Delayed pick-up release, delay counter value is held during the release time.

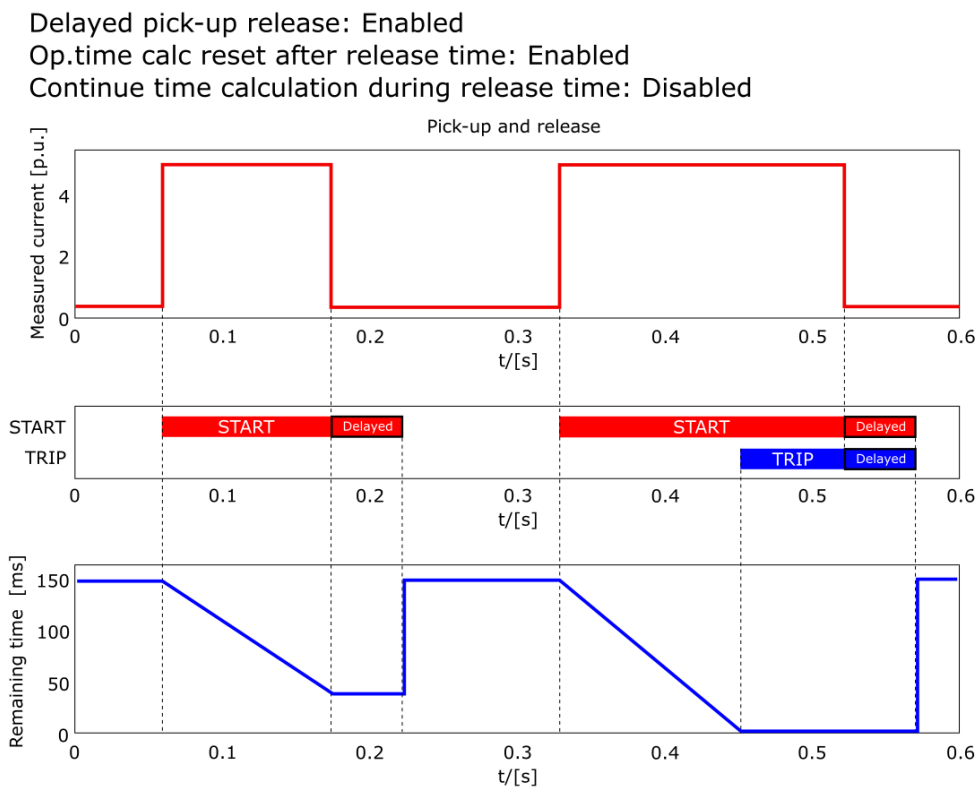
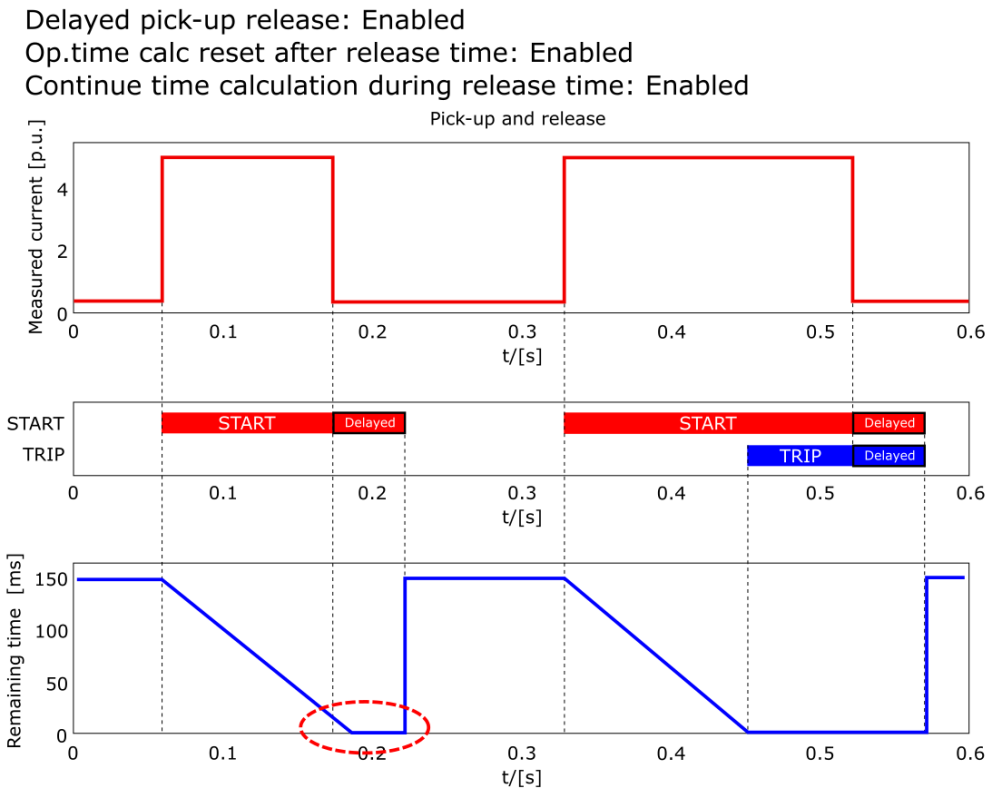


Figure 3.14 Delayed pick-up release, delay counter value is decreasing during the release time.



Resetting characteristics can be set according to the application. Default setting is delayed with 60 ms and the time calculation is held during the release time.

When using the release delay option where the operating time counter is calculating the operating time during the release time, function will not trip if the input signal is not activated again during the release time counting.

Stage forcing

It is possible to test the logic, event processing and the operation of the protection system of the relay by controlling the state of the protection functions by hand without injecting any current into the relay with stage forcing. To enable stage forcing set the Enable stage forcing to Enabled in General menu. After this it is possible to control the status of a protection function (Normal, Start, Trip, Blocked etc.) in the Info page of the function.

NOTE: When Stage forcing is enabled protection functions will change state also by user input, injected currents/voltages also affect the behavior of the relay. Despite this it is still advised to disable Stage Forcing after testing has ended.

3.2 Current protections

3.2.1 Non-directional overcurrent I> (50/51)

Overcurrent function (NOC) is used for non-directional instant- and time delayed overcurrent/short circuit protection for various applications including feeder, filter and machine applications of utilities and industry. The number of available instances of the function depends of the IED model. Function measures constantly phase current magnitudes which on the operating decisions are based. Available phase current magnitudes are fundamental component RMS, TRMS values (including harmonics up to 32^{nd}) or peak-to-peak values. Blocking signal and setting group selection controls the operating characteristics of the function during normal operation.

Outputs of the function are Start Trip and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. Non directional overcurrent function utilizes total of eight separate setting groups which can be selected from one common source.

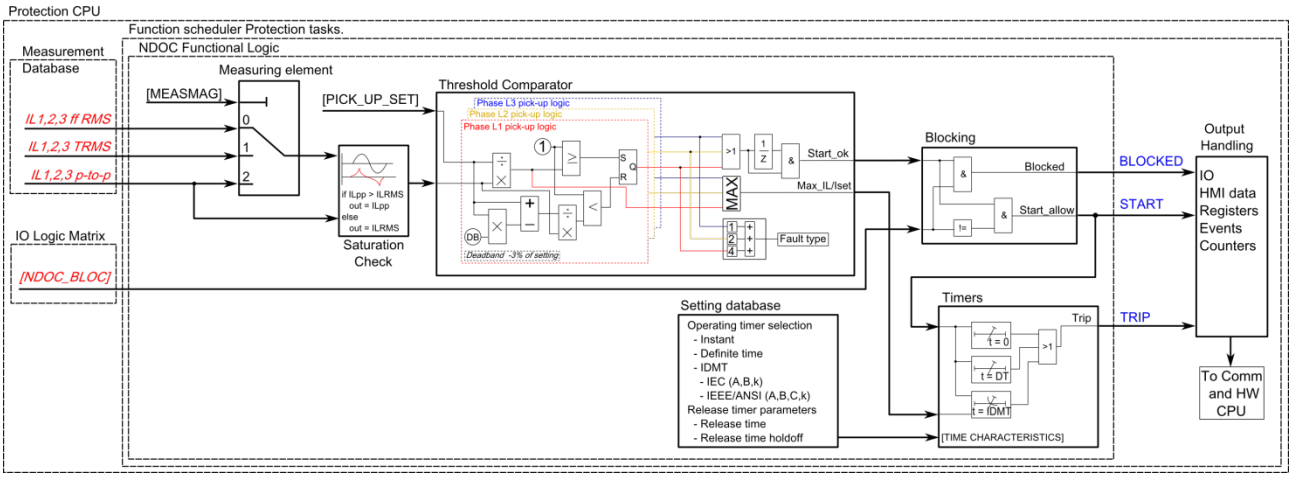
The function can be operating on instant or time delayed mode. In time delayed mode the operation can switched to definite time or IDMT mode. For IDMT operation IEC and ANSI standard time delays are supported as well as custom parameters. Function includes CT saturation checking which allows the function to start and operate accurately also in case of CT saturation condition.

The operational logic consists of input magnitude processing, input magnitude selection, saturation check, threshold comparator, block signal check, time delay characteristics and output processing. The basic design of the protection function is 3-pole operation.

Inputs for the function are the operating mode selections, setting parameters and measured and pre-processed current magnitudes and binary input signals. Function outputs START, TRIP and BLOCKED signals which can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the three output signal. In instant operating mode the function outputs START and TRIP events simultaneously with equivalent time stamp. Time stamp resolution is 1ms. Function provides also cumulative counters for START, TRIP and BLOCKED events.

In the following figure is presented the simplified function block diagram of the NOC function.

Figure 3.15 Simplified function block diagram of the NOC function.



Measured input values

Function block uses analog current measurement values. Function block always utilizes peak-to-peak measurement from samples and by user selection the monitored magnitude can be either fundamental frequency RMS values, True RMS values from the whole harmonic specter of 32 components or peak to peak values. -20ms averaged value of the selected magnitude is used for pre-fault data registering.

Table 3.4 Analogic magnitudes used by the NOC function.

Signal	Description	Time base
IL1PP	Peak-to-peak measurement of phase L1/A current	5 ms
IL2PP	Peak-to-peak measurement of phase L2/B current	5 ms
IL3PP	Peak-to-peak measurement of phase L3/C current	5 ms
IL1RMS	Fundamental RMS measurement of phase L1/A current	5 ms
IL2RMS	Fundamental RMS measurement of phase L2/B current	5 ms
IL3RMS	Fundamental RMS measurement of phase L3/C current	5 ms
IL1TRMS	TRMS measurement of phase L1/A current	5 ms
IL2TRMS	TRMS measurement of phase L2/B current	5 ms
IL3TRMS	TRMS measurement of phase L3/C current	5 ms

Selection of the used AI channel is made with a setting parameter. In all possible input channel variations pre-fault condition is presented with 20 ms averaged history value from -20 ms of Start or Trip event.

General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible change them with setting group switching.

Table 3.5 General settings of the function

Name	Description	Range	Step	Default
Setting control from comm bus	Activating this parameter permits changing the pick-up level of the protection stage via SCADA.	1:Disabled 2:Allowed	-	1:Disabled
Measured magnitude	Defines which available measured magnitude is used by the function.	1:RMS 2:TRMS	-	1:RMS

Name	Description	Range	Step	Default
		3:Peak-to-peak		
Meas side	Defines which current measurement module is used by the function.	1:Side1 2:Side2 3:Side3	-	1:Side1

Pick-up characteristics

Pick-up of the NOC function is controlled by Iset setting parameter, which defines the maximum allowed measured current before action from the function. The function constantly calculates the ratio in between of the Iset and measured magnitude (Im) per all three phases. Reset ratio of 97 % is inbuilt in the function and is always related to the Iset value. The setting value is common for all measured phases and single-, dual- or all phases Im exceed of the Iset value will cause pick-up operation of the function.

Table 3.6 Pick-up characteristics setting

Name	Description	Range	Step	Default
Iset	Pick-up setting	0.10 ... 50.00xIn	0.01xIn	1.20xIn

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Function blocking

In the blocking element the block signal is checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. Additionally, non-directional overcurrent protection includes internal inrush harmonic blocking option which is applied by user set parameter. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

Table 3.7 Internal inrush harmonic blocking settings

Name	Description	Range	Step	Default
Inrush Harmonic Blocking (Internal Only Trip)	2nd harmonic blocking enable/ disable	0;No 1;Yes	-	No
2nd Harmonic Block Limit (Iharm/ Ifund)	2nd harmonic blocking limit.	0.10...50.00*%Ifund	0.01*%Ifund	0.01*%Ifund

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup current values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Operating time characteristics for trip and reset

This function supports definite time delay (DT) and inverse definite minimum time (IDMT) delay types. For detailed information on these delay types refer to chapter General properties of a protection function.

Events and registers

The NOC function generates events and registers from the status changes of start, trip and blocked. To main event buffer is possible to select status “On” or “Off” messages. The NOC function offers four independent instances which events are segregated for each instance operation.

12 last registers are available in the function where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values.

Table 3.8 Event codes of the NOC function instances.

Event Number	Event channel	Event block name	Event Code	Description
1280	20	NOC1	0	Start ON
1281	20	NOC1	1	Start OFF
1282	20	NOC1	2	Trip ON
1283	20	NOC1	3	Trip OFF
1284	20	NOC1	4	Block ON
1285	20	NOC1	5	Block OFF
1286	20	NOC1	6	Phase A Start On
1287	20	NOC1	7	Phase A Start Off
1288	20	NOC1	8	Phase B Start On
1289	20	NOC1	9	Phase B Start Off
1290	20	NOC1	10	Phase C Start On
1291	20	NOC1	11	Phase C Start Off
1292	20	NOC1	12	Phase A Trip On
1293	20	NOC1	13	Phase A Trip Off
1294	20	NOC1	14	Phase B Trip On
1295	20	NOC1	15	Phase B Trip Off
1296	20	NOC1	16	Phase C Trip On
1297	20	NOC1	17	Phase C Trip Off
1344	21	NOC2	0	Start ON
1345	21	NOC2	1	Start OFF
1346	21	NOC2	2	Trip ON
1347	21	NOC2	3	Trip OFF
1348	21	NOC2	4	Block ON
1349	21	NOC2	5	Block OFF
1350	21	NOC2	6	Phase A Start On
1351	21	NOC2	7	Phase A Start Off
1352	21	NOC2	8	Phase B Start On
1353	21	NOC2	9	Phase B Start Off
1354	21	NOC2	10	Phase C Start On
1355	21	NOC2	11	Phase C Start Off
1356	21	NOC2	12	Phase A Trip On
1357	21	NOC2	13	Phase A Trip Off
1358	21	NOC2	14	Phase B Trip On

Event Number	Event channel	Event block name	Event Code	Description
1359	21	NOC2	15	Phase B Trip Off
1360	21	NOC2	16	Phase C Trip On
1361	21	NOC2	17	Phase C Trip Off
1408	22	NOC3	0	Start ON
1409	22	NOC3	1	Start OFF
1410	22	NOC3	2	Trip ON
1411	22	NOC3	3	Trip OFF
1412	22	NOC3	4	Block ON
1413	22	NOC3	5	Block OFF
1414	22	NOC3	6	Phase A Start On
1415	22	NOC3	7	Phase A Start Off
1416	22	NOC3	8	Phase B Start On
1417	22	NOC3	9	Phase B Start Off
1418	22	NOC3	10	Phase C Start On
1419	22	NOC3	11	Phase C Start Off
1420	22	NOC3	12	Phase A Trip On
1421	22	NOC3	13	Phase A Trip Off
1422	22	NOC3	14	Phase B Trip On
1423	22	NOC3	15	Phase B Trip Off
1424	22	NOC3	16	Phase C Trip On
1425	22	NOC3	17	Phase C Trip Off
1472	23	NOC4	0	Start ON
1473	23	NOC4	1	Start OFF
1474	23	NOC4	2	Trip ON
1475	23	NOC4	3	Trip OFF
1476	23	NOC4	4	Block ON
1477	23	NOC4	5	Block OFF
1478	23	NOC4	6	Phase A Start On
1479	23	NOC4	7	Phase A Start Off
1480	23	NOC4	8	Phase B Start On
1481	23	NOC4	9	Phase B Start Off
1482	23	NOC4	10	Phase C Start On
1483	23	NOC4	11	Phase C Start Off
1484	23	NOC4	12	Phase A Trip On
1485	23	NOC4	13	Phase A Trip Off
1486	23	NOC4	14	Phase B Trip On
1487	23	NOC4	15	Phase B Trip Off
1488	23	NOC4	16	Phase C Trip On
1489	23	NOC4	17	Phase C Trip Off

In the register of the NOC function is recorded start, trip or blocked “On” event process data. In the table below is presented the structure of NOC function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 3.9 Register content.

Date & Time	Event code	Fault type	Trigger current	Fault current	Prefault current	Trip time remaining	Used SG
dd.mm.yyyy hh:mm:ss.mss	1280-1489 Descr.	L1-G ... L1-L2-L3	Start average current	Trip -20 ms averages	Start -200 ms averages	0ms -1800s	1 - 8

3.2.2 Non-directional earth fault I0> (50N/51N)

Non-directional earth fault function (NEF) is used for instant- and time delayed earth fault protection for various applications including feeder, filter and machine applications of utilities and industry. The number of available instances of the function depends of the IED model. Function measures constantly selected neutral current magnitudes which on the operating decisions are based. Available analog measuremen channels are Io1 and Io2 residual current measurement channels and IoCalc which is residual current calculated form phase current analog channels. These analog channels use either fundamental component RMS, TRMS values (including harmonics up to 32nd) or peak-to-peak values which is user selectable. Blocking signal and setting group selection controls the operating characteristics of the function during normal operation.

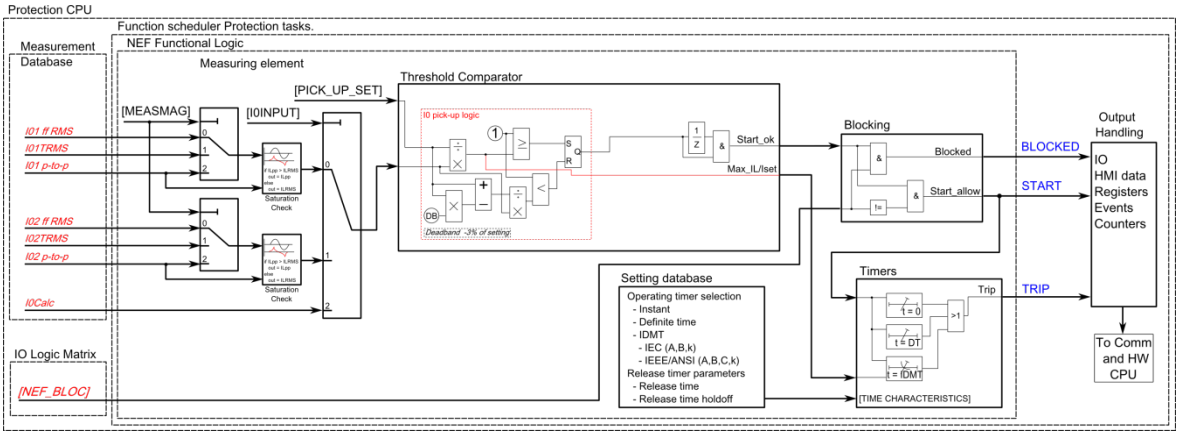
Outputs of the function are Start Trip and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. Non-directional overcurrent function utilizes total of eight separate setting groups which can be selected from one common source.

The function can be operating on instant or time delayed mode. In time delayed mode the operation can be switched to definite time or IDMT mode. For IDMT operation IEC and ANSI standard time delays are supported as well as custom parameters. Function includes saturation checking which allows the function to start and operate accurately also in case of CT saturation condition.

The operational logic consists of input magnitude processing, input magnitude selection, saturation check, threshold comparator, block signal check, time delay characteristics and output processing.

Inputs for the function are the operating mode selections, setting parameters and measured and pre-processed current magnitudes and binary input signals. Function outputs START, TRIP and BLOCKED signals which can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the three output signals. In instant operating mode the function outputs START and TRIP events simultaneously with equivalent time stamp. Time stamp resolution is 1ms. Function provides also cumulative counters for START, TRIP and BLOCKED events.

In the following figure is presented the simplified function block diagram of the NEF function.



Measured input values

Function block uses analog current measurement values. Function block always utilizes peak-to-peak measurement from samples and by user selection the monitored magnitude can be either fundamental frequency RMS values, True RMS values from the whole harmonic specter of 32 components or peak to peak values. -20ms averaged value of the selected magnitude is used for pre-fault data registering.

Table 3.10 Analogic magnitudes used by the NEF function.

Signal	Description	Time base
I01PP	Peak-to-peak measurement of coarse residual current measurement input I01	5 ms
I01RMS	Fundamental RMS measurement of coarse residual current measurement input I01	5 ms
I01TRMS	TRMS measurement of coarse residual current measurement input I01	5 ms
I02PP	Peak-to-peak measurement of sensitive residual current measurement input I02	5 ms
I02RMS	Fundamental RMS measurement of sensitive residual current measurement input I02	5 ms
I02TRMS	TRMS measurement of coarse sensitive current measurement input I02	5 ms
I0Calc	Fundamental RMS value of the calculated zero sequence current from the three phase currents	5 ms

Selection of the used AI channel is made with a setting parameter. In all possible input channel variations pre-fault condition is presented with 20 ms averaged history value from -20 ms of Start or Trip event.

General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible change them with setting group switching.

Table 3.11 General settings of the function

Name	Description	Range	Step	Default
Setting control from comm bus	Activating this parameter permits changing the pick-up level of the protection stage via SCADA	1:Disabled 2:Allowed	-	1:Disabled
Measured magnitude	Defines which available measured magnitude is used by the function	1:RMS 2:TRMS 3:Peak-to-peak	-	1:RMS
Meas side	Defines which current measurement module is used by the function.	1:Side1 2:Side2 3:Side3	-	1:Side1
Input selection	Defines which measured residual current is used by the function.	1:I01 2:I02 3:I0Calc	-	1:I01

Pick-up characteristics

Pick-up of the NEF function is controlled by I0set setting parameter, which defines the maximum allowed measured current before action from the function. The function constantly calculates the ratio in between of the Iset and measured magnitude (Im) per all three phases. Reset ratio of 97 % is inbuilt in the function and is always related to the Iset value. The setting value is common for all measured phases and single-, dual- or all phases Im exceed of the Iset value will cause pick-up operation of the function.

Table 3.12 Pick-up characteristics setting

Name	Description	Range	Step	Default
I0set	Pick-up setting	0.0001 ... 40.00xIn	0.0001xIn	1.20xIn

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Function blocking

In the blocking element the block signal is checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. Additionally, non-directional earth-fault protection includes internal inrush harmonic blocking option which is applied by user set parameter. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

Table 3.13 Internal inrush harmonic blocking settings

Name	Description	Range	Step	Default
Inrush Harmonic Blocking (Internal Only Trip)	2nd harmonic blocking enable/ disable	0; No 1; Yes	-	No
2nd Harmonic Block Limit (Iharm/ Ifund)	2nd harmonic blocking limit.	0.10...50.00*%Ifund	0.01*%Ifund	0.01*%Ifund

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup current values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Operating time characteristics for trip and reset

This function supports definite time delay (DT) and inverse definite minimum time (IDMT) delay types. For detailed information on these delay types refer to chapter General properties of a protection function.

Events and registers

The NEF function generates events and registers from the status changes of start, trip and blocked. To main event buffer is possible to select status “On” or “Off” messages. The NEF function offers four independent instances which events are segregated for each instance operation.

12 last registers are available in the function where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values.

Table 3.14 Event codes of the NEF-function instances.

Event Number	Event channel	Event block name	Event Code	Description
1664	26	NEF1	0	Start ON
1665	26	NEF1	1	Start OFF
1666	26	NEF1	2	Trip ON
1667	26	NEF1	3	Trip OFF
1668	26	NEF1	4	Block ON
1669	26	NEF1	5	Block OFF
1728	27	NEF2	0	Start ON
1729	27	NEF2	1	Start OFF
1730	27	NEF2	2	Trip ON
1731	27	NEF2	3	Trip OFF
1732	27	NEF2	4	Block ON
1733	27	NEF2	5	Block OFF
1792	28	NEF3	0	Start ON
1793	28	NEF3	1	Start OFF
1794	28	NEF3	2	Trip ON
1795	28	NEF3	3	Trip OFF
1796	28	NEF3	4	Block ON
1797	28	NEF3	5	Block OFF
1856	29	NEF4	0	Start ON
1857	29	NEF4	1	Start OFF
1858	29	NEF4	2	Trip ON
1859	29	NEF4	3	Trip OFF
1860	29	NEF4	4	Block ON
1861	29	NEF4	5	Block OFF

In the register of the NEF function is recorded start, trip or blocked “On” event process data. In the table below is presented the structure of NEF function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 3.15 Register content

Date & Time	Event code	Fault type	Trigger current	Fault current	Prefault current	Trip time remaining	Used SG
dd.mm.yyyy hh:mm:ss.mss	1664-1861 Descr.	A-G-R... C-G-F	Start average current	Trip -20 ms averages	Start -200 ms averages	0ms -1800s	1 - 8

3.2.3 Directional overcurrent IDir> (67)

Directional overcurrent function (DOC) is used for directional instant- and time delayed overcurrent/short circuit protection for various applications including feeder and machine applications of utilities and industry. IED with both voltage and current protection module may have four available instances of the function (IDir>, IDir>>, IDir>>>, IDir>>>>). Function constantly measures phase current magnitudes on which the operating decisions are based. Selectable monitored phase current

magnitudes are fundamental component RMS, TRMS values (including harmonics up to 31st) or peak-to-peak values. Blocking signal and setting group selection controls the operating characteristics of the function during normal operation.

Outputs of the function are Start Trip and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. Directional overcurrent function utilizes total of eight separate setting groups which can be selected from one common source.

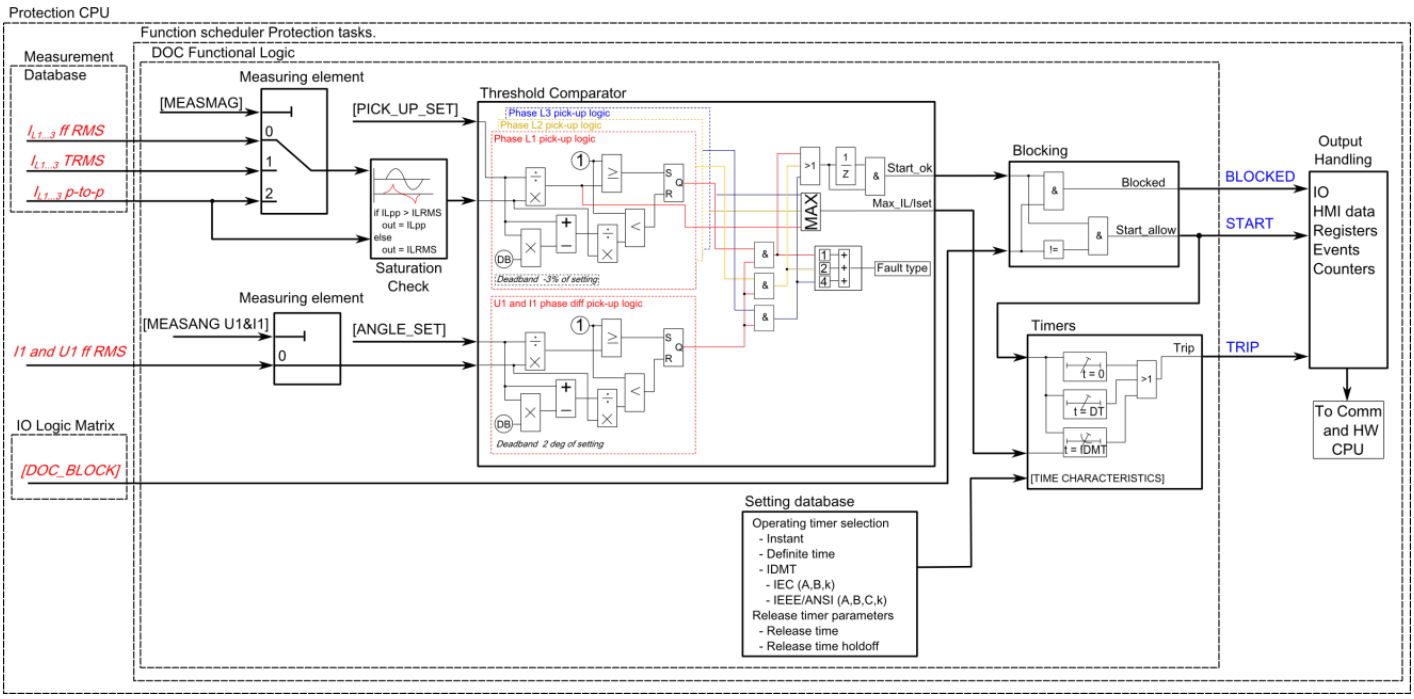
The function can be operating on instant or time delayed mode. In time delayed mode the operation mode can be switched to definite time or IDMT mode. For IDMT operation IEC and ANSI standard time delays are supported as well as custom parameters. Function includes CT saturation checking which allows the function to start and operate accurately also in case of CT saturation condition.

The operational logic consists of input magnitude and angle processing, input magnitude selection, saturation check, threshold comparator, block signal check, time delay characteristics and output processing. The basic design of the protection function is 3-pole operation.

Inputs for the function are the operating mode selections, setting parameters and measured and pre-processed current magnitudes and binary input signals. Function outputs START, TRIP and BLOCKED signals which can be used for direct IO controlling and for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the three output signals. In instant operating mode the function outputs START and TRIP events simultaneously with equivalent time stamp. Time stamp resolution is 1ms. Function provides also cumulative counters for START, TRIP and BLOCKED events.

Simplified function block diagram of DOC function is presented in the figure below.

Figure 3.16 Simplified function block diagram of the DOC function.



Measured input values

Function block uses analog current measurement values. Function block always utilizes peak-to-peak measurement from samples and by user selection the monitored magnitude can be either fundamental frequency RMS values, True RMS values from the whole harmonic specter of 32 components or peak-to-peak values. -20ms averaged value of the selected magnitude is used for pre-fault data registering.

Fault current angle is based on comparison of positive sequence voltage U1 and positive sequence current I1. If positive sequence voltage is not available (3 line-to-line voltages but no U0) voltage angle is based on faulty phase line to line

voltage. In case voltage drops below 1V in the secondary side during fault, voltage memory is used for 0.5 seconds. When 0.5 exceeds the reference angle of voltage is forced to 0°.

Table 3.16 Analogic magnitudes used by the DOC function.

Signal	Description	Time base
IL1PP	Peak-to-peak measurement of phase L1/A current	5 ms
IL2PP	Peak-to-peak measurement of phase L2/B current	5 ms
IL3PP	Peak-to-peak measurement of phase L3/C current	5 ms
IL1RMS	Fundamental RMS measurement of phase L1/A current	5 ms
IL2RMS	Fundamental RMS measurement of phase L2/B current	5 ms
IL3RMS	Fundamental RMS measurement of phase L3/C current	5 ms
IL1TRMS	TRMS measurement of phase L1/A current	5 ms
IL2TRMS	TRMS measurement of phase L2/B current	5 ms
IL3TRMS	TRMS measurement of phase L3/C current	5 ms
U_1RMS	Fundamental RMS measurement of voltage U_1/V	5 ms
U_2RMS	Fundamental RMS measurement of voltage U_2/V	5 ms
U_3RMS	Fundamental RMS measurement of voltage U_3/V	5 ms
U_4RMS	Fundamental RMS measurement of voltage U_4/V	5 ms

Selection of the used current AI channel is made with a setting parameter. In all possible input channel variations pre-fault condition is presented with 20 ms averaged history value from -20 ms of Start or Trip event.

General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible change them with setting group switching.

Table 3.17 General settings of the function

Name	Description	Range	Step	Default
Measured magnitude	Defines which available measured magnitude is used by the function.	1:RMS 2:TRMS 3:Peak-to-peak	-	1:RMS
Meas side	Defines which current measurement module is used by the function. Visible if unit has more than one current measurement module.	1:Side1 2:Side2 3:Side3	-	1:Side1

Real-time info displayed by the function

The relays Info-page displays useful information in real time of the state of the protection function either through relays HMI display or with MVR utility software when connection there is a connection to relay and Live Edit-mode is activated.

Table 3.18 Info displayed by the function

Name	Unit	Description
Operating angle now	Deg	Positive sequence current angle in relation to positive sequence voltage
Expected operating time	s	Displays the expected operating time in case a fault occurs
Time remaining to trip	s	When the relay has picked up and is counting time towards pick-up
Imeas/Iset at the moment	Im/Iset	Ratio between positive sequence current and the pick-up value.

Pick-up characteristics

Pick-up of the DOC function is controlled by Iset setting parameter, which defines the maximum allowed measured current before action from the function. The function constantly calculates the ratio in between the Iset and measured magnitude (Im) per all three phases. Reset ratio of 97 % is inbuilt in the function and is always related to the Iset value. The setting value is common for all measured phases and single-, dual- or all phases Im exceed of the Iset value will cause pick-up operation of the function.

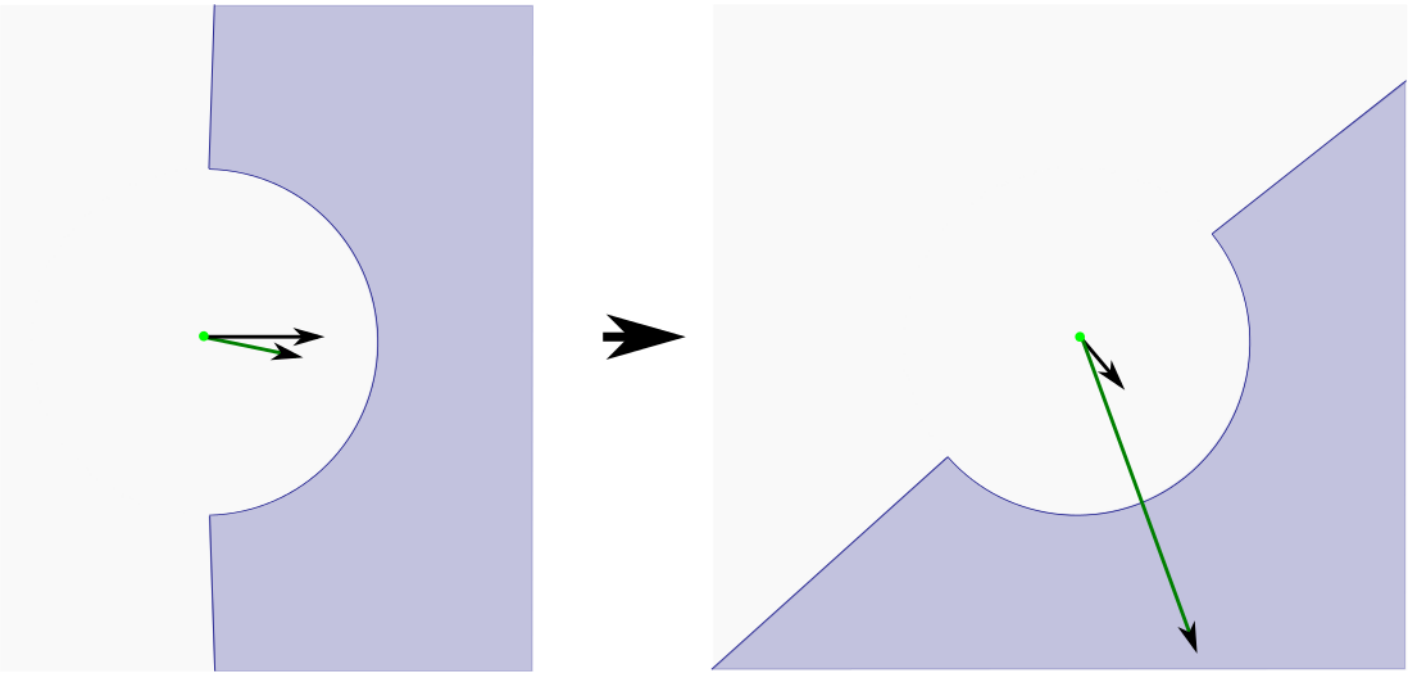
Trip characteristic can be set to directional or non-directional. In non-directional mode only positive sequence current magnitude pick-up value must be fulfilled for the function to trip. In directional mode the fault must be in the monitored direction as well to fulfill the terms to trip. By default tripping area is ±88° (176°) and reference angle is based on calculated positive sequence voltage U1 angle. In case U1 voltage is not available and only line to line voltages are measured the angle reference is based on healthy line to line voltage and during short circuit to impedance calculation. If voltage drops below 1V secondary the angle memory is used for 0.5 seconds. Angle memory forces the angle reference to the value that was measured or calculated before the fault. Angle memory captures the measured voltage angle 100 ms before the fault starts. After 0.5 seconds the angle memory is not used anymore, and reference voltage is forced to 0°. Inbuilt reset ratio for the trip area angle is 2°.

Table 3.19 Pick-up characteristics setting

Name	Description	Range	Step	Default
Iset	Pick-up setting	0.10 ... 40.00xIn	0.01xIn	1.20 x In
Center	Pick-up center	-180.0...180.0°	0.1°	0°
Angle	Pick-up area	±1.0...170.0°	0.1°	±88°

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Figure 3.17 Angle tracking of DOC function (3LN or 3LL+U0 mode).



Notice in picture above that tripping area is linked to the angle of positive sequence voltage U1. Positive sequence current I1 angle is compared to U1 angle and in case the fault is in correct direction it is possible to perform trip when amplitude of I_{L1}, I_{L2} or I_{L3} increases above the pick-up limit.

In case 3LL mode is used without U0 measurement in one phase fault situation voltage reference comes from the healthy phase and current reference from faulty phase. In short-circuit the angle comes from impedance calculation.

Function blocking

In the blocking element the block signal is checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. Additionally, directional overcurrent protection includes internal inrush harmonic blocking option which is applied by user set parameter. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

Table 3.20 Internal inrush harmonic blocking settings

Name	Description	Range	Step	Default
Inrush Harmonic Blocking (Internal Only Trip)	2nd harmonic blocking enable/ disable	0:No 1:Yes	-	No
2nd Harmonic Block Limit (Iharm/ Ifund)	2nd harmonic blocking limit.	0.10...50.00*%Ifund	0.01*%Ifund	0.01*%Ifund

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function HMI displays event as well as time stamped blocking event with information of the startup current values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Operating time characteristics for trip and reset

This function supports instant operation, definite time delay (DT) and inverse definite minimum time (IDMT) delay types. For detailed information on these delay types refer to chapter General properties of a protection function.

Events and registers

The DOC function generates events and registers from the status changes of start, trip and blocked. To main event buffer is possible to select status “On” or “Off” messages. The DOC function offers four independent instances which events are segregated for each instance operation.

In the function is available 12 last registers where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values.

Table 3.21 Event codes of the DOC function instances 1 – 4.

Event Number	Event channel	Event block name	Event Code	Description
4800	75	DOC1	0	Start ON
4801	75	DOC1	1	Start OFF
4802	75	DOC1	2	Trip ON
4803	75	DOC1	3	Trip OFF
4804	75	DOC1	4	Block ON
4805	75	DOC1	5	Block OFF
4806	75	DOC1	6	No voltage, Blocking On
4807	75	DOC1	7	Voltage measurable, Blocking Off
4808	75	DOC1	8	Measuring live angle On
4809	75	DOC1	9	Measuring live angle Off

Event Number	Event channel	Event block name	Event Code	Description
4810	75	DOC1	10	Using voltmem On
4811	75	DOC1	11	Using voltmem Off
4864	76	DOC2	0	Start ON
4865	76	DOC2	1	Start OFF
4866	76	DOC2	2	Trip ON
4867	76	DOC2	3	Trip OFF
4868	76	DOC2	4	Block ON
4869	76	DOC2	5	Block OFF
4870	76	DOC2	6	No voltage, Blocking On
4871	76	DOC2	7	Voltage measurable, Blocking Off
4872	76	DOC2	8	Measuring live angle On
4873	76	DOC2	9	Measuring live angle Off
4874	76	DOC2	10	Using voltmem On
4875	76	DOC2	11	Using voltmem Off
4928	77	DOC3	0	Start ON
4929	77	DOC3	1	Start OFF
4930	77	DOC3	2	Trip ON
4931	77	DOC3	3	Trip OFF
4932	77	DOC3	4	Block ON
4933	77	DOC3	5	Block OFF
4934	77	DOC3	6	No voltage, Blocking On
4935	77	DOC3	7	Voltage measurable, Blocking Off
4936	77	DOC3	8	Measuring live angle On
4937	77	DOC3	9	Measuring live angle Off
4938	77	DOC3	10	Using voltmem On
4939	77	DOC3	11	Using voltmem Off
4992	78	DOC4	0	Start ON
4993	78	DOC4	1	Start OFF
4994	78	DOC4	2	Trip ON
4995	78	DOC4	3	Trip OFF
4996	78	DOC4	4	Block ON
4997	78	DOC4	5	Block OFF
4998	78	DOC4	6	No voltage, Blocking On
4999	78	DOC4	7	Voltage measurable, Blocking Off
5000	78	DOC4	8	Measuring live angle On
5001	78	DOC4	9	Measuring live angle Off
5002	78	DOC4	10	Using voltmem On
5003	78	DOC4	11	Using voltmem Off

Register of the DOC function records start, trip or blocked “On” event process data. In the table below is presented the structure of DOC function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 3.22 Register content

Column name	Content description
Date & Time	dd.mm.yyyy hh:mm:ss.mss
Event code	4800-4997 Descr.
Fault type	L1-G...L1-L2-L3
Trigger current	Start average current
Fault current	Trip -20ms averages
Prefault current	Start -200ms averages
Trip time remaining	0 s ... 1800 s
Used SG	1...8 Setting group
Operating angle	0...250 deg

3.2.4 Directional earth fault I0Dir> (67N)

Directional earth fault function (DEF) is used for instant- and time delayed earth fault protection for various applications including feeder and machine applications of utilities and industry. IED with both voltage and current protection module may have four available instances of the function (I0Dir>, I0Dir>>, I0Dir>>>, I0Dir>>>>). Function constantly measures selected neutral current –or voltage magnitudes on which the operating decisions are based. Available residual current magnitudes are fundamental component RMS, TRMS values (including harmonics up to 31st) or peak-to-peak values of residual current measurement inputs I01 and I02 or from phase current measurements calculated residual current I0Calc. Current angle is compared to the angle of measured or calculated zero sequence voltage. Certain amount of zero sequence voltage has to be present to activate the trip. Blocking signal and setting group selection controls the operating characteristics of the function during normal operation.

Outputs of the function are Start Trip and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. Directional earth fault function utilizes total of eight separate setting groups which can be selected from one common source.

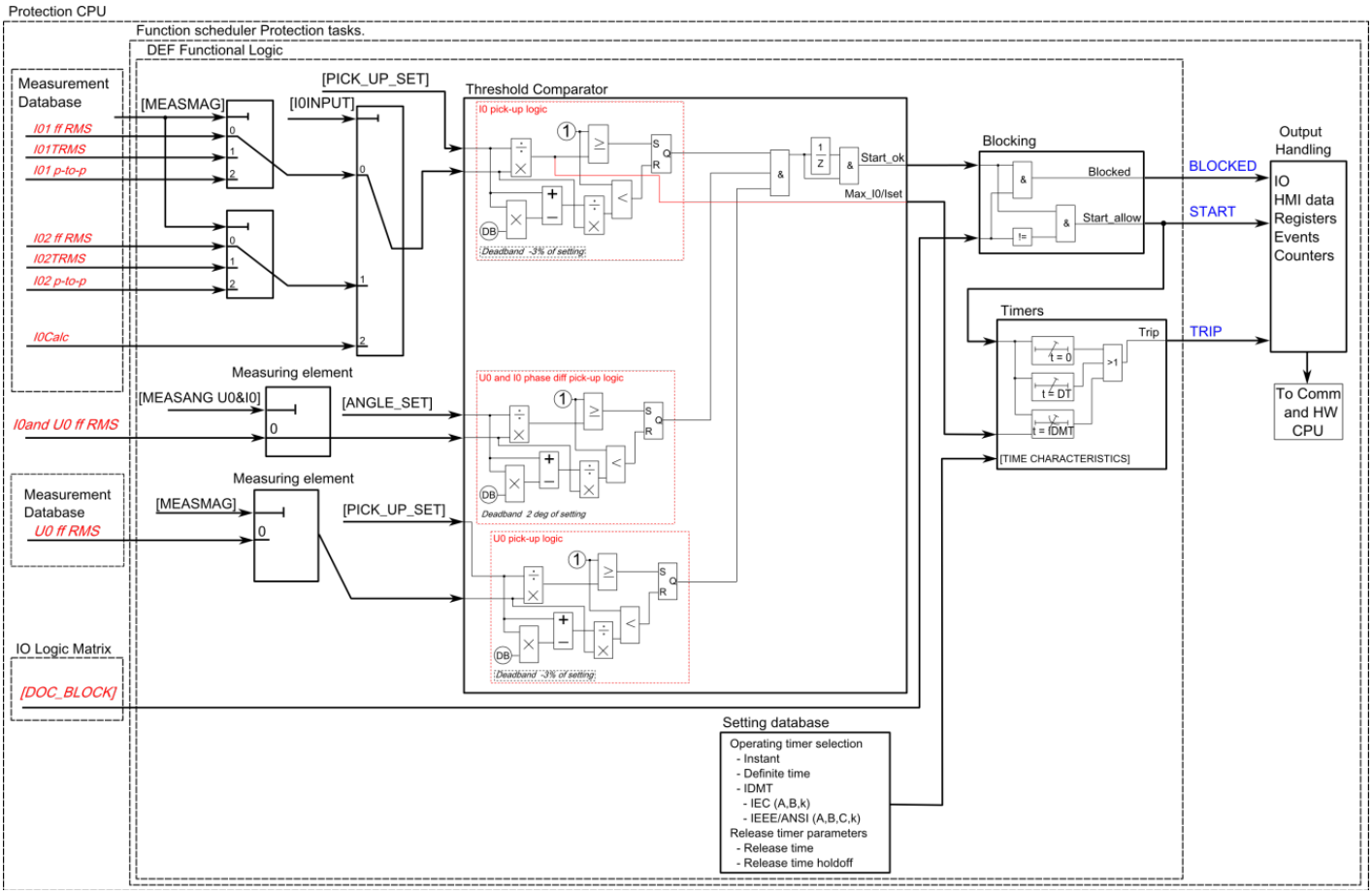
The function can be operating on instant or time delayed mode. In time delayed mode the operation can be switched to definite time or IDMT mode. For IDMT operation IEC and ANSI standard time delays are supported as well as custom parameters.

The operational logic consists of input magnitude processing, input magnitude selection, threshold comparator, angle check, block signal check, time delay characteristics and output processing.

Inputs for the function are the operating mode selections, setting parameters and measured and pre-processed current magnitudes and binary input signals. Function outputs START, TRIP and BLOCKED signals which can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the output signals. In instant operating mode the function outputs START and TRIP events simultaneously with equivalent time stamp. Time stamp resolution is 1ms. Function provides also cumulative counters for START, TRIP and BLOCKED events.

Simplified function block diagram of the DEF function is presented in the figure below.

Figure 3.18 Simplified function block diagram of the DEF function.



Measured input value

Function block uses analog current measurement values. Function block always utilizes peak-to-peak measurement from samples and by user selection the monitored magnitude can be either fundamental frequency RMS values, True RMS values from the whole harmonic specter of 32 components or peak to peak values. -20ms averaged value of the selected magnitude is used for pre-fault data registering.

Fault current angle is based on comparing neutral voltage U0 angle. Both I0 and U0 must be above squelch limit to be able to detect the angle. Squelch limit for I0 current is 0.01 x In and for voltage 0.01 x Un.

Table 3.23 Analogic magnitudes used by the DEF function.

Signal	Description	Time base
I01PP	Peak-to-peak measurement of coarse residual current measurement input I01	5 ms
I01RMS	Fundamental RMS measurement of coarse residual current measurement input I01	5 ms
I01TRMS	TRMS measurement of coarse residual current measurement input I01	5 ms
I02PP	Peak-to-peak measurement of sensitive residual current measurement input I02	5 ms
I02RMS	Fundamental RMS measurement of sensitive residual current measurement input I02	5 ms
I02TRMS	TRMS measurement of coarse sensitive current measurement input I02	5 ms
I0Calc	Fundamental RMS value of the calculated residual current from the three phase currents	5 ms
U0RMS	Fundamental RMS measurement of zero sequence voltage measurement input U0	5 ms
U0Calc	Fundamental RMS value of the calculated zero sequence voltage from the three phase voltages	5 ms

Selection of the used AI channel is made with a setting parameter. In all possible input channel variations pre-fault condition is presented with 20 ms averaged history value from -20 ms of Start or Trip event.

General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible change them with setting group switching.

Table 3.24 General settings of the function

Name	Description	Range	Step	Default
U0 directional phase	If connected neutral voltage polarity is opposite to connected residual current this parameter can swap the angle reference.	1:U0 2:-U0	-	1:U0
U0> Meas input select	Defines which available neutral voltage measurement is used. Available neutral voltages depend on measurement settings set at Measurements → Transformers → VT module.	1:Select 2:U0Calculated 3:U3 Input 4:U4 Input	-	Select
Measured magnitude	Defines which available measured magnitude is used by the function.	1:RMS 2:TRMS 3:Peak-to-peak	-	1:RMS
Meas side	Defines which current measurement module is used by the function.	1:Side1 2:Side2 3:Side3	-	1:Side1
Input selection	Defines which measured residual current is used by the function.	1:I01 2:I02 3:I0Calc	-	1:I01

Pick-up characteristics

Pick-up of the DEF function is controlled by I0setsetting parameter, which defines the maximum allowed measured current, U0set setting parameter which defines the maximum allowed measured voltage and checks the angle difference before action from the function. The function constantly calculates the ratio between Iset/Uset and measured magnitudes (Im/Um). Reset ratio of 97 % is inbuilt in the function and is always related to the I0set value (or U0set). Im exceeding the I0set value will cause pick-up operation of the function.

Table 3.25 Pick-up characteristics settings

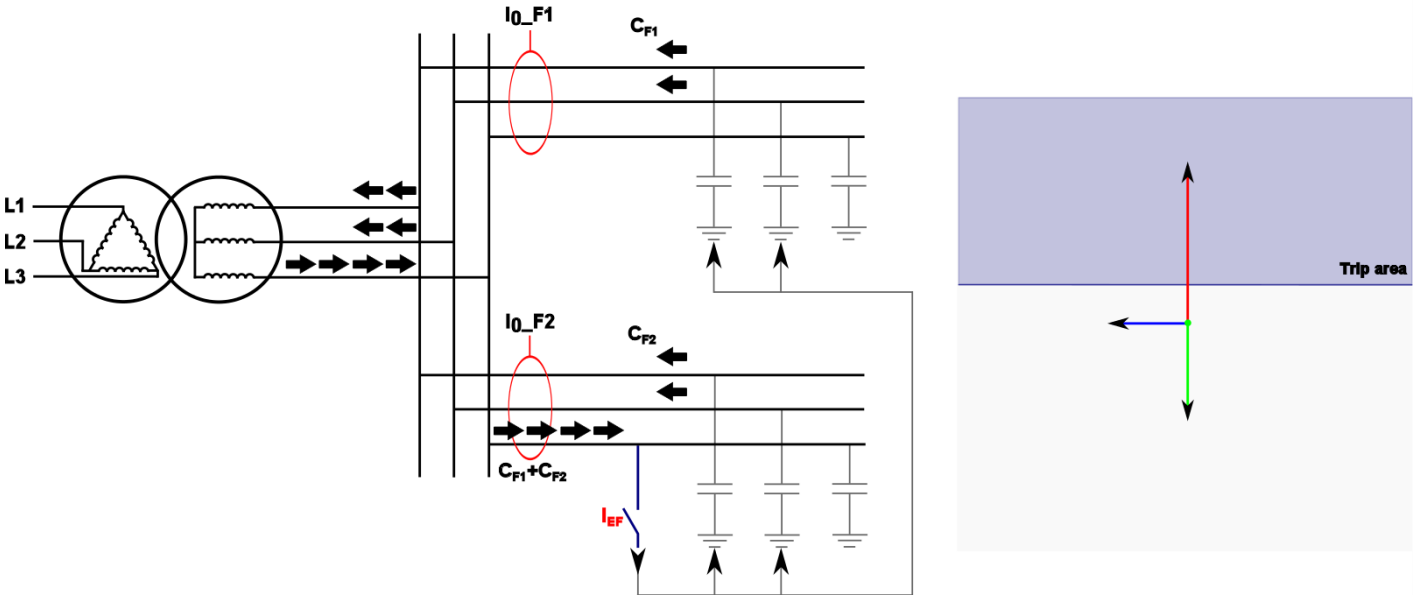
Name	Description	Range	Step	Default
I0set	Pick-up setting	0.005 ... 40.00xIn	0.001xIn	1.20xIn
U0set	Pick-up setting	1...75%Un	0.01 (%Un)	20%Un
Grounding type	Network grounding method	1:Unearthed 2:Petersen coil grounded 3:Grounded network 4:I0Cos&I0Sin Broadrange mode	-	Unearthed
Multi-criteria detection	Activation of detecting healthy or unhealthy feeder by analyzing symmetrical components of currents and voltages. Visible when grounding type is set to I0Cos&I0Sin Broadrange mode	1:Not used 2:Used	-	Not used
Unearthed / Compensated border angle	Dividing angle between unearthed and compensated tripping. See description later in this document. Visible when grounding type is set to I0Cos&I0Sin Broadrange mode	-45.0...90deg	0.1deg	45deg
Angle	Trip area size (Grounded network)	±45.0...135.0°	0.1°	±88°

Name	Description	Range	Step	Default
Angle offset	Protection area direction (Grounded network)	0.0...360.0°	0.1°	0.0°
Angle blinder	Io angle blinder (Petersen coil grounded)	-90.0...0.0°	0.1°	-90°

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Unearthed network

Figure 3.19 Angle tracking of DEF function in unearthed network model.



When unearthed (capacitive) network mode is chosen IED expects the fault current to be lagging zero sequence voltage by 90 degrees. Healthy phases of healthy feeders produce capacitive current during ground fault just like faulty feeder but current is flowing towards busbar and trough incoming transformer or grounding transformer to faulty feeder. Healthy feeders do not trip since capacitive current is floating to opposite direction and selective tripping can be ensured.

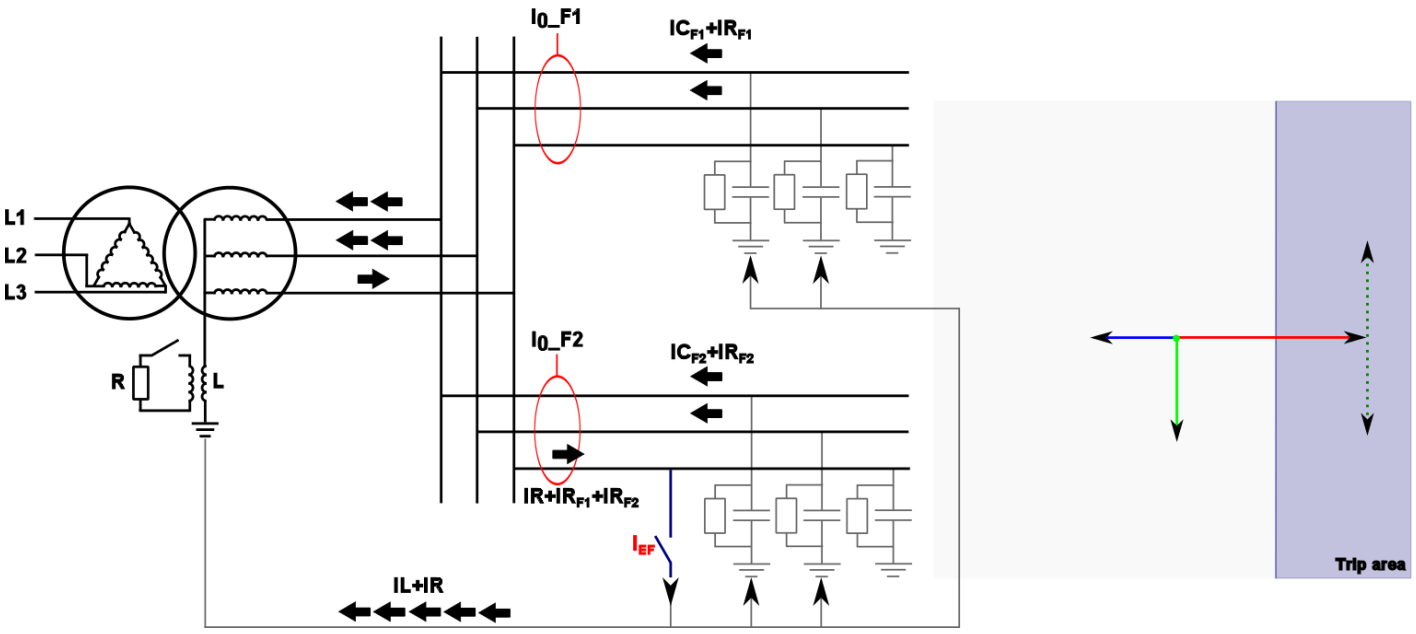
Amplitude of fault current depends of the capacitance of the network. The sources of capacitive currents are the outgoing feeders. The bigger the network the greater the capacitive current during fault is. Each outgoing feeder produces capacitance according the zero sequence capacitive reactance of the line (ohms per kilometer). It is normal that in cable networks fault currents are higher compared to overhead lines.

Resistance of the fault affects to the amount of voltage drop during the fault. In direct earth fault the zero sequence voltage amplitude is equal to system line to earth voltage. In direct earth fault the voltage of faulty phase drops close to zero and healthy phase voltages increase to amplitude of line to line voltages.

Petersen coil grounded (compensated) network

There are many benefits with Petersen coil grounded network. Amount of automatic reclosing is highly decreased and therefore maintenance of breakers is diminished. Arc faults die on their own and cables and equipment suffer less damage. In emergency situations line with earth fault can be used for certain time.

Figure 3.20 Angle tracking of DEF function in Petersen coil grounded network model.

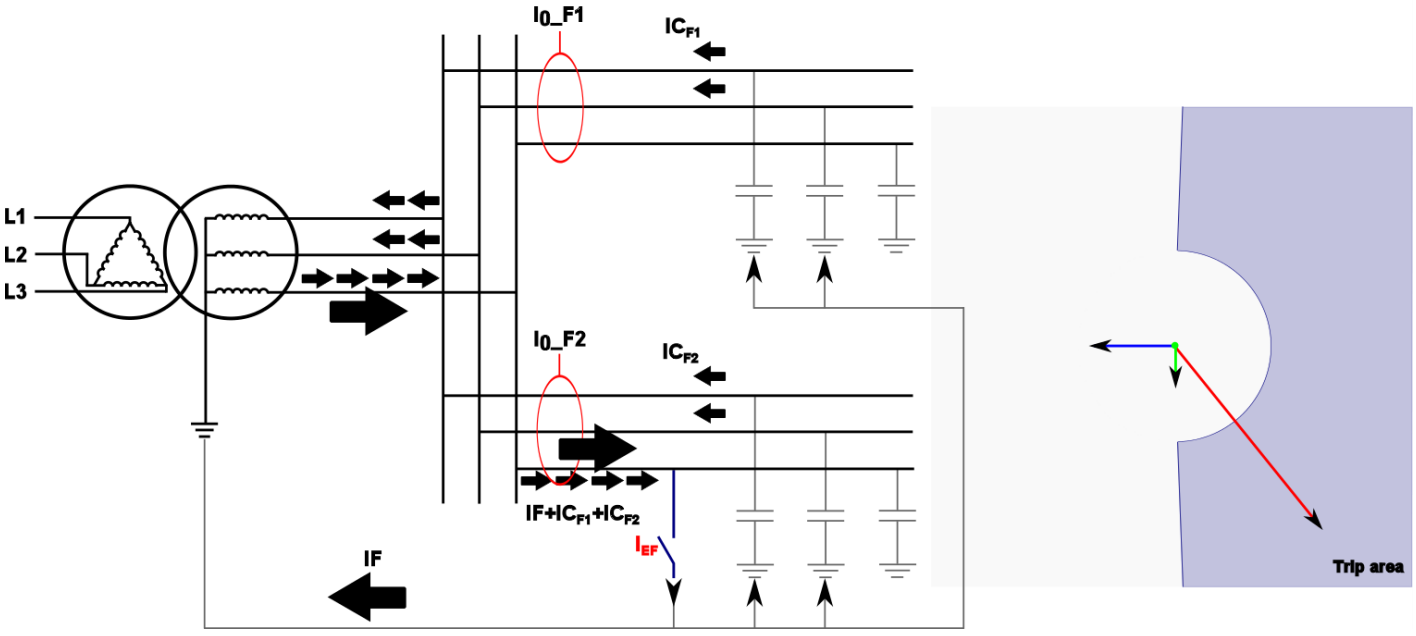


When Petersen coil grounded (compensated) network mode is chosen the IED expects the fault current to be opposite direction to zero sequence voltage. Healthy phases of healthy feeders and faulty feeder produce capacitive current similar to unearthed network. Inductance of Petersen coil is compensating the capacitive current and therefore residual current in fault location is close to zero. Size of the inductance is chosen according the prospective earth fault current of the network. Desired compensation grade is achieved when k-factor is close to 1.0 and network is fully compensated. Network is over compensated when k-factor is greater than one and under compensated if the factor is smaller than one.

Inductance connected to the star point of incoming transformer or like in most cases to grounding transformer compensates the capacitance of the network but due this the capacitive fault current cannot be measured anymore. Fault detection is handled by connecting a resistance on parallel with the inductance. This resistance defines the amplitude of fault current. In under –or over compensated situations the resistive component during the fault does not change, therefore selective tripping is ensured even if the network is bit under –or over compensated.

Directly or small impedance grounded network

Figure 3.21 Angle tracking of DEF function in grounded network model.



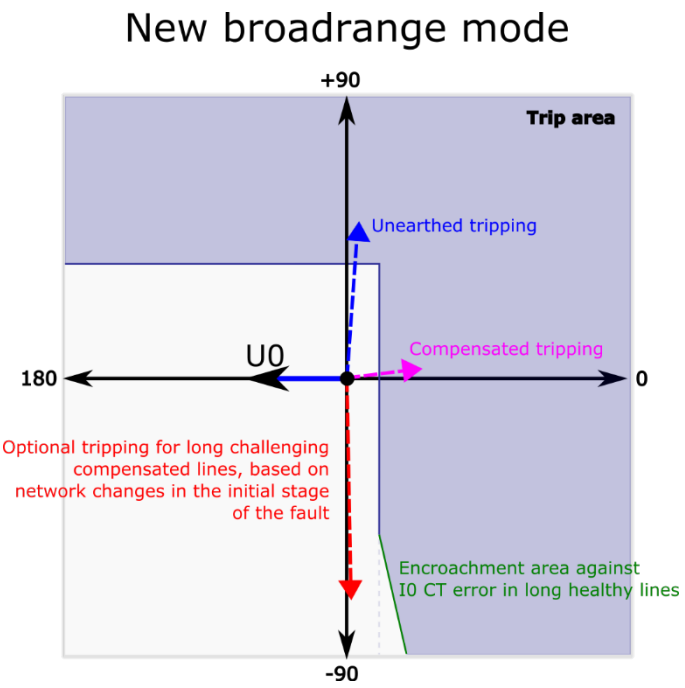
In directly grounded network the amplitude of single phase fault current is similar to amplitude of short circuit current. Directly or small impedance grounded network schemes are normal in transmission, distribution and in industry.

Phase angle setting of the trip area is adjustable as is the base direction of the area (angle offset).

Broad range mode with multi-criteria detection for unearthed and compensated networks

When protecting compensated long-distance cables and overhead lines it is in some cases difficult to distinguish between healthy- and faulty feeder. Merely measuring the angle and magnitude of residual voltage and currents is not always enough, but changes in symmetrical components of phase currents and voltages are also needed. Also, when protecting feeders from earth faults two modes are used depending on the network status (ungrounded or compensated). When changing between these two statuses setting group must be changed and especially in case of distributed compensation the change may be difficult or impossible to arrange. Lastly, in a compensated network protection, the relay with traditional algorithms may sporadically detect an earth-fault in a long healthy feeder due to CT errors. For all these reasons, there is an improved alternative to these traditional directional earth fault protections.

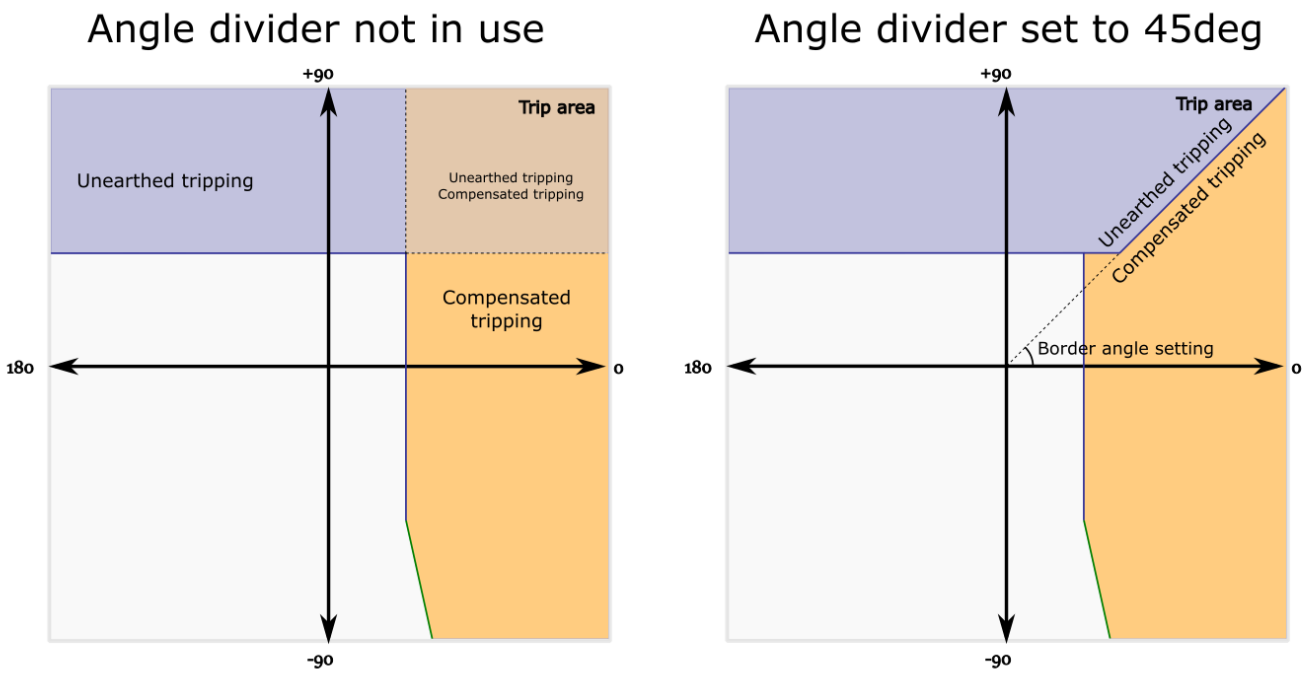
Figure 3.22 Angle tracking of DEF function. Broadrange mode.



New broad range mode is capable of detecting earth-fault directionally in both ungrounded and compensated networks not only by just combining the two stages together but using a new multi-criteria detection. This optional additional tripping condition for compensated networks uses patented, high-resolution intermittent earth-fault algorithm with added symmetrical component calculation of phase currents and voltages. If this mode is activated the tripping criteria comprises of a measured residual current in the fourth quadrant and the symmetrical components of voltages and currents detecting a fault. No extra parameterization is required compared to traditional method. Multi-criteria algorithm can be tested with COMTRADE files supplied by DEIF. Function requires connection of 3-phase currents, residual current and residual voltage to operate correctly.

To avoid unnecessary trips encroachment area against I0 CT errors in compensated long healthy lines can be added.

Figure 3.23 Effect of angle divider when in use and when disabled.



To receive more accurate indication whether the trip was in a compensated or unearthed network angle divider can divide the area which would be otherwise overlapped between the two network models. By default the setting is 45 degrees. If the angle is set to zero degrees the divider is disabled.

Real-time info displayed by the function

The IEDs Info-page displays useful information in real time of the state of the protection function either through relays HMI display or with MVR utility software when connection there is a connection to relay and Live Edit-mode is activated.

Table 3.26 Information displayed by the function

Name	Unit	Description
U0> Pick-up setting	V	Required residual voltage on the primary side for the relay to trip.
Detected U0I0 angle (fi)	Deg	The angle in degrees between the monitored residual voltage and current
I0 Magnitude	xI0n	Per-unit-value of the monitored residual current
I0 Wattmetric I0xCos(fi)	xI0n	Wattmetric per-unit-value of the monitored residual current
I0 Varmetric I0xSin(fi)	xI0n	Varmetric per-unit-value of the monitored residual current
I0 direction now	Undefined Forward Reverse	Detected direction of the residual current.
I0 meas / I0 set now	xI0n	Ratio between monitored residual current and pick-up setting
U0 meas now	%U0n	The measured voltage in the chosen voltage channel.
Expected operating time	s	Displays the expected operating time in case a fault occurs
Time remaining to trip	s	When the relay has picked up and is counting time towards pick-up

Function blocking

In the blocking element the block signal is checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. Additionally, directional earth-fault protection includes internal inrush harmonic blocking option which is applied by user set parameter. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

Table 3.27 Internal inrush harmonic blocking settings

Name	Description	Range	Step	Default
Inrush Harmonic Blocking (Internal Only Trip)	2nd harmonic blocking enable/ disable	0:No 1:Yes	-	No
2nd Harmonic Block Limit (Iharm/ Ifund)	2nd harmonic blocking limit.	0.10...50.00*%Ifund	0.01*%Ifund	0.01*%Ifund

If blocking signal is active when pick-up element activates BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function an HMI display event as well as time stamped blocking event with information of the startup current values and fault type is issued.

Blocking signal can be tested in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Operating time characteristics for trip and reset

This function supports definite time delay (DT) and inverse definite minimum time (IDMT) delay types. For detailed information on these delay types refer to chapter General properties of a protection function.

Events and registers

The DEF function generates events and registers from the status changes of start, trip and blocked. To main event buffer is possible to select status “On” or “Off” messages. The DEF function offers four independent instances which events are segregated for each instance operation.

In the function is available 12 last registers where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values.

Table 3.28 Event codes of the DEF-function instances.

Event Number	Event channel	Event block name	Event Code	Description
5184	81	DEF1	0	Start ON
5185	81	DEF1	1	Start OFF
5186	81	DEF1	2	Trip ON
5187	81	DEF1	3	Trip OFF
5188	81	DEF1	4	Block ON
5189	81	DEF1	5	Block OFF
5190	81	DEF1	6	I0Cosfi Start On
5191	81	DEF1	7	I0Cosfi Start Off
5192	81	DEF1	8	I0Sinfi Start On
5193	81	DEF1	9	I0Sinfi Start Off
5248	82	DEF2	0	Start ON
5249	82	DEF2	1	Start OFF
5250	82	DEF2	2	Trip ON
5251	82	DEF2	3	Trip OFF

Event Number	Event channel	Event block name	Event Code	Description
5252	82	DEF2	4	Block ON
5253	82	DEF2	5	Block OFF
5254	82	DEF2	6	I0Cosfi Start On
5255	82	DEF2	7	I0Cosfi Start Off
5256	82	DEF2	8	I0Sinfi Start On
5257	82	DEF2	9	I0Sinfi Start Off
5312	83	DEF3	0	Start ON
5313	83	DEF3	1	Start OFF
5314	83	DEF3	2	Trip ON
5315	83	DEF3	3	Trip OFF
5316	83	DEF3	4	Block ON
5317	83	DEF3	5	Block OFF
5318	83	DEF3	6	I0Cosfi Start On
5319	83	DEF3	7	I0Cosfi Start Off
5320	83	DEF3	8	I0Sinfi Start On
5321	83	DEF3	9	I0Sinfi Start Off
5376	84	DEF4	0	Start ON
5377	84	DEF4	1	Start OFF
5378	84	DEF4	2	Trip ON
5379	84	DEF4	3	Trip OFF
5380	84	DEF4	4	Block ON
5381	84	DEF4	5	Block OFF
5382	84	DEF4	6	I0Cosfi Start On
5383	84	DEF4	7	I0Cosfi Start Off
5384	84	DEF4	8	I0Sinfi Start On
5385	84	DEF4	9	I0Sinfi Start Off

In the register of the DEF function is recorded start, trip or blocked “On” event process data. In the table below is presented the structure of DEF function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 3.29 Register content

Column name	Content description
Event Code	dd.mm.yyyy hh:mm:ss.mss
Date & Time	5184-5385 Descr.
Io pretriggering current	Start average current
Io fault current	Trip -20ms averages
Fault capacity Io	Trip -20ms averages
Fault resist Io	Trip -20ms averages
Fault Uo (%)	Trip -20ms averages
Fault Uo (V)	Trip -20ms averages

Column name	Content description
Io fault angle	0 - 360°
Trip time remaining	0ms – 1800 s
Used SG	1-8
Network GND	Unearthed, Petersen coil grounded, Grounded network
Io prefault current	Start -200ms averages

3.2.5 Current unbalance I2> (46)

Current unbalance function (CUB) is used for instant- and time delayed unbalanced network protection and detection of broken conductor for various applications including feeder, filter and machine applications of utilities and industry. The number of available instances of the function depends of the IED model. Function measures constantly negative- and positive sequence current magnitudes which on the operating decisions are based. In broken conductor mode (I2/I1) phase current magnitudes are monitored also for minimum allowed loading current.

Two possible operating modes are available, I2 mode which monitors negative sequence current and I2/I1 mode, which monitors the ratio of negative sequence current ratio to positive sequence current. The used symmetrical component magnitudes are calculated in the relay from the phase current inputs IL1, IL2 and IL3. Zero sequence current is also recorded into the registers as well as the angles of the positive, negative and zero sequence currents for better verification of the fault cases. Blocking signal and setting group selection controls the operating characteristics of the function during normal operation.

Outputs of the function are Start Trip and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. Non-directional unbalance function utilizes total of eight separate setting groups which can be selected from one common source.

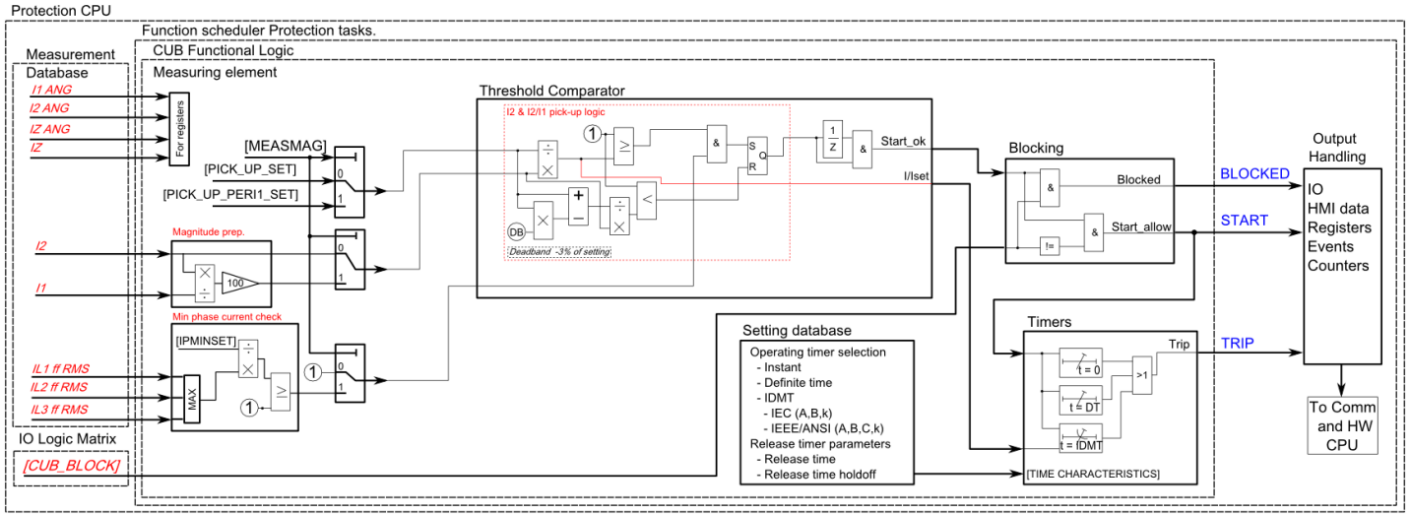
The function can be operating on instant or time delayed mode. In time delayed mode the operation can be switched to definite time or IDMT mode. For IDMT operation IEC and ANSI standard time delays are supported as well as custom parameters.

The operational logic consists of input magnitude processing, input magnitude selection, threshold comparator, block signal check, time delay characteristics and output processing.

Inputs for the function are the operating mode selections, setting parameters and measured and pre-processed current magnitudes and binary input signals. Function outputs START, TRIP and BLOCKED signals which can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the three output signals. In instant operating mode the function outputs START and TRIP events simultaneously with equivalent time stamp. Time stamp resolution is 1ms. Function provides also cumulative counters for START, TRIP and BLOCKED events.

In the following figure is presented the simplified function block diagram of the CUB function.

Figure 3.24 Simplified function block diagram of the CUB function.



Measured input values

Function block uses analog current measurement values. Function block utilizes calculated positive and negative sequence currents. In broken conductor mode (I2/I1) also the phase currents RMS values are used for the minimum current check. Zero sequence and the component sequence angles are used for the fault registering and for fault analysis processing. -20ms averaged value of the selected magnitude is used for pre-fault data registering.

Table 3.30 Analogic magnitudes used by the CUB function.

Signal	Description	Time base
I1	Positive sequence current magnitude	5 ms
I2	Negative sequence current magnitude	5 ms
IZ	Zero sequence current magnitude	5 ms
I1 ANG	Positive sequence current angle	5 ms
I2 ANG	Negative sequence current angle	5 ms
IZ ANG	Zero sequence current angle	5 ms
IL1RMS	Phase L1 (A) measured RMS current	5 ms
IL2RMS	Phase L2 (B) measured RMS current	5 ms
IL3RMS	Phase L3 (C) measured RMS current	5 ms

Selection of the used AI channel is made with a setting parameter. In all possible input channel variations pre-fault condition is presented with 20 ms averaged history value from -20 ms of Start or Trip event.

General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible change them with setting group switching.

Name	Description	Range	Step	Default
Meas side	Defines which current measurement module is used by the function. Visible if unit has more than one current measurement module.	1:Side1 2:Side2	-	1:Side1

Name	Description	Range	Step	Default
		3:Side3		
Measured magnitude	Defines if the ratio between positive and negative sequence currents are supervised or if only negative sequence is used in unbalance detection.	1:I2pu 2:I2/I1	-	1:I2pu

Pick-up characteristics

Pick-up of the CUB function is controlled by I2set or I2/I1set setting parameters, which define the maximum allowed measured negative sequence current or negative/positive sequence current ratio before action from the function. The function constantly calculates the ratio in between of the Iset and measured magnitude (Im). Reset ratio of 97 % is inbuilt in the function and is always related to the Ixset value. The reset ratio is common for both modes.

Table 3.31 Pick-up characteristics setting

Name	Description	Range	Step	Default
I2set	Pick-up setting for I2 mode	0.01...40.00xIn	0.01xIn	0.2xIn
I2/I1set	Pick-up setting for I2/I1 mode	1...200%	0.01%	20%

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Function blocking

In the blocking element the block signal is checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup current values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Operating time characteristics for trip and reset

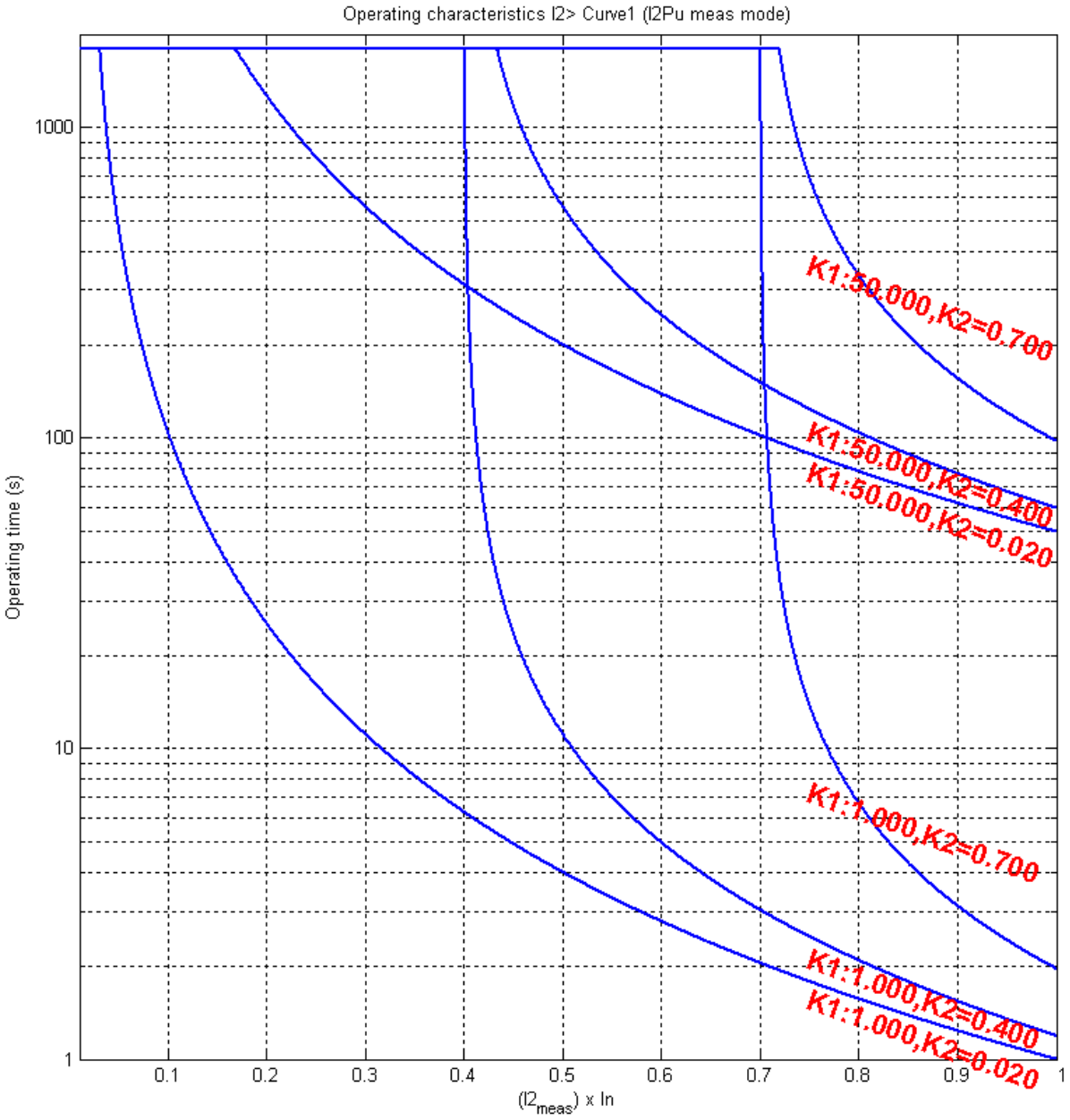
The operating timers' behavior of the function can be set for trip signal and also for the release of the function in case the pick-up element is reset before the trip time has been reached. There are three basic operating modes available for the function. Instant operation gives the trip signal with no additional time delay simultaneously with start signal. Definite time operation (DT) will give trip signal with user given time delay regardless of the measured current as long as the current is above the Iset value and thus pick-up element is active (independent time characteristics). Inverse definite minimum time (IDMT) will give the trip signal in time which is in relation of the set pick-up current Iset and measured current Im (dependent time characteristics). For the IDMT operation is available IEC and IEEE/ANSI standard characteristics as well as user settable parameters.

Uniquely to current unbalance protection there is also “Curve2” delay available which follows the formula below:

$$t = \frac{k}{{I_{2meas}}^2 - {I_{set}}^2}$$

- t = Operating time
- I_{2meas} = Calculated negative sequence
- I_N = Nominal current
- k = Constant k value (user settable delay multiplier)
- I_{set} = Pick-up setting of the function

Figure 3.25 Operation characteristics curve for I2 > Curve2



Following table presents the setting parameters for the function time characteristics.

Table 3.32 Operating time characteristics setting parameters.

Name	Range	Step	Default	Description
Delay Type	DT IDMT	-	DT	Selection of the delay type time counter. Selection possibilities are dependent (IDMT, Inverse Definite Minimum Time) and independent (DT, Definite Time) characteristics.
Definite operating time delay	0.000...1800.000s	0.005s	0.040s	Definite time operating delay. Setting is active and visible when Delay Type is selected to DT.

Name	Range	Step	Default	Description
				When set to 0.000 s the stage operates as instant (PIOC, 50) stage without added delay. When the parameter is set to 0.005 – 1800 s the stage operates as independent delayed (PTOC, 51).
Delay curve series	IEC IEEE Non-standard	-	IEC	Setting is active and visible when Delay Type is selected to IDMT. Delay curve series for IDMT operation following either IEC or IEEE/Ansi standard defined characteristics. Non-standard characteristics include delay curves outside of the two sandards.
Delay characteristics IEC	NI EI VI LTI Param	-	NI	Setting is active and visible when Delay Type is selected to IDMT. IEC standard delay characteristics. Normally Inverse, Extremely Inverse, Very Inverse and Long Time Inverse characteristics. Param selection allows the tuning of the constants A and B which allows setting of characteristics following the same formula as the IEC curves mentioned here.
Delay characteristics IEEE	LTI LTVI LTEI MI VI EI STI STEI Param	-	LTI	Setting is active and visible when Delay Type is selected to IDMT. IEEE standard delay characteristics. Long Time Inverse, Long Time Very Inverse, Long Time Extremely Inverse, Moderately Inverse, Very Inverse, Extremely Inverse, Short Time Inverse, Short Time Extremely Inverse characteristics. Param selection allows the tuning of the constants A, B and C which allows setting of characteristics following the same formula as the IEEE curves mentioned here.
Non standard delay char.	RI-type RD-type Curve2	-	RI-type	Non-standard RI-type, RD-type and Curve2
Time dial setting k	0.01...25.00s	0.01s	0.05s	Setting is active and visible when Delay Type is selected to IDMT. Time dial / multiplier setting for IDMT characteristics.
A	0.0000...250.0000	0.0001	0.0860	Setting is active and visible when Delay Type is selected to IDMT. Constant A for IEC/IEEE characteristics.
B	0.0000...5.0000	0.0001	0.1850	Setting is active and visible when Delay Type is selected to IDMT. Constant B for IEC/IEEE characteristics.
C	0.0000...250.0000	0.0001	0.0200	Setting is active and visible when Delay Type is selected to IDMT. Constant C for IEEE characteristics.
K	0.0000...250.0000	0.0001	0.0200	Setting is active and visible when selected delay curve is Curve1. Constant K for Curve1 characteristics.

Table 3.33 Reset time characteristics setting parameters.

Name	Range	Step	Default	Description
Release Time delay	0.000... 150.000s	0.005s	0.06s	Resetting time. Time allowed in between of pick-ups if the pick-up has not lead into trip operation. During this time the start signal is held on for the timers if delayed pick-up release is active.
Delayed Pick-up release	No Yes	-	Yes	Resetting characteristics selection either time delayed or instant after pick-up element is released. If activated the start signal is reset after set release time delay.

Name	Range	Step	Default	Description
Time calc reset after release time	No Yes	-	Yes	Operating timer resetting characteristics selection. When active the operating time counter is reset after set release time if pick-up element is not activated during this time. When disabled the operating time counter is reset directly after the pick-up element reset.
Continue time calculation during release time	No Yes	-	No	Time calculation characteristics selection. If activated the operating time counter is continuing until set release time even the pick-up element is reset.

Resetting characteristics can be set according to the application. Default setting is delayed with 60 ms and the time calculation is held during the release time.

When using the release delay option where the operating time counter is calculating the operating time during the release time, function will not trip if the input signal is not activated again during the release time counting.

Events and registers

The CUB function generates events and registers from the status changes of start, trip and blocked. To main event buffer it is possible to select status “On” or “Off” messages. The CUB function offers four independent instances which events are segregated for each instance operation. Function includes 12 last registers where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values.

Table 3.34 Event codes of the CUB-function instances.

Event Number	Event channel	Event block name	Event Code	Description
2048	32	CUB1	0	Start ON
2049	32	CUB1	1	Start OFF
2050	32	CUB1	2	Trip ON
2051	32	CUB1	3	Trip OFF
2052	32	CUB1	4	Block ON
2053	32	CUB1	5	Block OFF
2112	33	CUB2	0	Start ON
2113	33	CUB2	1	Start OFF
2114	33	CUB2	2	Trip ON
2115	33	CUB2	3	Trip OFF
2116	33	CUB2	4	Block ON
2117	33	CUB2	5	Block OFF
2176	34	CUB3	0	Start ON
2177	34	CUB3	1	Start OFF
2178	34	CUB3	2	Trip ON
2179	34	CUB3	3	Trip OFF
2180	34	CUB3	4	Block ON
2181	34	CUB3	5	Block OFF
2240	35	CUB4	0	Start ON
2241	35	CUB4	1	Start OFF
2242	35	CUB4	2	Trip ON
2243	35	CUB4	3	Trip OFF

Event Number	Event channel	Event block name	Event Code	Description
2244	35	CUB4	4	Block ON
2245	35	CUB4	5	Block OFF

In the register of the CUB function recorded events are start, trip or blocked “On” event process data. Table below presents the structure of CUB function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 3.35 Register content

Date & Time	Event code	Fault type	Trigger current	Fault current	Prefault current	Fault currents	Trip time remaining	Used SG
dd.mm.yyyy hh:mm:ss.mss	2048-2245 Descr.	Unbalance	Start average current	Trip -20ms averages	Start -200ms averages	I1,I2,IZ mag. and ang.	0ms -1800s	1 – 8

3.2.6 Circuit breaker failure protection CBFP (50BF)

Circuit breaker failure protection (CBFP) function is used for monitoring the circuit breaker operation after it has been tripped. CBFP function can be used for Retrip to the failing breaker and if the Retrip fails the upstream breaker can be tripped by using CBFP output. Retrip functionality can be disabled if the breaker does not have two open coils.

CBFP function can be triggered from overcurrent (phases and residual), digital output monitor, digital signal or combination of these mentioned triggers.

In current dependent mode CBFP function constantly measures phase current magnitudes and selected residual current. In signal dependent mode any of the IED binary signal can be used for triggering the CBFP. In binary output dependent mode CBFP monitors selected output relay control signal status. Blocking signal and setting group selection controls the operating characteristics of the function during normal operation.

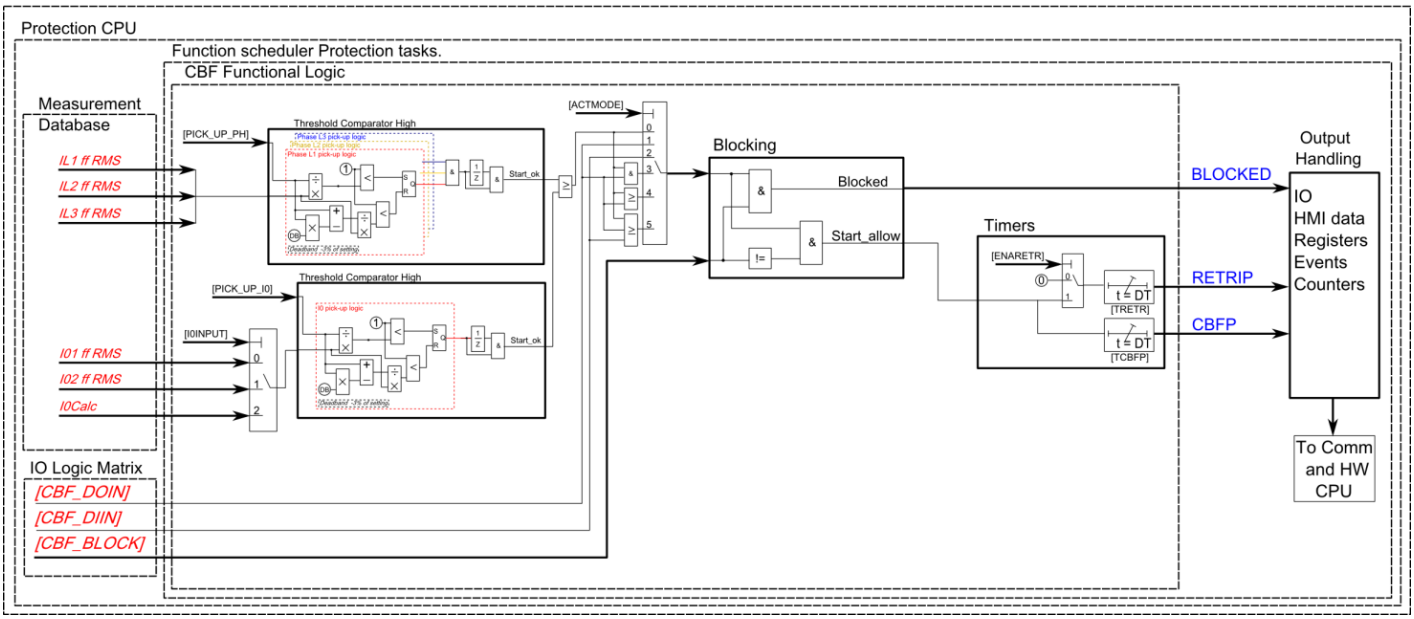
Outputs of the function are CBFP START, RETRIP, CBFP ACT and BLOCKED signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. CBFP function utilizes total of eight separate setting groups which can be selected from one common source. Also the operating mode of the CBFP can be changed by setting group selection.

The operational logic consists of input magnitude processing, threshold comparator, block signal check, time delay characteristics and output processing.

Inputs for the function are setting parameters and measured and pre-processed current magnitudes and binary input and output signals. Function output signals can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the two output signal. Time stamp resolution is 1ms. Function provides also cumulative counters for RETRIP, CBFP, CBFP START and BLOCKED events.

In the following figure is presented the simplified function block diagram of the CBFP function.

Figure 3.26 Simplified function block diagram of the CBFP function



Measured input values

Function block uses analog current measurement values. Function uses always the fundamental frequency magnitude of the current measurement input. For residual current measurement I01, I02 or calculated I0 can be selected. -20ms averaged value of the selected magnitude is used for pre-fault data registering.

Table 3.36 Analogic magnitudes used by the CBFP function.

Signal	Description	Time base
IL1RMS	Fundamental RMS measurement of phase L1/A current	5 ms
IL2RMS	Fundamental RMS measurement of phase L2/B current	5 ms
IL3RMS	Fundamental RMS measurement of phase L3/C current	5 ms
I01RMS	Fundamental RMS measurement of residual input I01	5 ms
I02RMS	Fundamental RMS measurement of residual input I02	5 ms
I0Calc	Calculated residual current from the phase current inputs	5 ms
DOIN	Monitoring of the digital output relay status	5 ms
DIIN	Monitoring of digital input status	5 ms

Selection of the used AI channel is made with a setting parameter. In all possible input channel variations pre-fault condition is presented with 20 ms averaged history value from -20 ms of Start or Trip event.

General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible change them with setting group switching.

Table 3.37 General settings of the function

Name	Description	Range	Step	Default
Meas side	Defines which current measurement module is used by the function.	1:Side1 2:Side2 3:Side3	-	1:Side1

Pick-up characteristics

Current dependent pick-up and activation of the CBFP function is controlled by *ISet* and *I0set* setting parameters, which defines the minimum allowed measured current before action from the function. The function constantly calculates the ratio in between of the setting values and measured magnitude (Im) per all three phases and selected residual current input. Reset ratio of 97 % is inbuilt in the function and is always related to the settingvalue. The setting value is common for all measured phases and single-, dual- or all phases Im exceed of the Iset value will cause pick-up operation of the function.

Table 3.38 Operating mode and input signals selection

Name	Range	Step	Default	Description
I0Input	Not in use I01 I02 I0Calc	-	Not in use	Selection of the residual current monitoring from the two separate residual measurements I01 and I02 or from phase currents calculated residual current.
Actmode	0:Current only 1:DO only 2:Signals only 3:Current and DO 4:Current or DO 5:Current and signals 6:Current or signals 7:Signals and DO 8:Signals or DO 9:Current or DO or signals 10:Current and DO and Signals	-	0:Current only	Operating mode selection. Mode can be dependent of current measurement, digital channel status or combination of these.

Figure 3.27 Pick-up characteristics setting

Name	Range	Step	Default	Description
Iset	0.01 ... 40.00xIn	0.01xIn	0.20 x In	Pick-up threshold for phase current measurement. This setting limit defines the upper limit for the phase current pick-up element.
I0set	0.005 ... 40.000xIn	0.001xIn	1.200xIn	Pick-up threshold for residual current measurement. This setting limit defines the upper limit for the phase current pick-up element.

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active. From binary signals the activation of the pick-up is immediate when the monitored signal is activated.

Function blocking

In the blocking element the block signal is checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup current values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Operating time characteristics

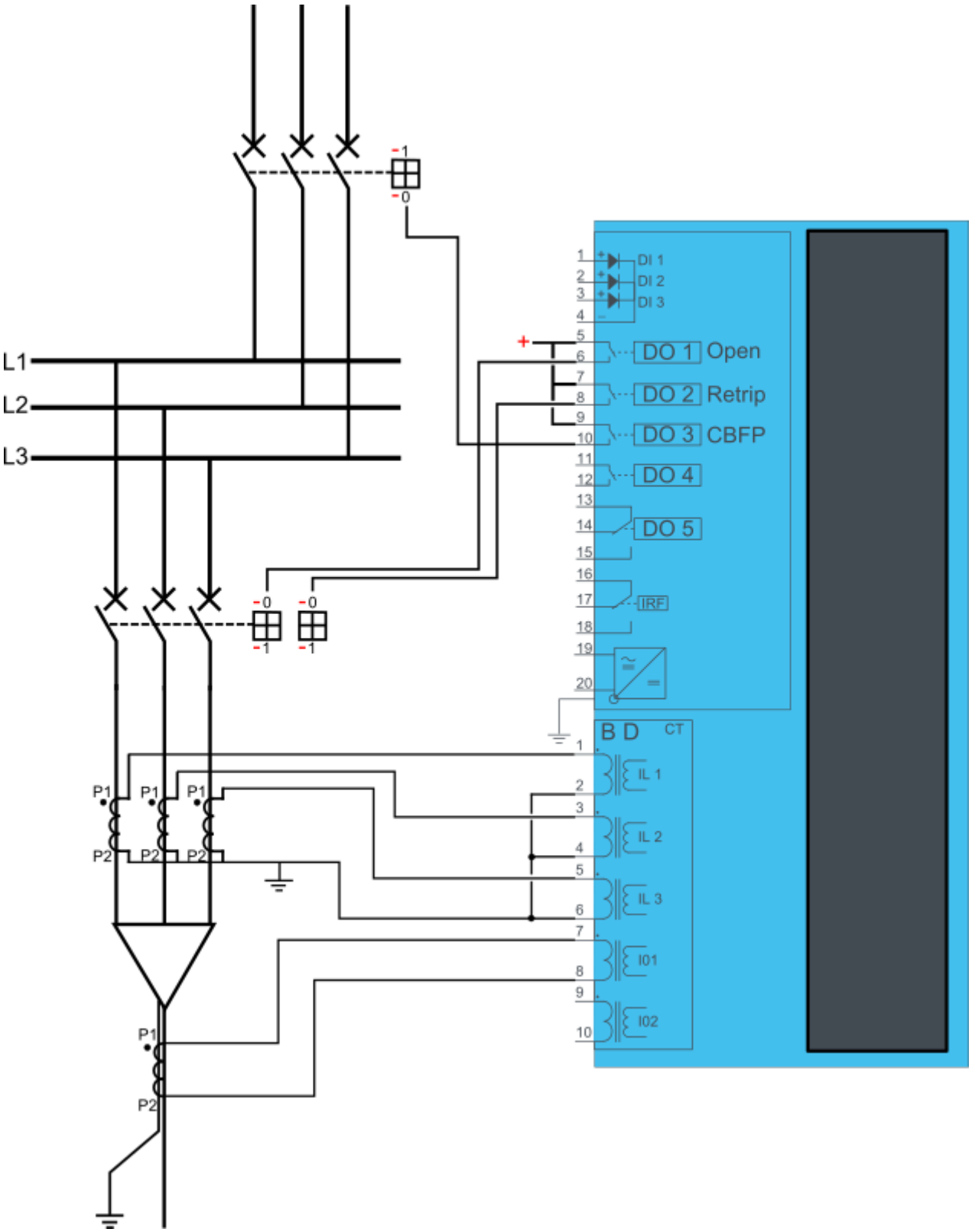
The operating timers' behavior of the function is set depending of the application. Both timers are started from the same pick-up signal, which means that in case Retrip is used the time grading should be set so that the Retrip time added with expected operating time and releasing time of the CBFP pick up conditions is shorter than the set CBFP time in order to avoid unnecessary CBFP in cases when re tripping to another breaker coil clears the fault. In the following table are presented the setting parameters for the function time characteristics.

Table 3.39 Operating time characteristics setting parameters.

Name	Range	Step	Default	Description
Retrip	0:No 1:Yes	-	Yes	Retrip enabled or disabled. If Retrip is disabled the output will not be visible and also the TRetr setting parameter will not be available.
Retrip time delay	0.000...1800.000s	0.005s	0.100s	Retrip start timer, this setting defines how long the starting condition has to last before RETRIP signal is activated.
CBFP	0.000...1800.000s	0.005s	0.200s	CBFP start timer, this setting defines how long the starting condition has to last before CBFP signal is activated.

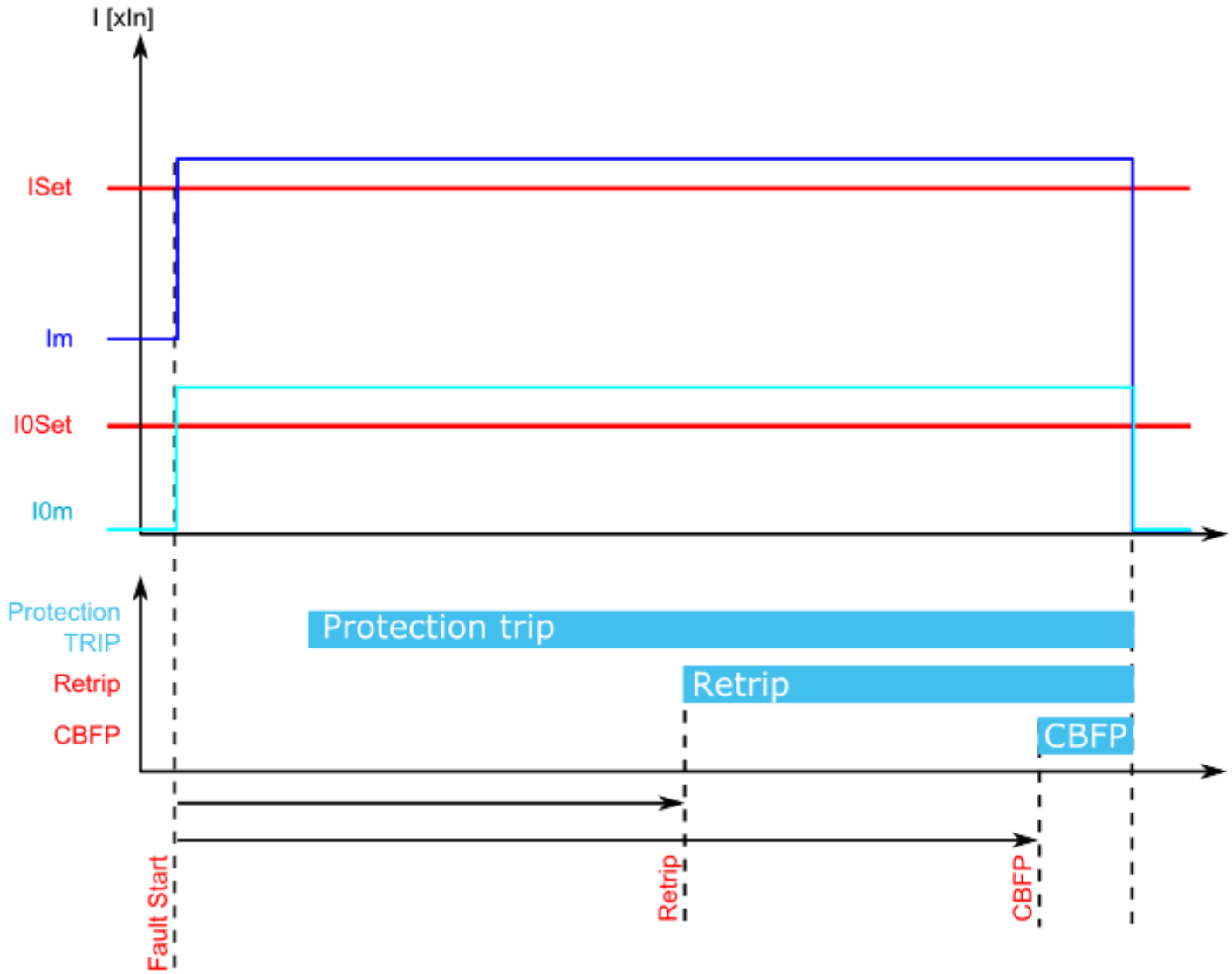
A few typical cased of CBFP are presented in the following figures.

Figure 3.28 Trip, Retrip and CBFP are configured to the IED.



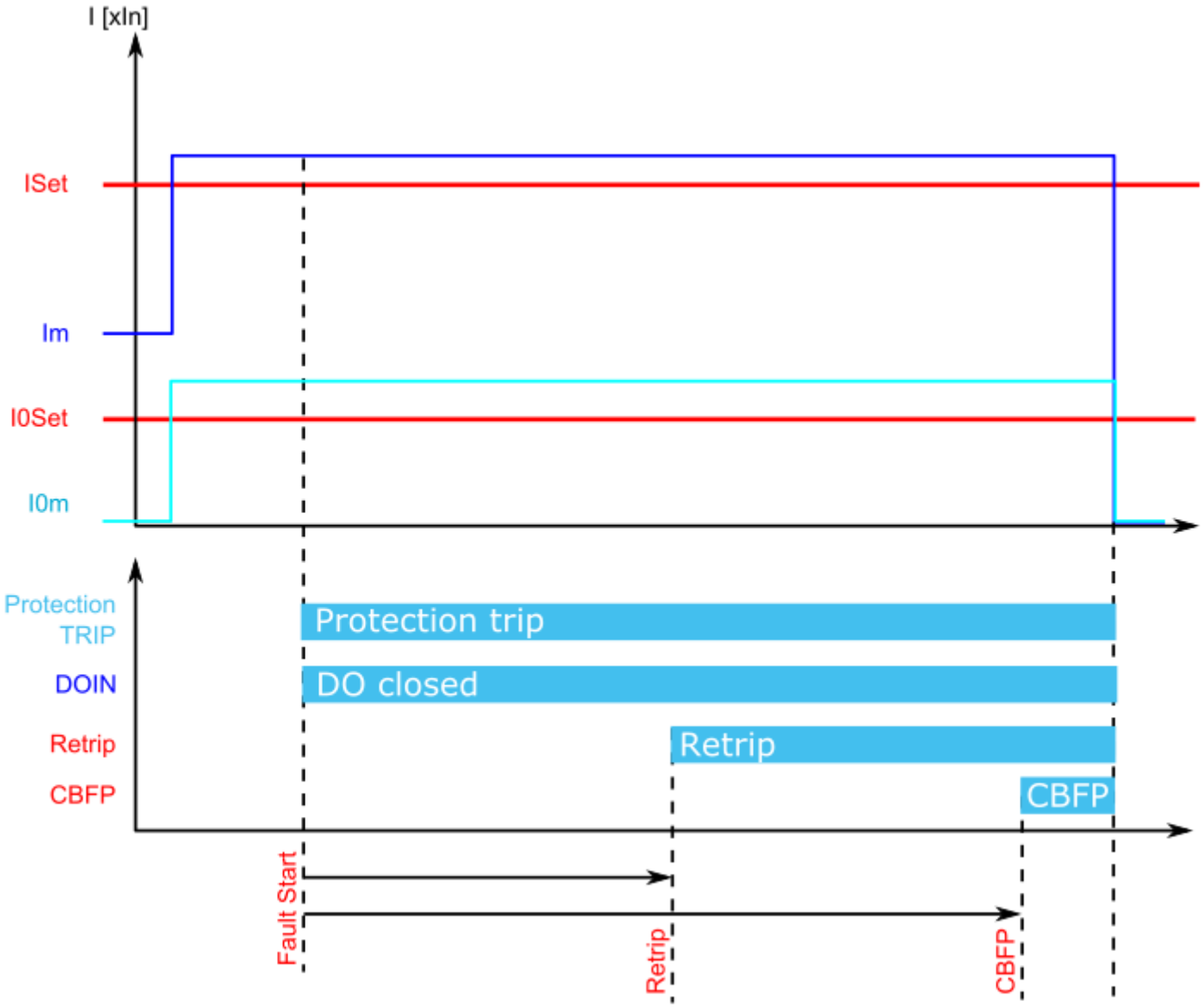
In application where the circuit breaker has retrip / redundant trip coil available, retrip functionality can be used. The trip signal is wired normally to the trip coil of the breaker from the trip output of the IED. Retrip is wired in parallel from its own output contact in the IED to the second tripping coil of the circuit breaker. CBFP signal to upstream is wired normally from its output contact in the IED to the upstream / incomer breaker. In following are few operational cases presented regarding to the different applications.

Figure 3.29 Retrip and CBFP when selected criteria is current only.



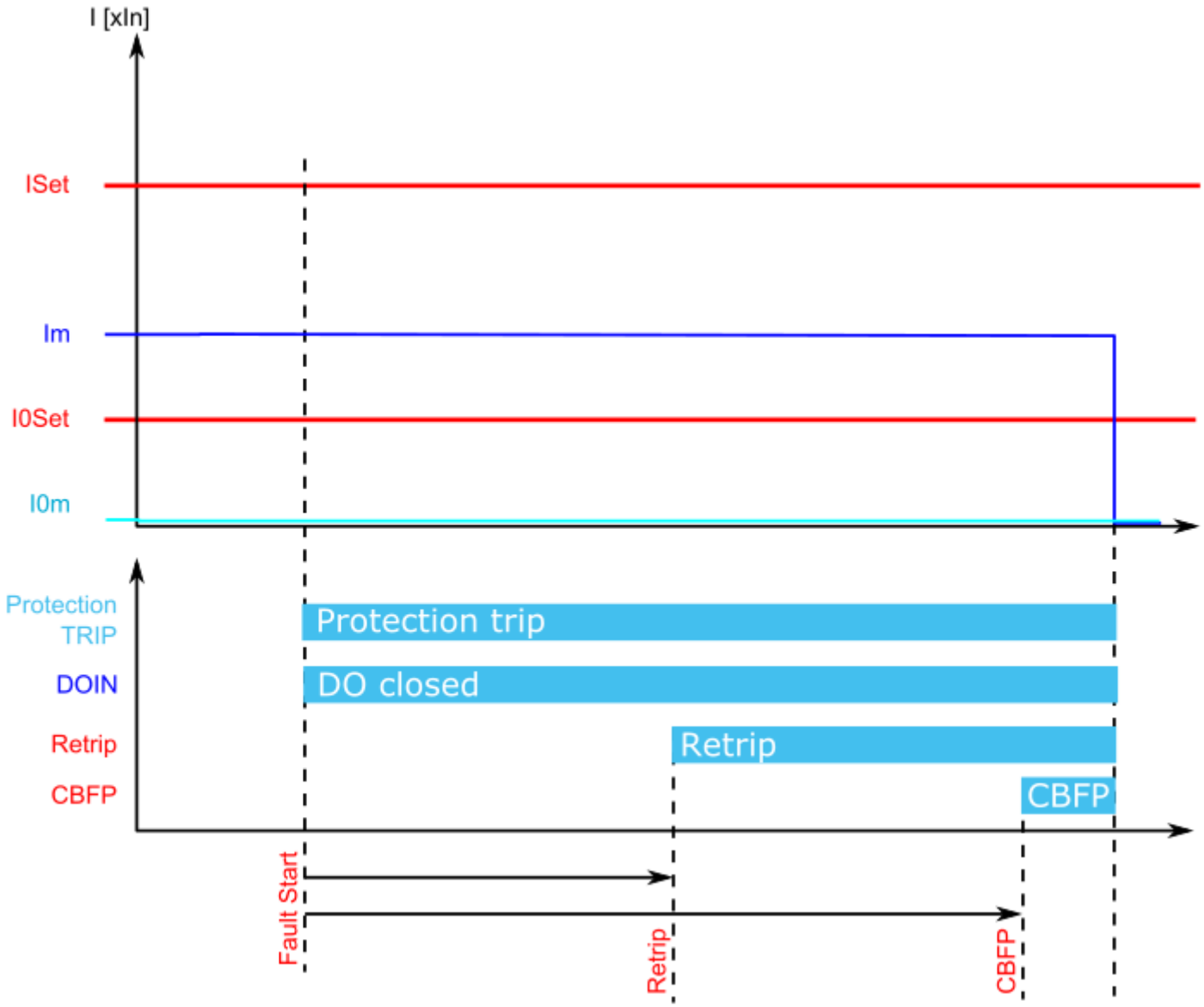
In case when the current based protection activates so that either Iset and/or I0Sset current threshold setting is exceeded the counters for retrip and CBFP start to calculate the set operating time. The tripping of the primary protection stage is not monitored in this configuration and if the current is not decreased under the setting limit first is issued retrip and if the current is not decreased in time also CBFP will be issued to upstream breaker. If the primary protection function clears the fault e.g. the circuit breaker operates normally the counters for retrip and CBFP are reset immediately the current is measured below the threshold settings.

Figure 3.30 Retrip and CBFP when selected criteria is current and DO.



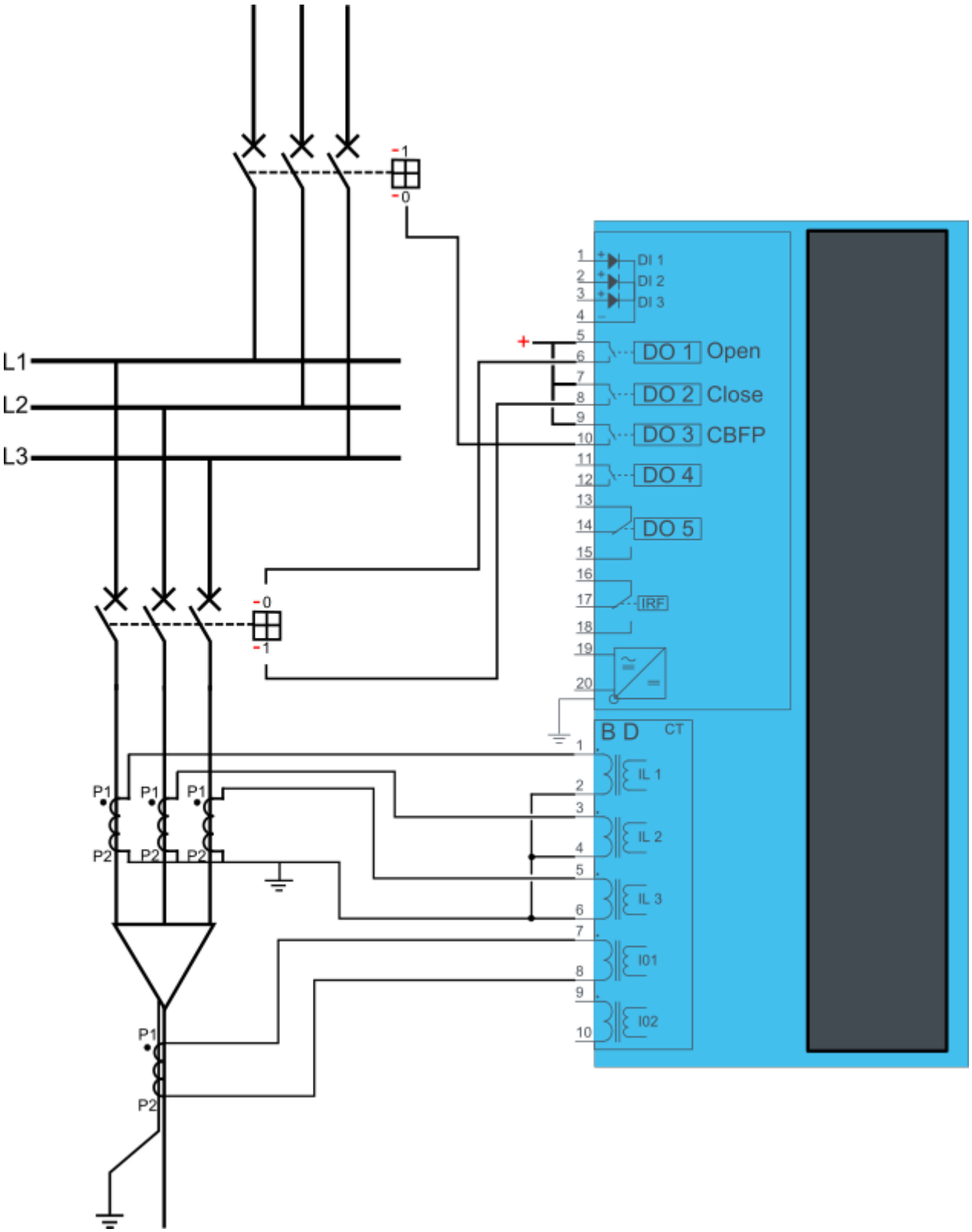
In case when the current based protection activates so that either Iset and/or I0Sset current threshold setting are exceeded the counters for retrip and CBFP are halted until the monitored output contact is controlled (primary protection operates). From the tripping signal of the primary protection stage the counters for retrip and CBFP start to calculate the set operating time. The tripping of the primary protection stage is constantly monitored in this configuration and if the current is not decreased under the setting limit and the trip signal from primary stage is not reset first is issued retrip and if the current is not decreased in time also CBFP will be issued to upstream breaker. If the primary protection function clears the fault e.g. the circuit breaker operates normally the counters for retrip and CBFP are reset immediately the current is measured below the threshold settings or the trip signal is reset. This configuration allows the CBFP to be controlled on current based functions only and other function trips can be excluded from the CBFP functionality.

Figure 3.31 Retrip and CBFP when selected criteria is current or DO.



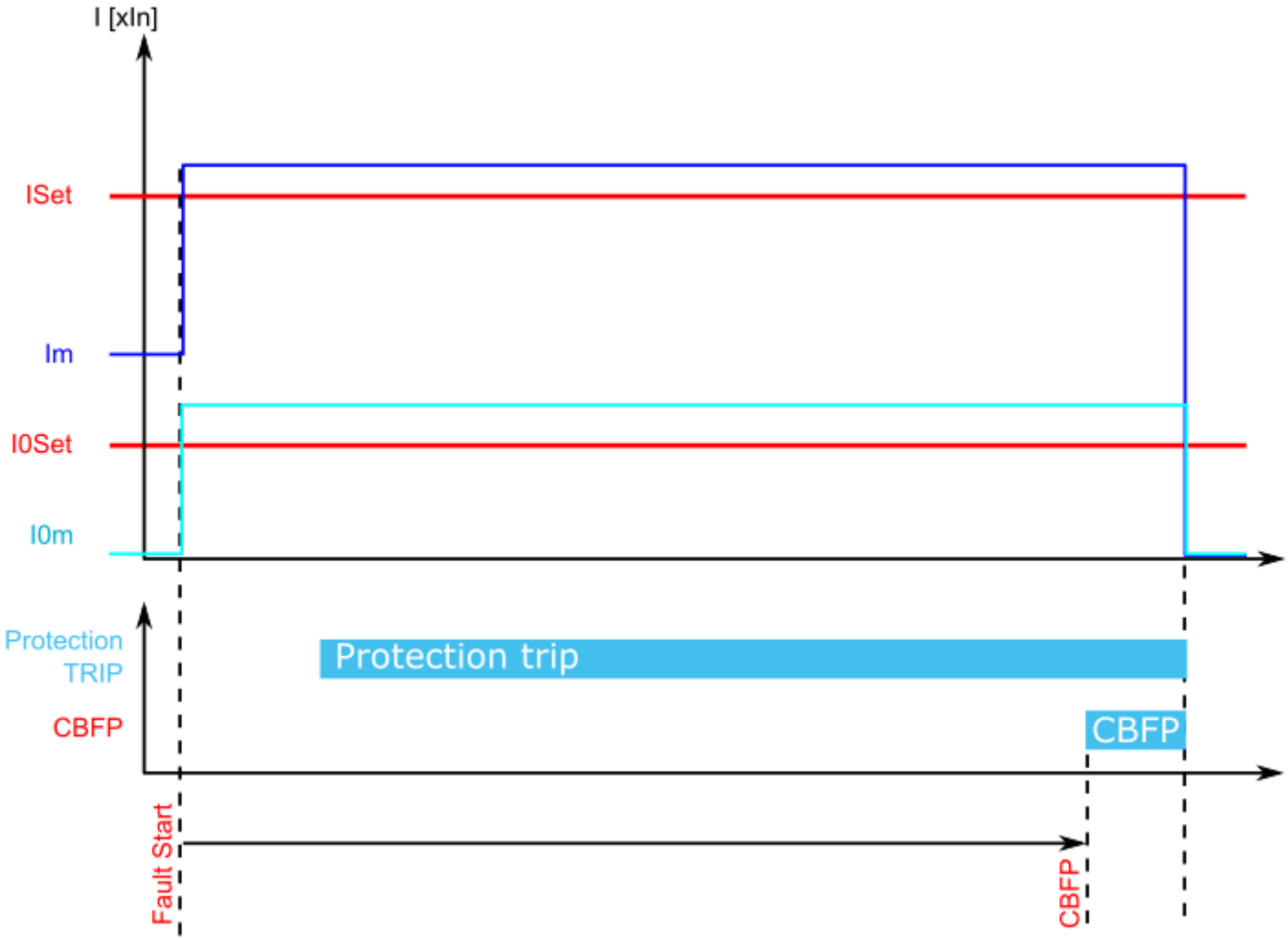
In case when the current based protection activates so that either Iset and/or I0Sset current threshold setting is exceeding the counters for retrip and CBFP start to calculate the set operating time. From the tripping signal of the primary protection stage the counters for retrip and CBFP start to calculate the set operating time. The tripping of the primary protection stage is constantly monitored in this configuration regardless of the current status. The pick-up of CBFP is active until current is not decreased under the setting limit or the trip signal from primary stage is not reset. In case if either of these conditions are met until the timers set time first is issued retrip and if either of the conditions is active also CBFP will be issued to upstream breaker. If the primary protection function clears the fault e.g. the circuit breaker operates normally the counters for retrip and CBFP are reset immediately the current is measured below the threshold settings and the trip signal is reset. This configuration allows the CBFP to be controlled on current based functions with added security from the current monitoring of the CBFP function and other function trips can be also included to the CBFP functionality.

Figure 3.32 Trip and CBFP are configured to the IED.



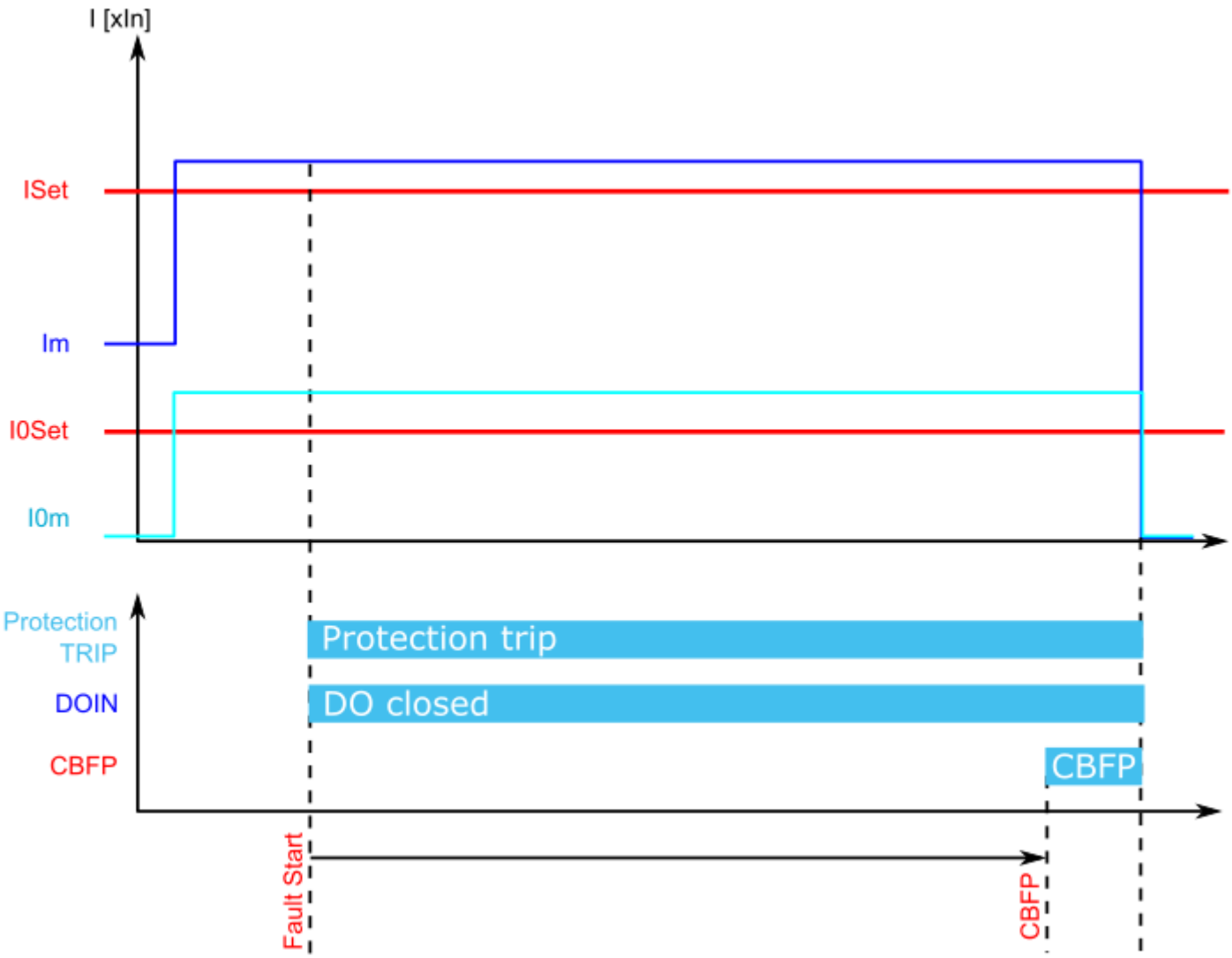
Probably the most common application is the case where the circuit breaker trip coil is controlled with the IED trip output and CBFP is controlled with one dedicated CBFP contact. In following are few operational cases presented regarding to the different applications and settings of the CBFP function.

Figure 3.33 CBFP when selected criteria is current only.



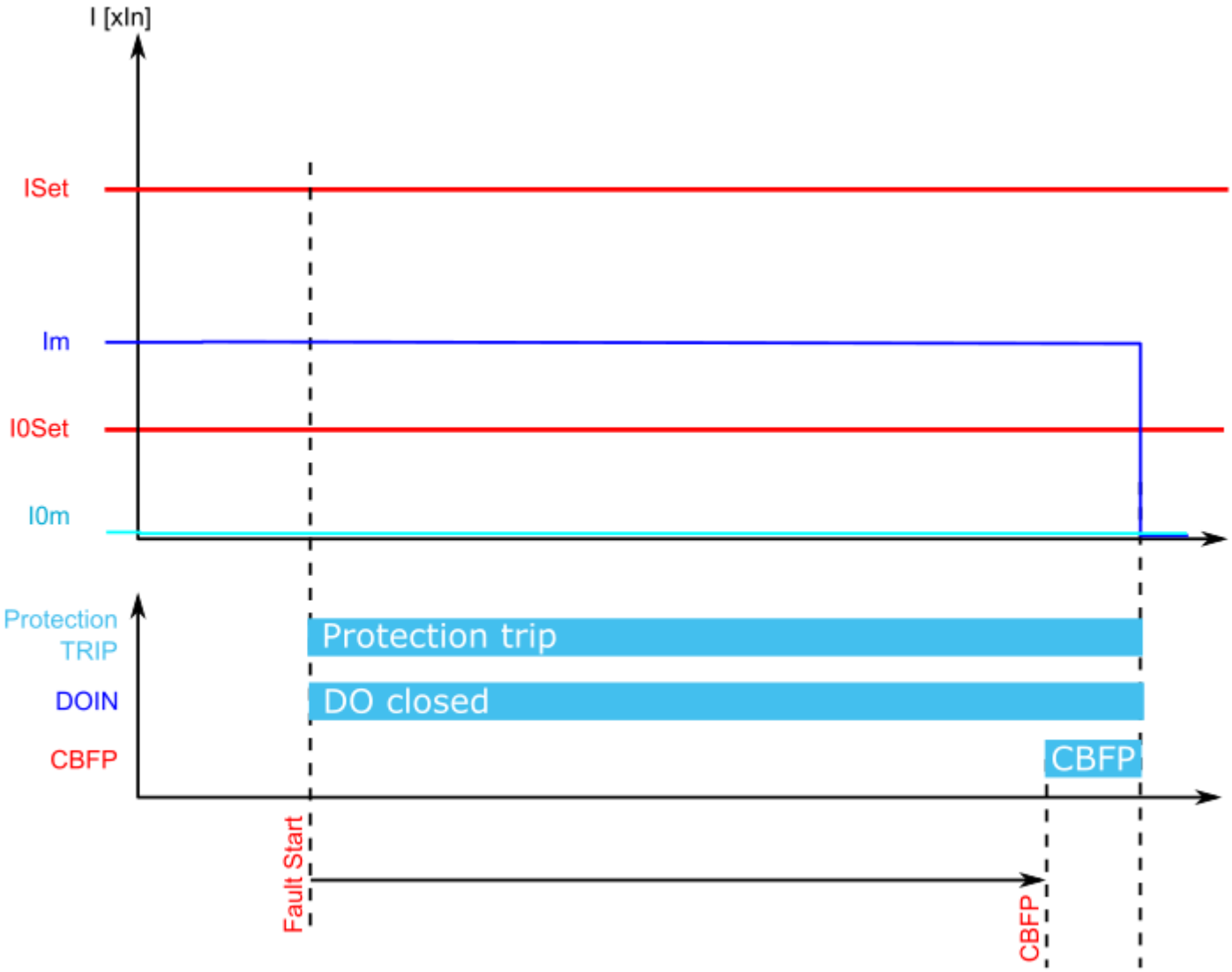
In case when the current based protection activates so that either Iset and/or I0Sset current threshold setting is exceeded, the counter for CBFP start to calculate the set operating time. The tripping of the primary protection stage is not monitored in this configuration and if the current is not decreased under the setting limit CBFP will be issued to upstream breaker. If the primary protection function clears the fault e.g. the circuit breaker operates normally the counter for CBFP are reset immediately the current is measured below the threshold settings.

Figure 3.34 CBFP when selected criteria is current and DO.



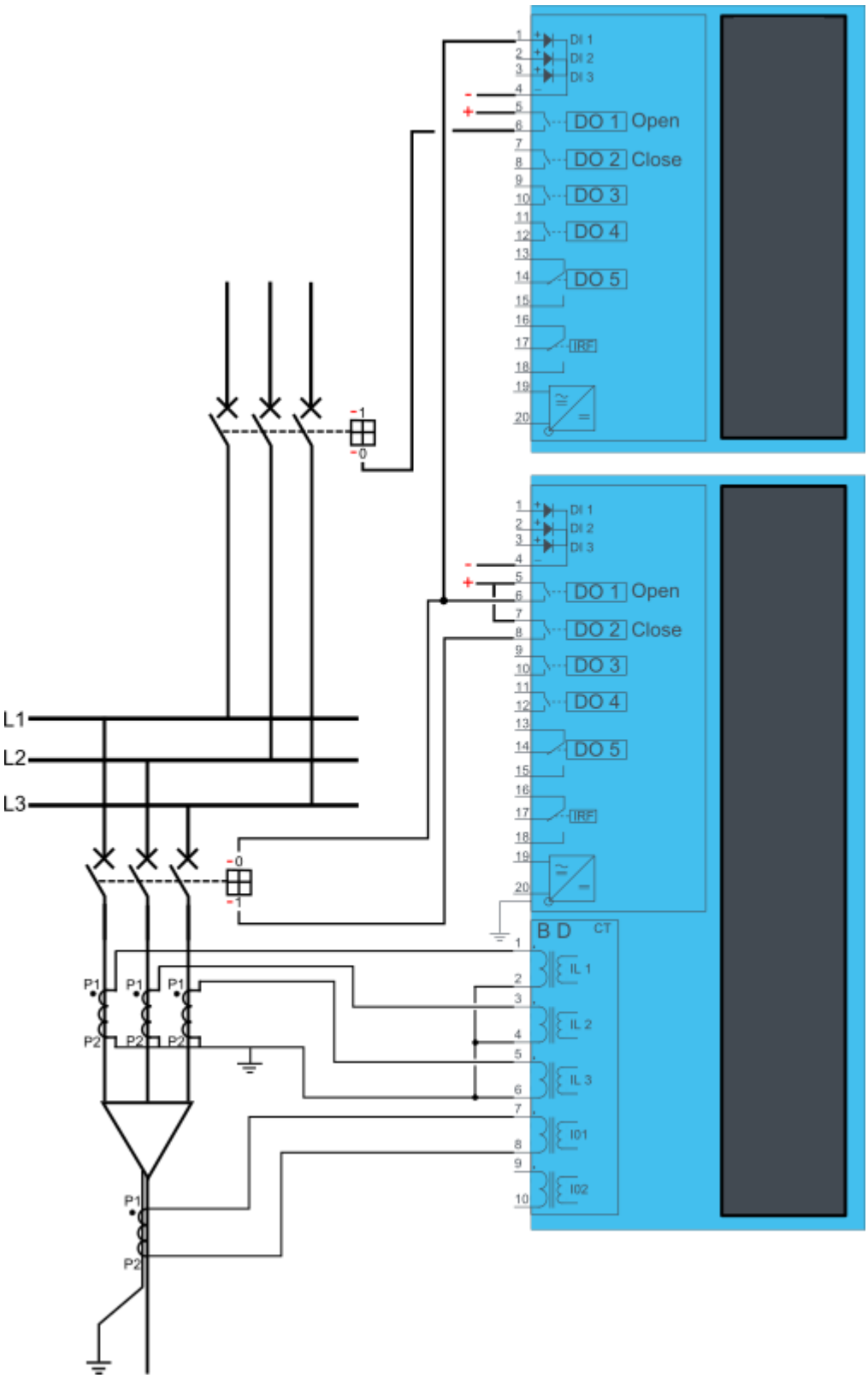
In case when the current based protection activates so that either Iset and/or I0Sset current threshold setting are exceeded the counter for CBFP is halted until the monitored output contact is controlled (primary protection operates). From the tripping signal of the primary protection stage the counter for CBFP start to calculate the set operating time. The tripping of the primary protection stage is constantly monitored in this configuration and if the current is not decreased under the setting limit and the trip signal from primary stage is not reset CBFP will be issued to upstream breaker. If the primary protection function clears the fault e.g. the circuit breaker operates normally the counter for CBFP is reset immediately the current is measured below the threshold settings or the trip signal is reset. This configuration allows the CBFP to be controlled on current based functions only and other function trips can be excluded from the CBFP functionality.

Figure 3.35 CBFP when selected criteria is current or DO.



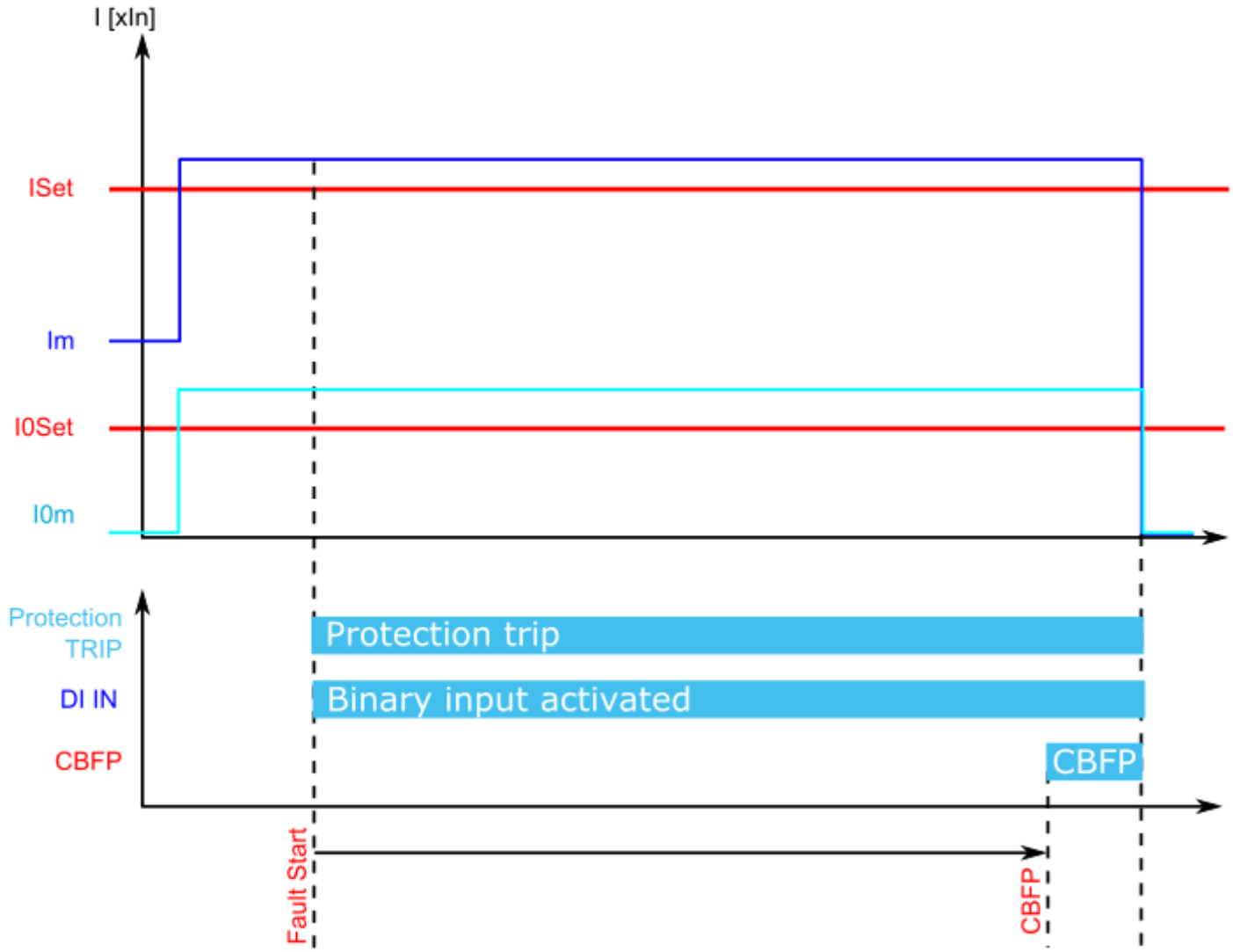
The counter for CBFP starts to calculate the set operating time either from current exceeding the setting limit or from the primary protection stage trip signal. The tripping of the primary protection stage is constantly monitored in this configuration regardless of the current status. The pick-up of CBFP is active until current is not decreased under the setting limit or the trip signal from primary stage is not reset. In case if either of these conditions are met until the timers set time first is issued retrip and if either of the conditions is active also CBFP will be issued to upstream breaker. If the primary protection function clears the fault e.g. the circuit breaker operates normally the counter for CBFP is reset immediately the current is measured below the threshold settings and the trip signal is reset. This configuration allows the CBFP to be controlled on current based functions with added security from the current monitoring of the CBFP function and other function trips can be also included to the CBFP functionality.

Figure 3.36 IED is configured as a dedicated CBFP unit.



In some applications dedicated circuit breaker protection unit is required. When the CBFP function is configured to operate with DI signal it can be used in these applications. When the IED is used for this purpose the tripping signal is wired to the IED digital input and the IED:s own trip signal is used for CBFP purpose only. In this application the retrip and also CBFP to upstream are also available for different types of requirements. Retrip signal can be used for the section incomer breaker tripping and CBFP for the upstream breaker tripping. In this example no retripping is utilized and CBFP signal is used for the incomer trip from the outgoing breaker trip signal. The trip signal can be transported in between of the IED:s also by using GOOSE messages if so wanted.

Figure 3.37 Dedicated CBFP operation from binary input signal.



In this mode the CBFP operates from binary input signal only. Additionally also current and output relay monitoring can be used. The counter for the CBFP is started when the digital input is activated. If the counter is active until the time in the CBFP counter is used the IED will issue CBFP command to the incomer breaker. In this application all of the outgoing feeders IED:s tripping signals can be connected to one dedicated CBFP IED which operates either on current based or all possible faults CBFP protection.

Events and registers

The CBFP function generates events and registers from the status changes of Retrip, CBFP activated and blocked signals as well as from the internal pick-up comparators. To main event buffer is possible to select status “On” or “Off” messages.

Function includes 12 last registers where the triggering event of the function (Retrip, CBFP activated or blocked) is recorded with time stamp and process data values.

Table 3.40 Event codes of the CBFP function instance

Event Number	Event channel	Event block name	Event Code	Description
2816	44	CBF1	0	Start ON
2817	44	CBF1	1	Start OFF
2818	44	CBF1	2	Retrip ON

Event Number	Event channel	Event block name	Event Code	Description
2819	44	CBF1	3	Retrip OFF
2820	44	CBF1	4	CBFP ON
2821	44	CBF1	5	CBFP OFF
2822	44	CBF1	6	Block ON
2823	44	CBF1	7	Block OFF
2824	44	CBF1	8	DO monitor On
2825	44	CBF1	9	DO monitor Off
2826	44	CBF1	10	Signal On
2827	44	CBF1	11	Signal Off
2828	44	CBF1	12	Phase current On
2829	44	CBF1	13	Phase current Off
2830	44	CBF1	14	Res current On
2831	44	CBF1	15	Res current Off

In the register of the CBFP function recorded events are activated, blocked etc. “On” event process data. Table below presents the structure of CBFP function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 3.41 Register content

Date & Time	Event code	Trigger current	Time to RETRact	Time to CBFPact	Ftype	Stype	Used SG
dd.mm.yyyy hh:mm:ss.mss	2816-2831 Descr.	Phase and residual currents on trigger time	Time remaining before RETR is active	Time remaining before CBFP is active	Monitored current status code	Activate start triggers	1 - 8

3.2.7 Restricted earth fault / cable end differential (REF) I0D> (87N)

Restricted Earth Fault function (REF) is used for residual differential current measurement for transformers. This function can also be used for Cable End Differential (CED) functionality. Operating principle is low impedance differential protection with settable bias characteristics where differential current is calculated in between of summed phase currents and selected residual current input. In CED mode the function provides natural measurement unbalance compensation to have higher operating sensitivity for monitoring cable end faults.

REF function constantly monitors phase currents and selected residual current instant values as well as calculated bias current and differential current magnitudes.

Blocking signal and setting group selection controls the operating characteristics of the function during normal operation.

Outputs of the function are REF Trip and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. REF function utilizes total of eight separate setting groups which can be selected from one common source. Also, the operating mode of the REF can be changed by setting group selection.

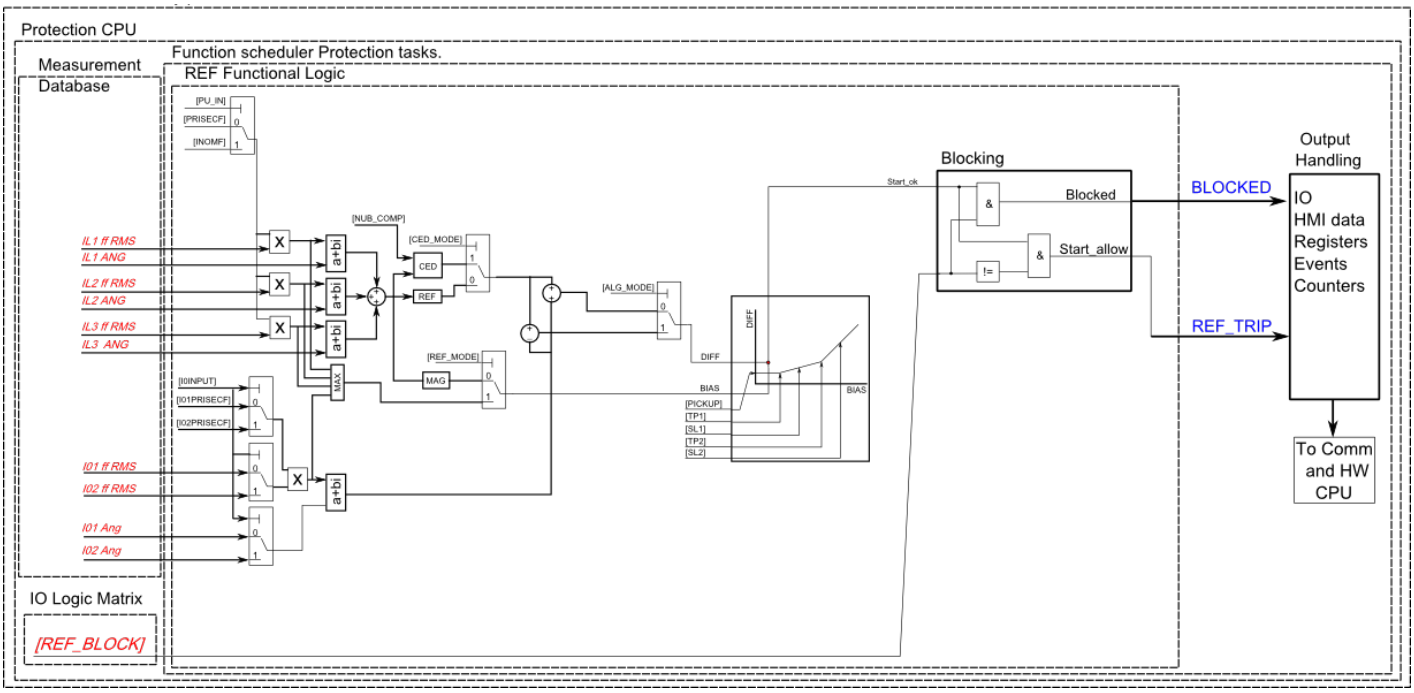
The operational logic consists of input magnitude processing, differential characteristic comparator, block signal check and output processing.

Inputs for the function are setting parameters and measured and pre-processed current magnitudes. Function output signals can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12

last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the two output signals. Time stamp resolution is 1ms. Function provides cumulative counters for REF Trip and BLOCKED events.

In the following figure is presented the simplified function block diagram of the REF function.

Figure 3.38 Simplified function block diagram of the REF function.



Measured input values

Function block uses analog current measurement values. Function uses the fundamental frequency magnitude of the current measurement inputs and calculated residual current with residual current measurement. For residual current measurement I01 or I02 can be selected.

Please note that in cable end differential mode the difference is calculated only when measured I0 current is available.

Table 3.42 Analogic magnitudes used by the REF function.

Signal	Description	Time base
IL1RMS	Fundamental RMS measurement of phase L1/A current	5 ms
IL2RMS	Fundamental RMS measurement of phase L2/B current	5 ms
IL3RMS	Fundamental RMS measurement of phase L3/C current	5 ms
I01RMS	Fundamental RMS measurement of residual input I01	5 ms
I02RMS	Fundamental RMS measurement of residual input I02	5 ms
IL1Ang	Fundamental angle of phase L1/A current	5 ms
IL2 Ang	Fundamental angle of phase L2/B current	5 ms
IL3 Ang	Fundamental angle of phase L3/C current	5 ms
I01 Ang	Fundamental angle of residual input I01	5 ms
I02 Ang	Fundamental angle of residual input I02	5 ms

Selection of the used residual current input AI channel is made with a setting parameter.

General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible change them with setting group switching.

Table 3.43 General settings of the REF stage (not SG selectable)

Name	Range	Step	Default	Description
I0d> in side	1: Side1 2: Side2 3: Side3	-	1: Side1	Defines which current measurement module is used by the function.
REF or Cable end Diff	0:REF 1:CED	-	REF	Selection of the operating characteristics. If selected REF the function operates with normal accuracies and if CED is selected the natural unbalance created by the phase current CT:s can be compensated for more sensitive operation. Default setting is REF.
Comp. natural unbal.	0:- 1:Comp	-	-	When activated in on line the currently present calculated residual current will be compensated to 0. This compensation does not have effect otherwise than in CED mode.

Operating characteristics

Current dependent pick-up and activation of the REF function is controlled bysetting parameters, which defines the used current calculating method and operating characteristics.

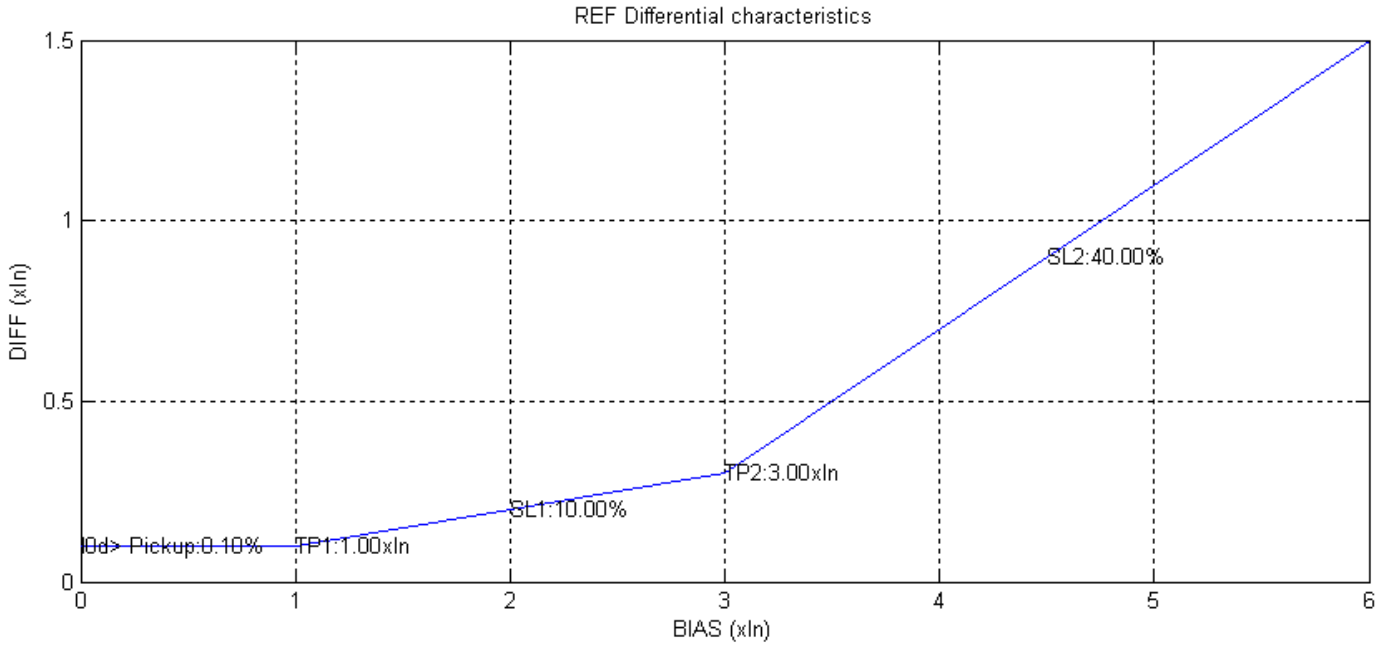
Table 3.44 Pick-up characteristics setting (SG selectable)

Name	Range	Step	Default	Description
I0 Input	0:I01 1:I02	-	I01	Selection of the used residual current measurement input. Default setting is 0: I01
I0 Direction	0:Add 1:Subtract	-	Add	Differential current calculation mode. With this selection the directions of the calculated and measured residual currents can be set to match the application. Default setting is Add which means that I0calc + I01 or I02 in through fault yields 0 of differential current.
Bias current calc	0:(3Io+IoCalc)/2 1:max(3Io.I0calc)	-	Residual current	Selection of bias current calculation. Either maximum of all measured currents or calculated residual current can be used for the differential characteristics biasing. Residual current mode is more sensitive while max current coarser. Default setting is Residual current.
I0d> pick up	0.01...50.00% (of In)	0.01%	10%	Setting for basic sensitivity of the differential characteristics.
Turnpoint 1	0.01...50.00xIn	0.01xIn	1.00xIn	Setting for first turn point in the bias axe of the differential characteristics.
Slope 1	0.01...150.00%	0.01%	10.00%	Setting for the first slope of the differential characteristics.
Turnpoint 1	0.01...50.00xIn	0.01xIn	3.00xIn	Setting for second turn point in the bias axe of the differential characteristics.
Slope 2	0.01...250.00%	0.01%	40.00%	Setting for the second slope of the differential characteristics.

The pick-up activation of the function is not directly equal to trip-signal generation of the function. Trip signal is allowed if blocking condition is not active.

In the following figure is presented the differential characteristics with default settings.

Figure 3.39 Differential characteristics for REF function with default settings.



Equations for the differential characteristics are as below:

Differential current (calculation is based on user selected inputs and direction):

$$I_{Diff+I01} = \left(\overline{IL1} + \overline{IL2} + \overline{IL3}\right) + \overline{I01}$$

$$I_{Diff-I01} = \left(\overline{IL1} + \overline{IL2} + \overline{IL3}\right) - \overline{I01}$$

$$I_{Diff+I02} = \left(\overline{IL1} + \overline{IL2} + \overline{IL3}\right) + \overline{I02}$$

$$I_{Diff-I02} = \left(\overline{IL1} + \overline{IL2} + \overline{IL3}\right) - \overline{I02}$$

Bias current (calculation is based on user selected mode):

$$I_{Bias1} = \left(\overline{IL1} + \overline{IL2} + \overline{IL3}\right)$$

$$I_{Bias2I01} = MAX(|IL1|, |IL2|, |IL3|, |I01|)$$

$$I_{Bias2I02} = MAX(|IL1|, |IL2|, |IL3|, |I02|)$$

Characteristics settings are calculated as follows:

$$Diff_{Bias<TP1} = I_{0d>Pick-up}$$

$$Diff_{Bias\,TP1\ldots TP2} = SL1 \times (Ix - TP1) + I_{0d>Pick-up}$$

$$Diff_{Bias>TP2} = SL2 \times (Ix - TP2) + SL1 \times (TP2 - TP1) + I_{0d>Pick-up}$$

Function blocking

In the blocking element the blocking signal is checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a Trip signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If Trip function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

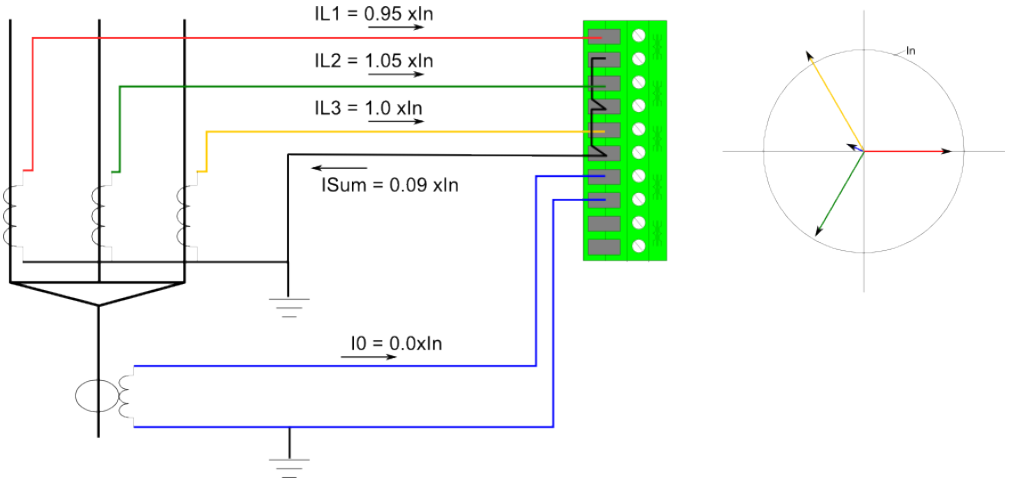
From blocking of the function HMI display event as well as time stamped blocking event with information of the startup current values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

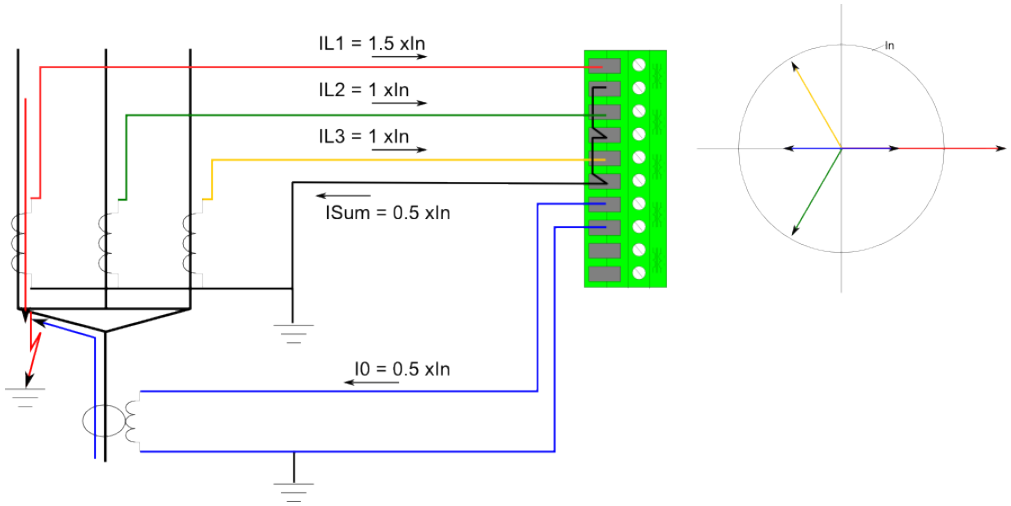
typical applications for this function are presented in the following figures.

Figure 3.40 Cable end differential with natural unbalance in the phase current measurement.



When calculating the residual current from phase currents the natural unbalance may be in total around 10% and still the used CT:s are in the promised 5P class (probably most common CT accuracy class). When the current natural unbalance is compensated in this same situation the differential settings may be set more sensitive and the natural unbalance does not affect into the calculation.

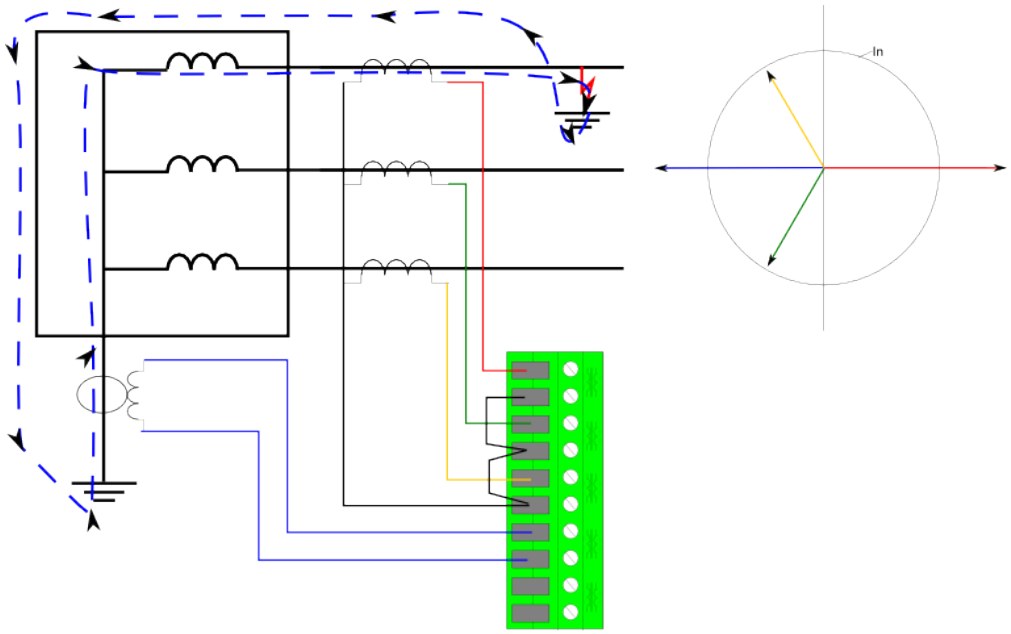
Figure 3.41 Cable end differential when fault happens.



If in the cable end should occur any starting faults the cable end differential catches the difference in between of the ingoing and outgoing residual currents and the resulting signal can be used for alarming or tripping purpose for the feeder with failing cable end. The sensitivity of the algorithm and settings are freely user settable.

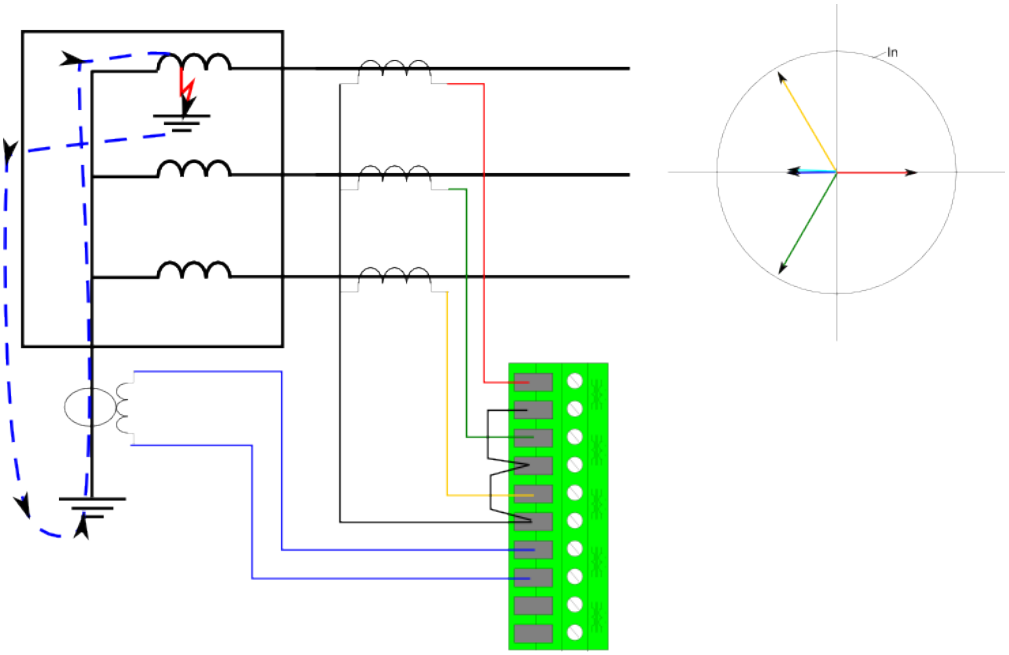
Restricted earth fault protection is normally used in Y winding of a power transformer. This function is needed to prevent the main differential protection from tripping in outside protection area faults in some cases it has disabled or limited sensitivity to catch inside area earth faults. For this purpose, restricted earth fault function is stabile since it monitors only the side it is wired to and compares the calculated and measured residual currents. In case of outside earth fault the circulating residual current in the faulty phase winding is not causing tripping because the comparison of measured starpoint current and calculated residual current differential is close to zero.

Figure 3.42 Restricted earth fault on outside of Y winding transformer.



If the fault is located inside of the transformer and thus inside of the protection area the REF function catches the fault with high sensitivity since the measured residual current directions are now opposite for the outside fault situation the measured differential current is high.

Figure 3.43 Restricted earth fault on inside of Y winding transformer.



Events and registers

The REF function generates events and registers from the status changes of the Trip activated and blocked signals. To main event buffer it is possible to select status “On” or “Off” messages.

12 last registers are available in the function where the triggering event of the function (Trip activated or blocked) is recorded with time stamp and process data values.

Table 3.45 Event codes of the REF function instance

Event Number	Event channel	Event block name	Event Code	Description
4224	66	REF1	0	REF Trip On
4225	66	REF1	1	REF Trip Off
4226	66	REF1	2	REF Block On
4227	66	REF1	3	REF Block Off

In the register of the REF function is recorded activated, blocked etc. “On” event process data. The structure of REF function register content is presented in the table below. This information is available in 12 last recorded events for all provided instances separately.

Table 3.46 Register content

Date & Time	Event code	Trigger currents	Trigger currents	Residual currents	Used SG
dd.mm.yyyy hh:mm:ss.mss	4224-4227 Descr.	Biascurrent trig Diffcurrent trig Characteristics diff trig	Biascurrent max Diffcurrent max Characteristics diff max	I0Calc I0 meas	1 - 8

3.2.8 Harmonic overcurrent Ih> (50H/51H/68H)

Harmonic overcurrent function (HOC) is used for non-directional instant- and time delayed harmonic overcurrent detection and clearing for various applications including feeder, filter and machine applications of utilities and industry. The number of available instances of the function depends of the IED model. Function measures constantly selected measurement

channels selected harmonic component either on absolute value or relative to the fundamental frequency component. Blocking signal and setting group selection controls the operating characteristics of the function during normal operation.

Outputs of the function are Start Trip and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. Non directional overcurrent function utilizes total of eight separate setting groups which can be selected from one common source.

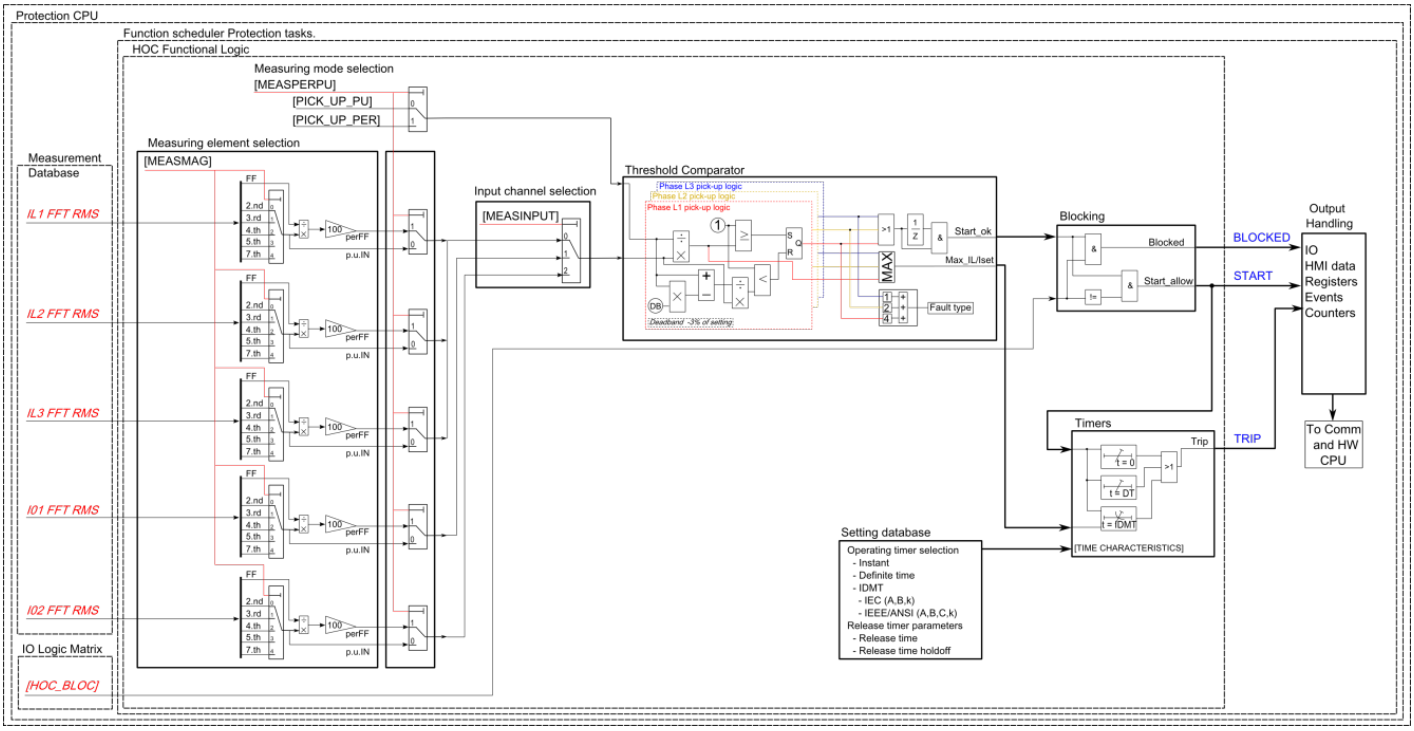
The function can be operating on instant or time delayed mode. If the stage is used in the instant mode (e.g. set operating time delay is 0 s) for blocking purposes of other protection stages either Start or Trip signal can be used. In time delayed mode the operation can be switched to definite time or IDMT mode. Start signal can be used for blocking other stages while in cases when the situation prolongs can Trip signal be used for other actions as time delayed. For IDMT operation IEC and ANSI standard time delays are supported as well as custom parameters.

The operational logic consists of input magnitude processing, input magnitude selection, saturation check, threshold comparator, block signal check, time delay characteristics and output processing. The basic design of the protection function is 3-pole operation.

Inputs for the function are the operating mode selections, setting parameters and measured and pre-processed current magnitudes and binary input signals. Function outputs START, TRIP and BLOCKED signals which can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the three output signal. In instant operating mode the function outputs START and TRIP events simultaneously with equivalent time stamp. Time stamp resolution is 1ms. Function provides also cumulative counters for START, TRIP and BLOCKED events.

In the following figure is presented the simplified function block diagram of the HOC function.

Figure 3.44 Simplified function block diagram of the HOC function.



Measured input values

Function block uses analog current measurement values from the phase currents or residual currents. For each measurement input the HOC function block utilizes the fundamental frequency and harmonic components of the selected current input and by user selection the monitored magnitude can be either per unit RMS values of the harmonic component or harmonic component percentage content compared to fundamental frequency RMS. -20ms averaged value of the selected magnitude is used for pre-fault data registering.

Table 3.47 Analogic magnitudes used by the HOC function.

Signal	Description	Time base
IL1FFT	Magnitudes (rms) of phase L1/A current components: Fundamental, 2nd harmonic, 3rd harmonic, 4th harmonic, 5th harmonic 7th, harmonic 9th, harmonic 11th, harmonic 13th, harmonic 15th, harmonic 17th, harmonic 19th harmonic current.	5 ms
IL2FFT	Magnitudes (rms) of phase L2/B current components: Fundamental, 2nd harmonic, 3rd harmonic, 4th harmonic, 5th harmonic 7th, harmonic 9th, harmonic 11th, harmonic 13th, harmonic 15th, harmonic 17th, harmonic 19th harmonic current.	5 ms
IL3FFT	Magnitudes (rms) of phase L3/C current components: Fundamental, 2nd harmonic, 3rd harmonic, 4th harmonic, 5th harmonic 7th, harmonic 9th, harmonic 11th, harmonic 13th, harmonic 15th, harmonic 17th, harmonic 19th harmonic current.	5 ms
I01FFT	Magnitudes (rms) of residual I01 current components: Fundamental, 2nd harmonic, 3rd harmonic, 4th harmonic, 5th harmonic 7th, harmonic 9th, harmonic 11th, harmonic 13th, harmonic 15th, harmonic 17th, harmonic 19th harmonic current.	5 ms
I02FFT	Magnitudes (rms) of residual I02 current components: Fundamental, 2nd harmonic, 3rd harmonic, 4th harmonic, 5th harmonic 7th, harmonic 9th, harmonic 11th, harmonic 13th, harmonic 15th, harmonic 17th, harmonic 19th harmonic current.	5 ms

Selection of the used AI channel and monitored harmonic as well as per unit monitoring or percentage of fundamental monitoring is made with a setting parameter. In all possible input channel variations pre-fault condition is presented with 20 ms averaged history value from -20 ms of Start or Trip event.

General settings

The function can be set to monitor the ratio of the measured harmonic to the measured fundamental component or directly the per unit value of the harmonic current. Also the user needs to select the correct measurement input.

Table 3.48 Operating mode selection settings of the HOC function

Name	Range	Step	Default	Description
Ih> meas side	Defines which current measurement module is used by the function. Visible if unit has more than one current measurement module.	1: Side1 2: Side2 3: Side3	-	1: Side1
Harmonic selection	2nd harmonic 3rd harmonic 4th harmonic 5th harmonic 7th harmonic 9th harmonic 11th harmonic 13th harmonic 15th harmonic 17th harmonic 19th harmonic	-	2nd harmonic	Selection of the monitored harmonic component
Per unit or relative	x In Ih/IL	-	x In	Selection of the monitored harmonic mode. Either directly per unit x In or in relation to the fundamental frequency magnitude.
Measurement input	IL1/IL2/IL3 I01 I02	-	IL1/IL2/IL3	Selection of the measurement input either phase currents or residual currents inputs.

Each HOC function instance provides these same settings. Multiple instances of HOC can be set to operate independently of each other.

Pick-up characteristics

Pick-up of the HOC function is controlled by Ihset pu, Ih/IL (depends of the selected operating mode) setting parameter, which defines the maximum allowed measured current before action from the function. The function constantly calculates the ratio in between of the Ihset pu or Ih/IL and measured magnitude (Im) per all three phases. Reset ratio of 97 % is inbuilt in the function and is always related to the Ihset / Ih/IL value. The setting value is common for all measured phases and single-, dual- or all phases Im exceed of the Iset value will cause pick-up operation of the function.

Table 3.49 Pick-up characteristics setting

Name	Range	Step	Default	Description
Ihset pu	0.05 ... 2.00 x In	0.01 x In	0.20 x In	Pick-up setting (per unit monitoring)
Ih/IL	5.00...200.00 %	0.01 %	20.00 %	Pick-up setting (percentage monitoring)

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Function blocking

In the blocking element the block signal is checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup current values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Operating time characteristics for trip and reset

This function supports definite time delay (DT) and inverse definite minimum time (IDMT) delay types. For detailed information on these delay types refer to chapter General properties of a protection function.

Events and registers

The HOC function generates events and registers from the status changes of start, trip and blocked. To main event buffer is possible to select status “On” or “Off” messages. The HOC function offers four independent instances which events are segregated for each instance operation.

In the function is available 12 last registers where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values.

Table 3.50 Event codes of the HOC function instances.

Event Number	Event channel	Event block name	Event Code	Description
2368	37	HOC1	0	Start ON
2369	37	HOC1	1	Start OFF
2370	37	HOC1	2	Trip ON
2371	37	HOC1	3	Trip OFF
2372	37	HOC1	4	Block ON
2373	37	HOC1	5	Block OFF
2432	38	HOC2	0	Start ON
2433	38	HOC2	1	Start OFF
2434	38	HOC2	2	Trip ON
2435	38	HOC2	3	Trip OFF
2436	38	HOC2	4	Block ON
2437	38	HOC2	5	Block OFF
2496	39	HOC3	0	Start ON
2497	39	HOC3	1	Start OFF
2498	39	HOC3	2	Trip ON
2499	39	HOC3	3	Trip OFF
2500	39	HOC3	4	Block ON
2501	39	HOC3	5	Block OFF
2560	40	HOC4	0	Start ON
2561	40	HOC4	1	Start OFF
2562	40	HOC4	2	Trip ON
2563	40	HOC4	3	Trip OFF
2564	40	HOC4	4	Block ON
2565	40	HOC4	5	Block OFF

In the register of the HOC function is recorded start, trip or blocked “On” event process data. In the table below is presented the structure of HOC function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 3.51 Register content

Date & Time	Event code	Fault type	Trigger current	Fault current	Prefault current	Trip time remaining	Used SG
dd.mm.yyyy hh:mm:ss.mss	2368-2565 Descr.	L1-G ... L1-L2-L3	Start average current	Trip -20 ms averages	Start -200 ms averages	0ms -1800s	1 - 8

3.3 Voltage protections

3.3.1 Overvoltage U> (59)

Overvoltage function (OV) is used for instant- and time delayed overvoltage protection for various applications including feeder, filter and machine applications of utilities and industry. Each IED with voltage protection module has four available instances of the function (U>, U>>, U>>>, U>>>>). Function measures constantly phase voltage magnitudes or line- to line

voltage magnitudes. Overvoltage protection is based to line- to line fundamental frequency component or to line- to neutral fundamental frequency component if so chosen. If protection is based to line- to line voltage, during earth fault in isolated or compensated networks the overvoltage protection is not affected. Blocking signal and setting group selection controls the operating characteristics of the function during normal operation.

Outputs of the function are Start Trip and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. Overvoltage function utilizes total of eight separate setting groups which can be selected from one common source.

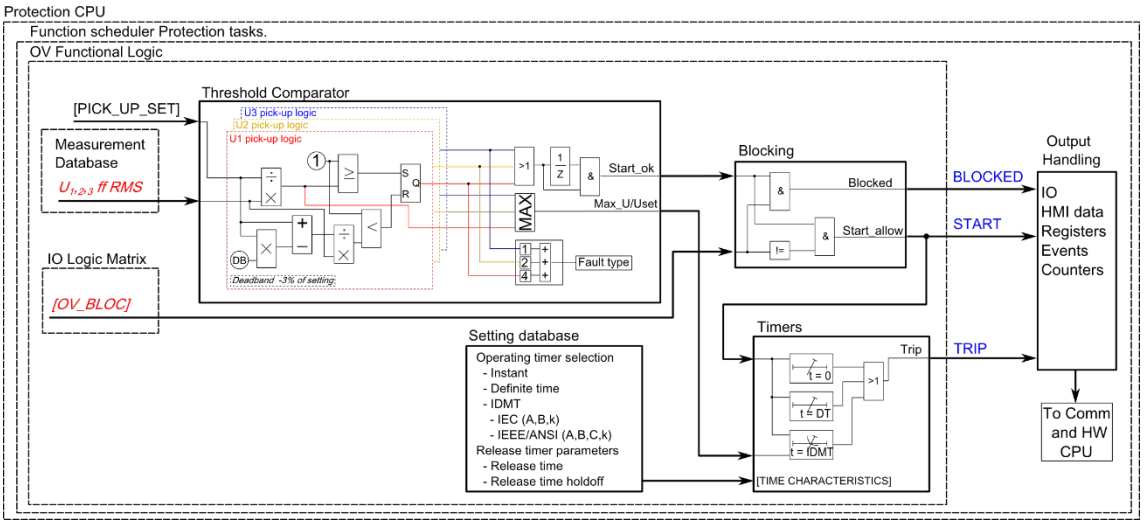
The function can be operating on instant or time delayed mode. In time delayed mode the operation can be selected for definite time or IDMT.

The operational logic consists of input magnitude processing, input magnitude selection, threshold comparator, block signal check, time delay characteristics and output processing.

Inputs for the function are the operating mode selections, setting parameters and measured and pre-processed voltage magnitudes and binary input signals. Function outputs START, TRIP and BLOCKED signals which can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the three output signal. In instant operating mode the function outputs START and TRIP events simultaneously with equivalent time stamp. Time stamp resolution is 1ms. Function provides also cumulative counters for START, TRIP and BLOCKED events.

In the following figure is presented the simplified function block diagram of the OV function.

Figure 3.45 Simplified function block diagram of the OV function.



Measured input values

Analog voltage measurement values are used by the function. Function block always utilizes peak-to-peak measurement from samples and the monitored magnitudes are fundamental frequency RMS values. -20 ms averaged value is used for the pre-fault data.

Table 3.52 Analogic magnitudes used by the OV function.

Signal	Description	Time base
U_{L12}RMS	Fundamental RMS measurement of voltage U_{L12}/V	5 ms
U_{L23}RMS	Fundamental RMS measurement of voltage U_{L23}/V	5 ms
U_{L31}RMS	Fundamental RMS measurement of voltage U_{L31}/V	5 ms
U_{L1}RMS	Fundamental RMS measurement of voltage U_{L1}/V	5 ms

Signal	Description	Time base
U_{L2}RMS	Fundamental RMS measurement of voltage U_{L2}/V	5 ms
U_{L3}RMS	Fundamental RMS measurement of voltage U_{L3}/V	5 ms

Table 3.53 Measured magnitude selection setting.

Name	Description	Range	Step	Default
Measured magnitude	Selection of P-P or P-E voltages. Additionally U3 or U4 input can be assigned as the voltage channel to be supervised.	0: P-P Voltages 1: P-E Voltages 2: U3Input (2LL-U3SS) 3: U4InputSS	-	0: P-P Voltages

Selection of the used AI channel is made with a setting parameter. In all possible input channel variations pre-fault condition is presented with 20 ms averaged history value from -20 ms of Start or Trip event.

Figure 3.46 Selectable measurement magnitudes with 3LN+U4 VT connection.

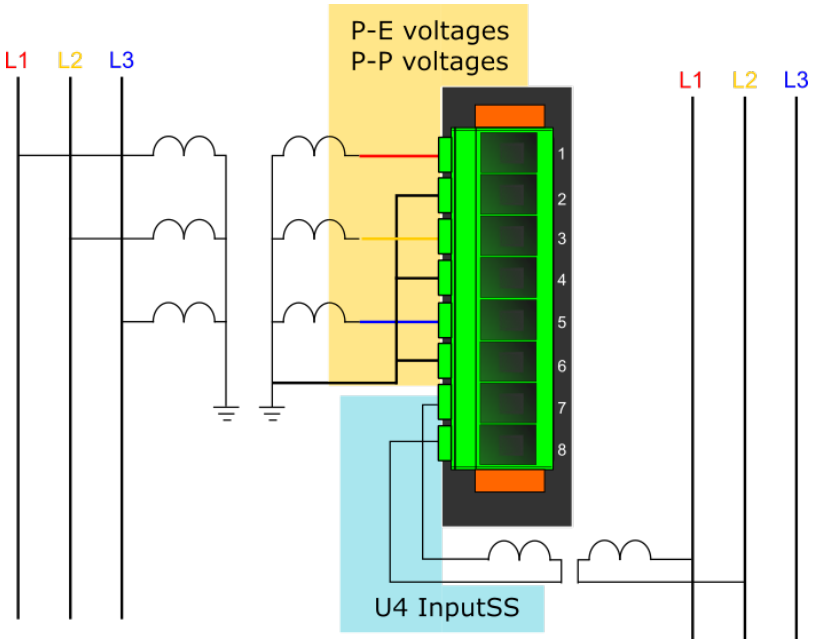


Figure 3.47 Selectable measurement magnitudes with 3LL+U4 VT connection. If no residual voltage is connected phase-to-earth voltages are not available.

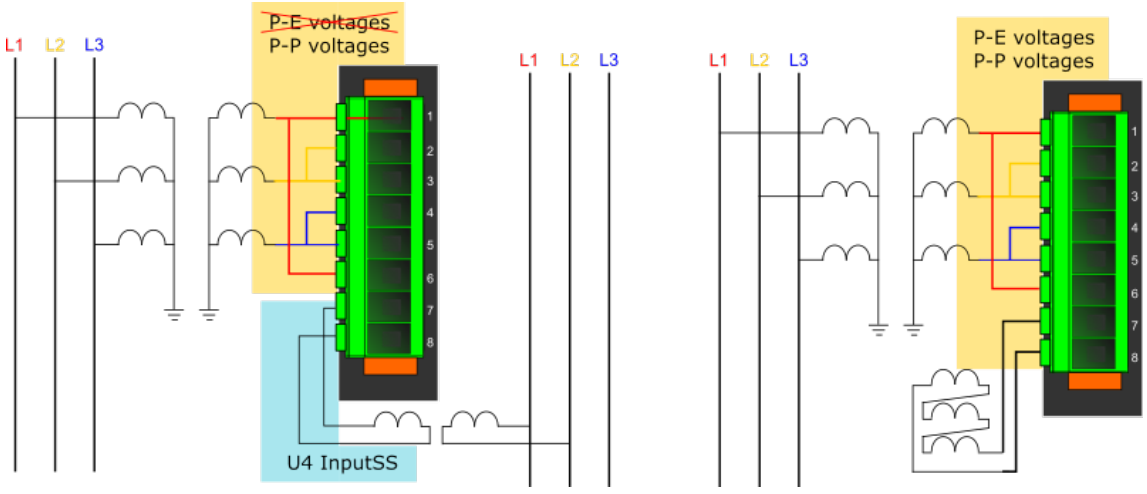
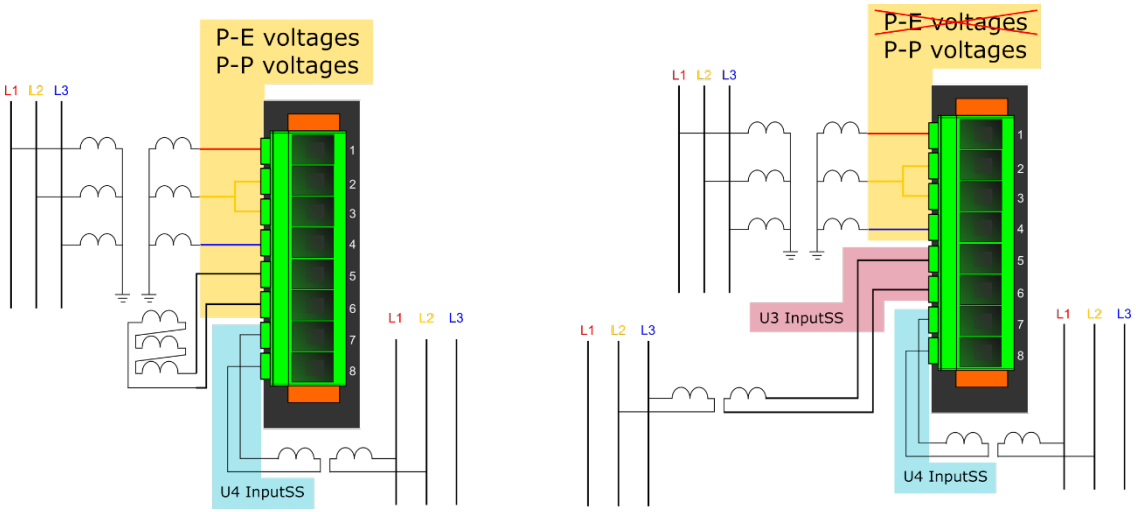


Figure 3.48 Selectable measurement magnitudes with 2LL+U4 VT connection. If no residual voltage is connected phase-to-earth voltages are not available.



P-P Voltages and *P-E Voltages* selections follow phase-to-neutral or phase-to-phase voltages in the first three voltage channels (or two first voltage channels in 2LL+U3+U4 mode). *U4 input* selection follows voltage in channel 4. *U3Input* selection follows only the voltage in channel 3 if 2LL+U3+U4 mode is in use.

Pick-up characteristics

Pick-up of the OV function is controlled by *Uset* setting parameter, which defines the maximum allowed measured voltage before action from the function. The function constantly calculates the ratio in between of the *Uset* and measured magnitude (Um) per all three voltages. Reset ratio of 97 % is inbuilt in the function and is always related to the *Uset* value. The setting value is common for all measured amplitudes and single-, dual- or each voltages Um exceed above the *Uset* value will cause pick-up operation of the function.

Table 3.54 Pick-up characteristics setting

Name	Description	Range	Step	Default
Operation mode	Pick-up criteria selection	0: All faults 1: P-P faults 2: Only 3P faults	-	0:All faults
Uset	Pick-up setting	50.00 ... 150.00%Un	0.1%Un	120%Un

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Real-time info displayed by the function

The relays Info-page displays useful information in real time of the state of the protection function either through relays HMI display or with MVR utility software when connection there is a connection to relay and Live Edit-mode is activated.

Name	Unit	Description
U< Pick-up setting	V	Primary voltage required for tripping. The displayed pick-up voltage level depends on the pick-up setting and the voltage transformer settings.
Expected operating time	s	Displays the expected operating time in case a fault occurs

Name	Unit	Description
Time remaining to trip	s	When the relay has picked up and is counting time towards pick-up
Umeas/Uset at the moment	Um/Uset	Ratio between measured voltage and the pick-up value.

Function blocking

In the blocking element the block signal is checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup voltage values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Operating time characteristics for trip and reset

The operating timers' behavior of the function can be set for trip signal and also for the release of the function in case the pick-up element is reset before the trip time has been reached. There are three basic operating modes available for the function. Instant operation gives the trip signal with no additional time delay simultaneously with start signal. Definite time operation (DT) will give trip signal with user given time delay regardless of the measured voltage as long as the voltage is above the Uset value and thus pick-up element is active (independent time characteristics). Inverse definite minimum time (IDMT) will give the trip signal in time which is in relation of the set pick-up voltage Uset and measured voltage Um (dependent time characteristics). The IDMT function follows this formula:

$$t = \frac{k}{\left(\left(\frac{Um}{Us}\right) - 1\right)^{a}}$$

Where:

- k = Time dial setting
- Um = Measured voltage
- Us = Pick-up setting
- a = IDMT Multiplier setting

In the following table are presented the setting parameters for the function time characteristics.

Table 3.55 Operating time characteristics setting parameters.

Name	Range	Step	Default	Description
Delay Type	DT IDMT	-	DT	Selection of the delay type time counter. Selection possibilities are dependent (IDMT, Inverse Definite Minimum Time) and independent (DT, Definite Time) characteristics.
Definite operating time delay	0.000... 1800.000s	0.005s	0.040s	Definite time operating delay. Setting is active and visible when Delay Type is selected to DT. When set to 0.000 s the stage operates as instant (PIOC, 50) stage without added delay. When the parameter is set to 0.005 – 1800 s the stage operates as independent delayed (PTOC, 51).
Time dial setting k	0.01...60.00s	0.01s	0.05s	Setting is active and visible when Delay Type is selected to IDMT. Time dial / multiplier setting for IDMT characteristics.
IDMT Multiplier	0.01...25.00s	0.01s	1.00	Setting is active and visible when Delay Type is selected to IDMT. IDMT time multiplier in the Um/Uset power.

Table 3.56 Reset time characteristics setting parameters.

Name	Range	Step	Default	Description
Release Time delay	0.000... 150.000s	0.005s	0.06s	Resetting time. Time allowed in between of pick-ups if the pick-up has not lead into trip operation. During this time the start signal is held on for the timers if delayed pick-up release is active.
Delayed Pick-up release	No Yes	-	Yes	Resetting characteristics selection either time delayed or instant after pick-up element is released. If activated the start signal is reset after set release time delay.
Time calc reset after release time	No Yes	-	Yes	Operating timer resetting characteristics selection. When active the operating time counter is reset after set release time if pick-up element is not activated during this time. When disabled the operating time counter is reset directly after the pick-up element reset.
Continue time calculation during release time	No Yes	-	No	Time calculation characteristics selection. If activated the operating time counter is continuing until set release time even the pick-up element is reset.

Resetting characteristics can be set according to the application. Default setting is delayed with 60 ms and the time calculation is held during the release time.

When using the release delay option where the operating time counter is calculating the operating time during the release time, function will not trip if the input signal is not activated again during the release time counting.

Events and registers

The OV function generates events and registers from the status changes of start, trip and blocked. To main event buffer is possible to select status “On” or “Off” messages. The OV function offers four independent instances which events are segregated for each instance operation.

In the function is available 12 last registers where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values.

Table 3.57 Event codes of the OV function instance 1 – 4.

Event Number	Event channel	Event block name	Event Code	Description
5440	85	OV1	0	Start ON
5441	85	OV1	1	Start OFF

Event Number	Event channel	Event block name	Event Code	Description
5442	85	OV1	2	Trip ON
5443	85	OV1	3	Trip OFF
5444	85	OV1	4	Block ON
5445	85	OV1	5	Block OFF
5504	86	OV2	0	Start ON
5505	86	OV2	1	Start OFF
5506	86	OV2	2	Trip ON
5507	86	OV2	3	Trip OFF
5508	86	OV2	4	Block ON
5509	86	OV2	5	Block OFF
5568	87	OV3	0	Start ON
5569	87	OV3	1	Start OFF
5570	87	OV3	2	Trip ON
5571	87	OV3	3	Trip OFF
5572	87	OV3	4	Block ON
5573	87	OV3	5	Block OFF
5632	88	OV4	0	Start ON
5633	88	OV4	1	Start OFF
5634	88	OV4	2	Trip ON
5635	88	OV4	3	Trip OFF
5636	88	OV4	4	Block ON
5637	88	OV4	5	Block OFF

In the register of the OV function is recorded start, trip or blocked “On” event process data. In the table below is presented the structure of OV function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 3.58 Register content.

Date & Time	Event code	Fault type	Trigger voltage	Fault voltage	Prefault voltage	Trip time remaining	Used SG
dd.mm.yyyy hh:mm:ss.mss	5440-5637 Descr.	L1-... L1-L2-L3	Start average voltage	Trip -20 ms averages	Start -200ms averages	0s ...1800s	1 - 8

3.3.2 Undervoltage U< (27)

Undervoltage function (UV) is used for instant- and time delayed undervoltage protection for various applications including feeder, filter and machine applications of utilities and industry. Each IED with voltage protection module has four available instances of the function (U<, U<<, U<<<, U<<<<). Function constantly measures phase voltage- or line to line voltage magnitudes. Undervoltage protection is based to line- to line fundamental frequency component or line- to neutral fundamental frequency component if so chosen. If protection is based to line- to line voltage, during earth fault in isolated or compensated networks the undervoltage protection is not affected. Undervoltage protection stage has two blocking instances, internal blocking based on voltage measurement and low voltage or external blocking during for example VT fuse failure. Blocking signal and setting group selection controls the operating characteristics of the function during normal operation.

Outputs of the function are Start Trip and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. Undervoltage function utilizes total of eight separate setting groups which can be selected from one common source.

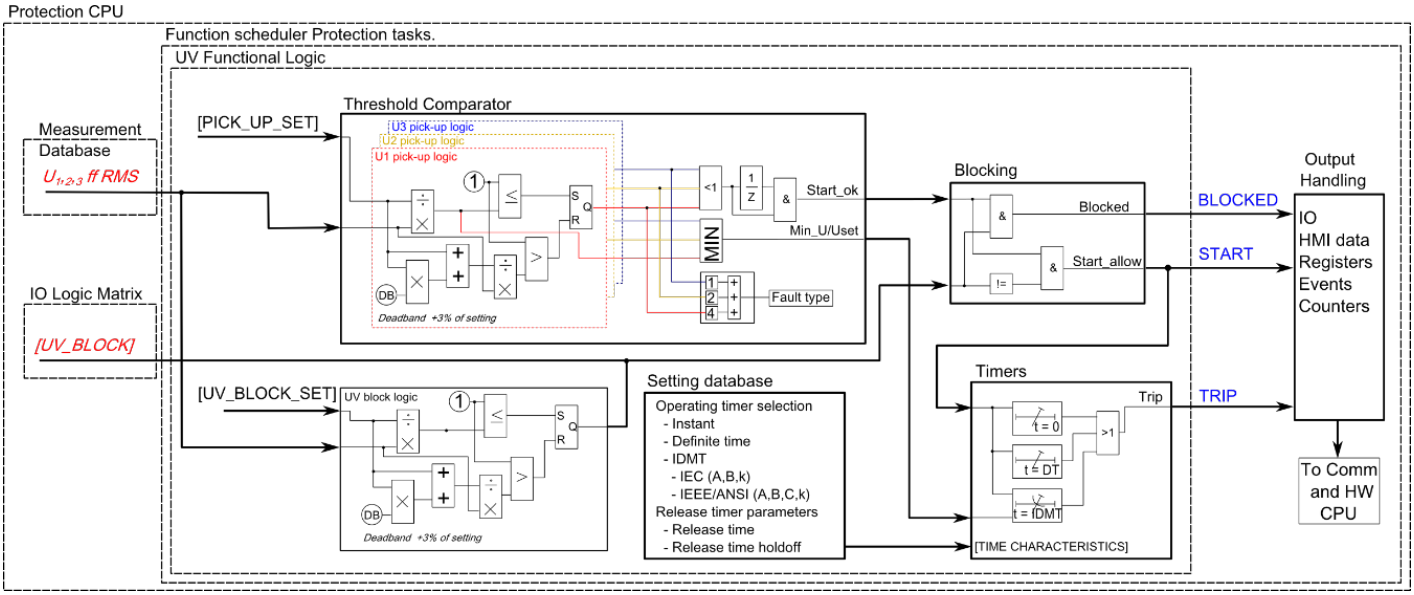
The function can operate on instant or time delayed mode. In time delayed mode the operation can be selected for definite time or IDMT.

The operational logic consists of input magnitude processing, input magnitude selection, threshold comparator, two block signal check, time delay characteristics and output processing.

Inputs for the function are the operating mode selections, setting parameters and measured and pre-processed voltage magnitudes and binary input signals. Function outputs START, TRIP and BLOCKED signals which can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the three output signal. In instant operating mode the function outputs START and TRIP events simultaneously with equivalent time stamp. Time stamp resolution is 1ms. Function provides also cumulative counters for START, TRIP and BLOCKED events.

In the following figure is presented the simplified function block diagram of the UV function.

Figure 3.49 Simplified function block diagram of the UV function.



Measured input values

Analog voltage measurement values are used by the function. Function block always utilizes peak-to-peak measurement from samples and the monitored magnitudes are fundamental frequency RMS values. -20 ms averaged value is used for the pre-fault data.

Table 3.59 Analogic magnitudes used by UV function.

Signal	Description	Time base
U_{L12}RMS	Fundamental RMS measurement of voltage U_{L12}/V	5 ms
U_{L23}RMS	Fundamental RMS measurement of voltage U_{L23}/V	5 ms
U_{L31}RMS	Fundamental RMS measurement of voltage U_{L31}/V	5 ms
U_{L1}RMS	Fundamental RMS measurement of voltage U_{L1}/V	5 ms
U_{L2}RMS	Fundamental RMS measurement of voltage U_{L2}/V	5 ms
U_{L3}RMS	Fundamental RMS measurement of voltage U_{L3}/V	5 ms

Table 3.60 Measured magnitude selection setting.

Name	Description	Range	Step	Default
Measured magnitude	Selection of P-P or P-E voltages. Additionally U3 or U4 input can be assigned as the voltage channel to be supervised.	0: P-P Voltages 1: P-E Voltages 2: U3Input (2LL-U3SS) 3: U4InputSS	-	0: P-P Voltages

Selection of the used AI channel is made with a setting parameter. In all possible input channel variations pre-fault condition is presented with 20 ms averaged history value from -20 ms of Start or Trip event.

Figure 3.50 Selectable measurement magnitudes with 3LN+U4 VT connection.

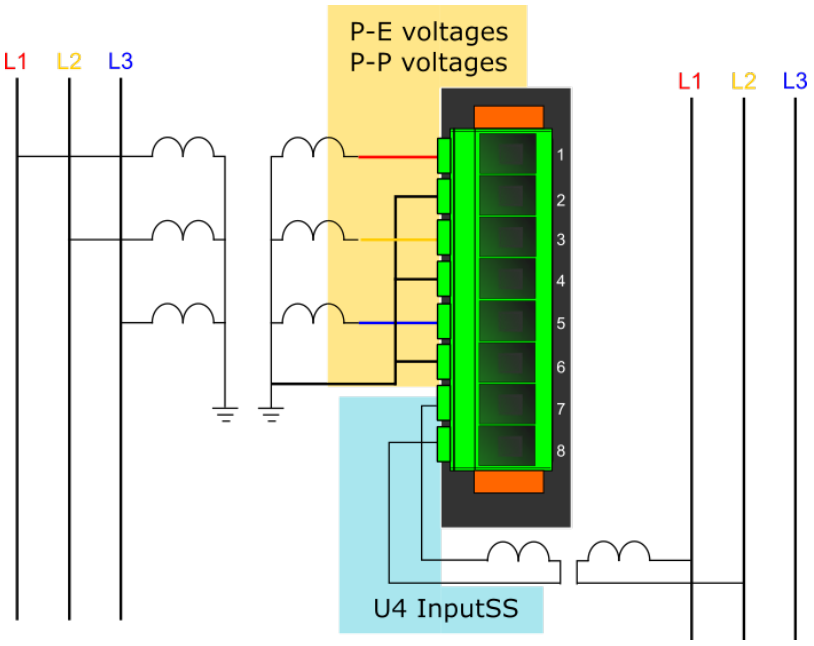


Figure 3.51 Selectable measurement magnitudes with 3LL+U4 VT connection. If no residual voltage is connected, phase-to-earth voltages are not available.

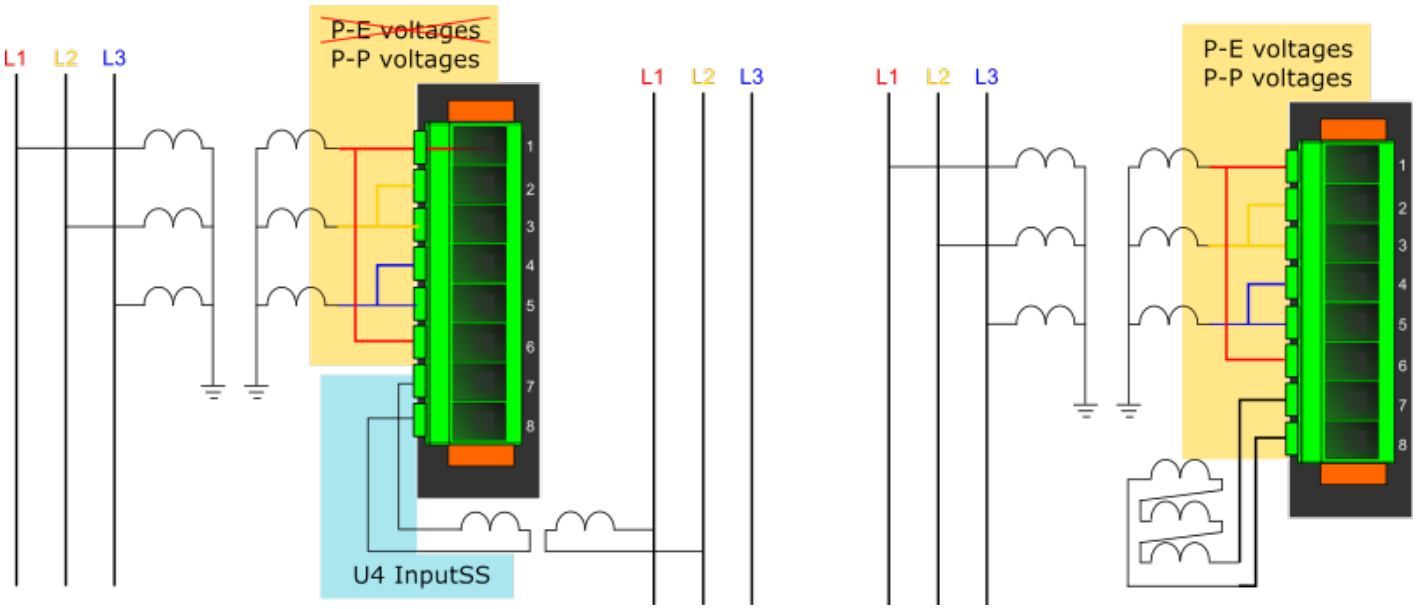
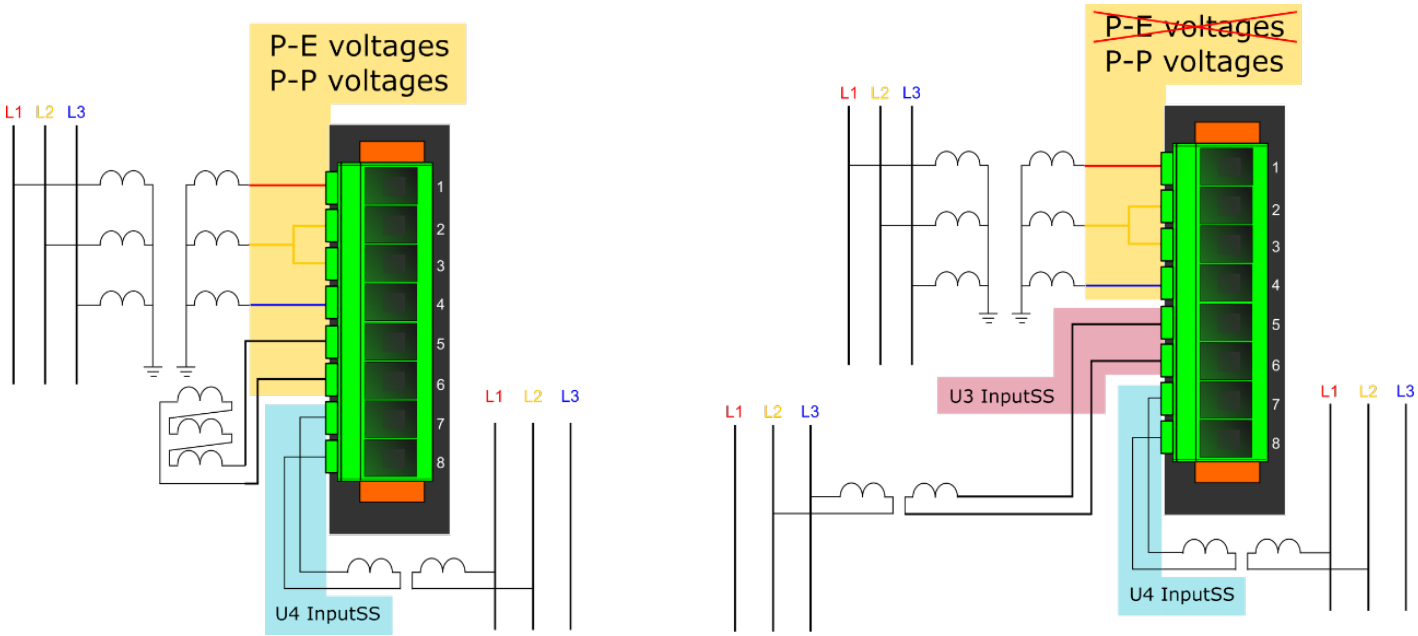


Figure 3.52 Selectable measurement magnitudes with 2LL+U4 VT connection. If no residual voltage is connected phase-to-earth voltages are not available.



P-P Voltages and P-E Voltages selections follow phase-to-neutral or phase-to-phase voltages in the first three voltage channels (or two first voltage channels in 2LL+U3+U4 mode). U4 selection follows voltage in channel 4. U3Input selection follows only the voltage in channel 3 if 2LL+U3+U4 mode is in use.

Pick-up characteristics

Pick-up of the UV function is controlled by Uset setting parameter, which defines the minimum allowed measured voltage before action from the function. The function constantly calculates the ratio in between of the Uset and measured magnitude (Um) per all three voltages. Reset ratio of 103 % is inbuilt in the function and is always related to the Uset value. The setting value is common for all measured amplitudes and single-, dual- or each voltage Um decrease below the Uset value will cause pick-up operation of the function.

Table 3.61 Pick-up characteristics setting

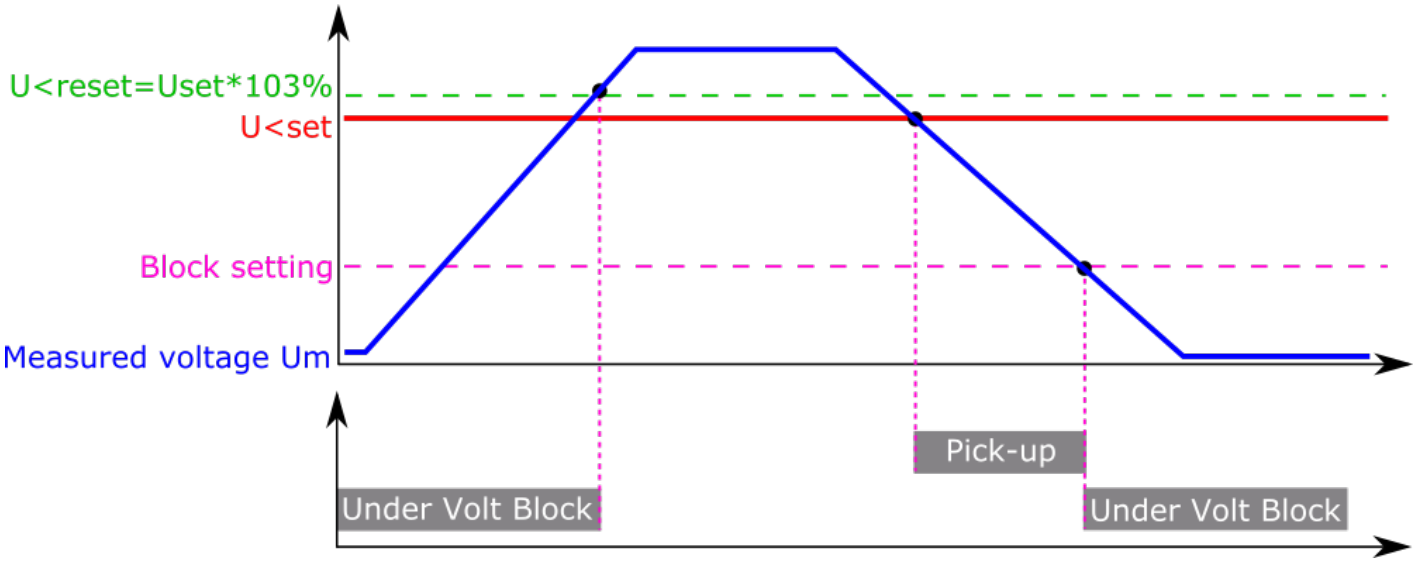
Name	Description	Range	Step	Default
Uset	Pick-up setting	0.00 ... 120.00%Un	0.01%Un	60%Un
U Block setting	Block setting. If set to zero blocking is not in use. Operation explained in the next chapter.	0.00 ... 100.00%Un	0.01%Un	10%Un

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Using block setting to prevent nuisance trips

To prevent the relay from tripping in a situation where the network is de-energized it is advised to use the Block setting parameter. When the measured voltage drops below the set value relay will not give a tripping signal. If the measured voltage has dropped below the Block setting the blocking will persist until all of the line voltages have risen over the U< pick-up setting. Please see the image for a visualization of this function.

Figure 3.53 Block setting operation example. If Block setting is set to zero blocking is not in use.



Real-time info displayed by the function

The relays Info-page displays useful information in real time of the state of the protection function either through relays HMI display or with MVR utility software when connection there is a connection to relay and Live Edit-mode is activated.

Name	Unit	Description
U< Pick-up setting	V	Primary voltage required for tripping. The displayed pick-up voltage level depends on the pick-up setting and the voltage transformer settings.
U< Block setting	V	Primary voltage level for trip blocking. If measured voltage is below this value the network is considered de-energized and function will not trip. To deactivate the blocking measured voltage must go above pick-up setting.
Expected operating time	s	Displays the expected operating time in case a fault occurs
Time remaining to trip	s	When the relay has picked up and is counting time towards pick-up
Umeas/Uset at the moment	Um/Uset	Ratio between measured voltage and the pick-up value.

Function blocking

In the blocking element the block signal is checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup voltage values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Operating time characteristics for trip and reset

The operating timers' behavior of the function can be set for trip signal and also for the release of the function in case the pick-up element is reset before the trip time has been reached. There are three basic operating modes available for the function. Instant operation gives the trip signal with no additional time delay simultaneously with start signal. Definite time operation (DT) will give trip signal with user given time delay regardless of the measured voltage as long as the voltage is below the Uset value and thus pick-up element is active (independent time characteristics). Inverse definite minimum time (IDMT) will give the trip signal in time which is in relation of the set pick-up voltage Uset and measured voltage Um (dependent time characteristics).

$$t = \frac{k}{\left(1 - \left(\frac{Um}{Us}\right)\right)^{a}}$$

Where:

- k = Time dial setting
- Um = Measured voltage
- Us = Pick-up setting
- a = IDMT Multiplier setting

In the following table are presented the setting parameters for the function time characteristics.

Table 3.62 Operating time characteristics setting parameters.

Name	Range	Step	Default	Description
Delay Type	DT IDMT	-	DT	Selection of the delay type time counter. Selection possibilities are dependent (IDMT, Inverse Definite Minimum Time) and independent (DT, Definite Time) characteristics.
Definite operating time delay	0.000... 1800.000s	0.005s	0.040s	Definite time operating delay. Setting is active and visible when Delay Type is selected to DT. When set to 0.000 s the stage operates as instant (PIOC, 50) stage without added delay. When the parameter is set to 0.005 – 1800 s the stage operates as independent delayed (PTOC, 51).
Time dial setting k	0.01...60.00s	0.01s	0.05s	Setting is active and visible when Delay Type is selected to IDMT. Time dial / multiplier setting for IDMT characteristics.
IDMT Multiplier	0.01...25.00s	0.01s	1.00	Setting is active and visible when Delay Type is selected to IDMT. IDMT time multiplier in the Um/Uset power.

Table 3.63 Reset time characteristics setting parameters.

Name	Range	Step	Default	Description
Release Time delay	0.000... 150.000s	0.005s	0.06s	Resetting time. Time allowed in between of pick-ups if the pick-up has not lead into trip operation. During this time the start signal is held on for the timers if delayed pick-up release is active.
Delayed Pick-up release	No Yes	-	Yes	Resetting characteristics selection either time delayed or instant after pick-up element is released. If activated the start signal is reset after set release time delay.
Time calc reset after release time	No Yes	-	Yes	Operating timer resetting characteristics selection. When active the operating time counter is reset after set release time if pick-up element is not activated during this time. When disabled the operating time counter is reset directly after the pick-up element reset.
Continue time calculation during release time	No Yes	-	No	Time calculation characteristics selection. If activated the operating time counter is continuing until set release time even the pick-up element is reset.

Resetting characteristics can be set according to the application. Default setting is delayed with 60 ms and the time calculation is held during the release time.

When using the release delay option where the operating time counter is calculating the operating time during the release time, function will not trip if the input signal is not activated again during the release time counting.

Events and registers

The UV function generates events and registers from the status changes of start, trip and blocked. To main event buffer is possible to select status “On” or “Off” messages. The UV function offers four independent instances which events are segregated for each instance operation.

In the function is available 12 last registers where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values.

Table 3.64 Event codes of UV function instance 1 – 4.

Event Number	Event channel	Event block name	Event Code	Description
5696	89	UV1	0	Start ON
5697	89	UV1	1	Start OFF
5698	89	UV1	2	Trip ON
5699	89	UV1	3	Trip OFF
5700	89	UV1	4	Block ON
5701	89	UV1	5	Block OFF
5702	89	UV1	6	Undervoltage Block On
5703	89	UV1	7	Undervoltage Block Off
5760	90	UV2	0	Start ON
5761	90	UV2	1	Start OFF
5762	90	UV2	2	Trip ON
5763	90	UV2	3	Trip OFF
5764	90	UV2	4	Block ON
5765	90	UV2	5	Block OFF
5766	90	UV2	6	Undervoltage Block On

Event Number	Event channel	Event block name	Event Code	Description
5767	90	UV2	7	Undervoltage Block Off
5824	91	UV3	0	Start ON
5825	91	UV3	1	Start OFF
5826	91	UV3	2	Trip ON
5827	91	UV3	3	Trip OFF
5828	91	UV3	4	Block ON
5829	91	UV3	5	Block OFF
5830	91	UV3	6	Undervoltage Block On
5831	91	UV3	7	Undervoltage Block Off
5888	92	UV4	0	Start ON
5889	92	UV4	1	Start OFF
5890	92	UV4	2	Trip ON
5891	92	UV4	3	Trip OFF
5892	92	UV4	4	Block ON
5893	92	UV4	5	Block OFF
5894	92	UV4	6	Undervoltage Block On
5895	92	UV4	7	Undervoltage Block Off

In the register of the UV function is recorded start, trip or blocked “On” event process data. In the table below is presented the structure of UV function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 3.65 Register content

Date & Time	Event code	Fault type	Pretrig voltage	Fault voltage	Prefault voltage	Trip time remaining	Used SG
dd.mm.yyyy hh:mm:ss.mss	5696-5895 Descr.	A...A-B-C	Start average voltage	Trip -20ms averages	Start -200ms averages	0ms - 1800s	1 - 8

3.3.3 Neutral voltage U0> (59N)

Neutral overvoltage function (NOV) is used for non-directional instant- and time delayed earth fault protection for various applications including feeder, filter and machine applications of utilities and industry. Each IED with voltage protection module has four available instances of the function (U0>, U0>>, U0>>>, U0>>>>).

NOV -function measures constantly phase to ground voltage magnitudes and calculates the zero sequence component. Neutral overvoltage protection is scaled to line- to line fundamental frequency component level. In case line to line voltage of system is 100 V secondary the earth fault is 100% of Un when calculated zero sequence voltage reaches 100/√3 V = 57.74 V.

Below is presented the formula for symmetric component calculation and therefore to zero sequence voltage calculation.

$$U0 = {}^{1}/_{3}\,(U_{L1} + U_{L2} + U_{L3})$$

$$U_{L1\ldots3} = Line\ to\ neutral\ voltages$$

See zero sequence calculation examples below.

Figure 3.54 Normal situation

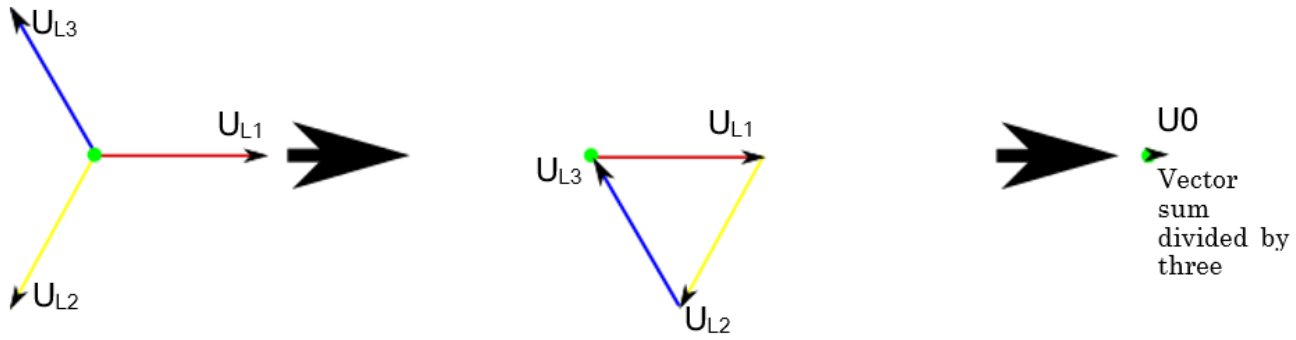


Figure 3.55 Earth fault in isolated network.

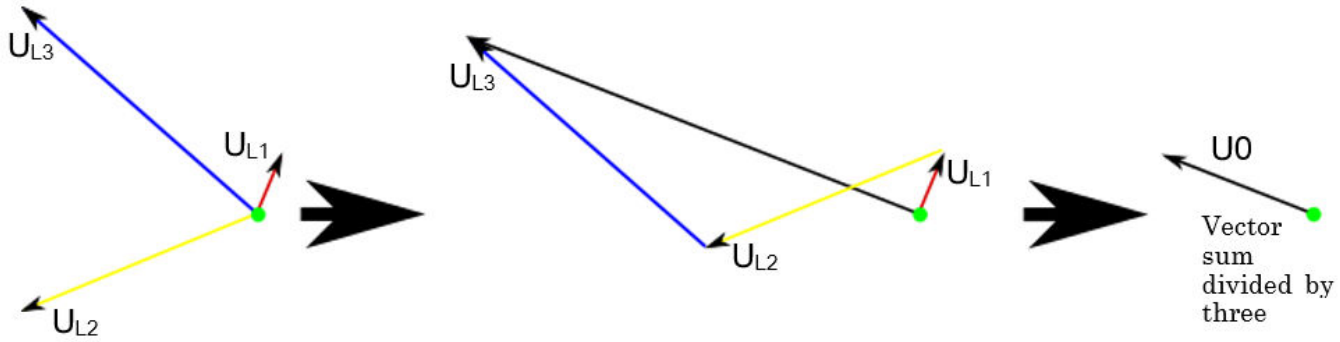
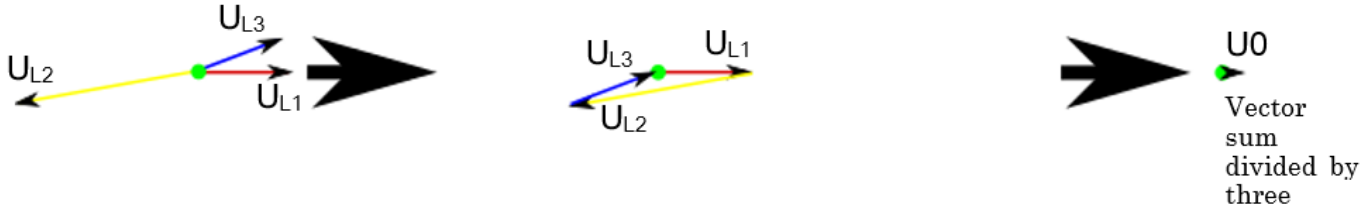


Figure 3.56 Close distance short circuit between phases 1 and 3.



NOV function is capable to use measured neutral voltage as well. In case line to line voltage of system is 100 V secondary the earth fault is 100% of Un when measured neutral voltage is 100 V. See picture below.

For monitored voltage magnitudes can be selected fundamental component RMS and TRMS values (including harmonics up to 31st). Blocking signal and setting group selection controls the operating characteristics of the function during normal operation.

Outputs of the function are Start Trip and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. Neutral overvoltage function utilizes total of eight separate setting groups which can be selected from one common source.

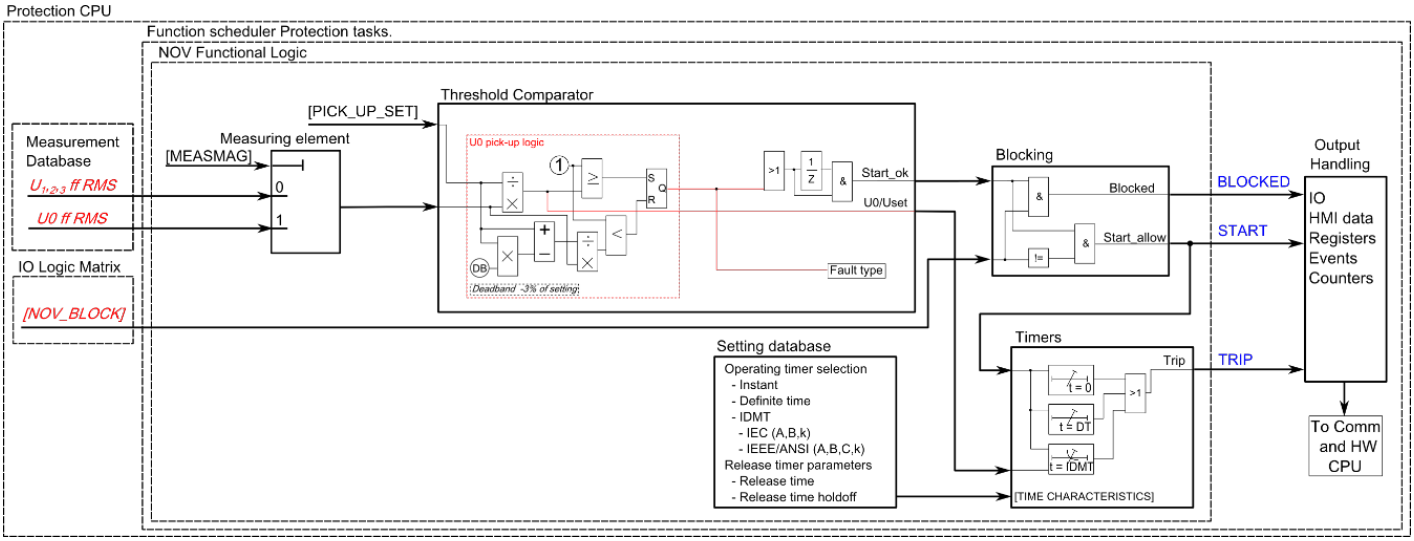
The function can be operating on instant or time delayed mode. In time delayed mode the operation can be selected for definite time or IDMT. For IDMT operation IEC and ANSI standard time delays are supported as well as custom parameters.

The operational logic consists of input magnitude processing, input magnitude selection, threshold comparator, block signal check, time delay characteristics and output processing.

Inputs for the function are the operating mode selections, setting parameters and measured and pre-processed voltage magnitudes and binary input signals. Function outputs START, TRIP and BLOCKED signals which can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the three output signal. In instant operating mode the function outputs START and TRIP events simultaneously with equivalent time stamp. Time stamp resolution is 1ms. Function provides also cumulative counters for START, TRIP and BLOCKED events.

In the following figure is presented the simplified function block diagram of the NOV function.

Figure 3.57 Simplified function block diagram of the NOV function.



Measured input values

Function block uses the analog voltage measurement values. Function block utilizes fundamental frequency RMS values. -20ms averaged value of the selected magnitude is used for pre-fault data registering.

Table 3.66 Analogic magnitude used by the NOV function.

Signal	Description	Time base
U0RMS	Fundamental RMS measurement of voltage U0/V	5 ms

Selection of the used AI channel is made with a setting parameter. In all possible input channel variations pre-fault condition is presented with 20 ms averaged history value from -20 ms of Start or Trip event.

Real-time info displayed by the function

The relays Info-page displays useful information in real time of the state of the protection function either through relays HMI display or with MVR utility software when connection there is a connection to relay and Live Edit-mode is activated.

Name	Unit	Description
U0> Pick-up setting	V	Primary voltage required for tripping. The displayed pick-up voltage level depends on the chosen U0 measurement input selection, pick-up setting and the voltage transformer settings.
Expected operating time	s	Displays the expected operating time in case a fault occurs
Time remaining to trip	s	When the relay has picked up and is counting time towards pick-up
Umeas/Uset at the moment	Um/Uset	Ratio between measured/calculated neutral voltage and the pick-up value.

General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible change them with setting group switching.

Table 3.67 General settings of the function

Name	Description	Range	Step	Default
Meas input select	Defines which available measured residual voltage is used by the function	1:Select 2:U4 Input 3:U3 Input 4:U0Calc	-	1:Select

Pick-up characteristics

Pick-up of the NOV function is controlled by Uset setting parameter, which defines the maximum allowed measured voltage before action from the function. The function constantly calculates the ratio in between of the Uset and measured magnitude (Um) per all three voltages. Reset ratio of 97 % is inbuilt in the function and is always related to the Uset value. The setting value is common for all measured amplitudes and single-, dual- or each voltages Um exceed above the Uset value will cause pick-up operation of the function.

Table 3.68 Pick-up characteristics setting

Name	Description	Range	Step	Default
Pick-up setting U0set>	Pick-up setting	1.00 ... 99.00%Un	0.01%	20%Un

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Function blocking

In the blocking element the block signal is checked at the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup voltage values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Operating time characteristics for trip and reset

The operating timers' behavior of the function can be set for trip signal and also for the release of the function in case the pick-up element is reset before the trip time has been reached. There are three basic operating modes available for the function. Instant operation gives the trip signal with no additional time delay simultaneously with start signal. Definite time operation (DT) will give trip signal with user given time delay regardless of the measured or calculated voltage as long as the voltage is above the Uset value and thus pick-up element is active (independent time characteristics). Inverse definite minimum time (IDMT) will give the trip signal in time which is in relation of the set pick-up voltage Uset and measured voltage Um (dependent time characteristics). IDMT function delay follows this formula:

$$t = \frac{k}{\left(\left(\frac{Um}{Us}\right) - 1\right)^{a}}$$

Where:k = Time dial settingUm = Measured voltageUs = Pick-up settinga = IDMT Multiplier setting

In the following table the setting parameters for the function time characteristics are presented.

Table 3.69 Operating time characteristics setting parameters.

Name	Range	Step	Default	Description
Delay Type	DT IDMT	-	DT	Selection of the delay type time counter. Selection possibilities are dependent (IDMT, Inverse Definite Minimum Time) and independent (DT, Definite Time) characteristics.
Definite operating time delay	0.000… 1800.000s	0.005s	0.040s	Definite time operating delay. Setting is active and visible when Delay Type is selected to DT. When set to 0.000 s the stage operates as instant (PIOC, 50) stage without added delay. When the parameter is set to 0.005 – 1800 s the stage operates as independent delayed (PTOC, 51).
Time dial setting k	0.01…60.00s	0.01s	0.05s	Setting is active and visible when Delay Type is selected to IDMT. Time dial / multiplier setting for IDMT characteristics.
IDMT Multiplier	0.01…25.00	0.01	1.00	Setting is active and visible when Delay Type is selected to IDMT. IDMT time multiplier in the Um/Uset power.

Table 3.70 Reset time characteristics setting parameters.

Name	Range	Step	Default	Description
Release Time delay	0.000... 150.000s	0.005s	0.06s	Resetting time. Time allowed in between of pick-ups if the pick-up has not lead into trip operation. During this time the start signal is held on for the timers if delayed pick-up release is active.
Delayed Pick-up release	No Yes	-	Yes	Resetting characteristics selection either time delayed or instant after pick-up element is released. If activated the start signal is reset after set release time delay.
Time calc reset after release time	No Yes	-	Yes	Operating timer resetting characteristics selection. When active the operating time counter is reset after set release time if pick-up element is not activated during this time. When disabled the operating time counter is reset directly after the pick-up element reset.
Continue time calculation during release time	No Yes	-	No	Time calculation characteristics selection. If activated the operating time counter is continuing until set release time even the pick-up element is reset.

Resetting characteristics can be set according to the application. Default setting is delayed with 60 ms and the time calculation is held during the release time.

When using the release delay option where the operating time counter is calculating the operating time during the release time, function will not trip if the input signal is not activated again during the release time counting.

Events and registers

The NOV function generates events and registers from the status changes of start, trip and blocked. To main event buffer is possible to select status “On” or “Off” messages. The NOV function offers four independent instances which events are segregated for each instance operation.

In the function is available 12 last registers where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values.

Table 3.71 Event codes of the NOV function instance 1 – 4.

Event Number	Event channel	Event block name	Event Code	Description
5952	93	NOV1	0	Start ON
5953	93	NOV1	1	Start OFF
5954	93	NOV1	2	Trip ON
5955	93	NOV1	3	Trip OFF
5956	93	NOV1	4	Block ON
5957	93	NOV1	5	Block OFF
6016	94	NOV2	0	Start ON
6017	94	NOV2	1	Start OFF
6018	94	NOV2	2	Trip ON
6019	94	NOV2	3	Trip OFF
6020	94	NOV2	4	Block ON
6021	94	NOV2	5	Block OFF
6080	95	NOV3	0	Start ON
6081	95	NOV3	1	Start OFF
6082	95	NOV3	2	Trip ON

Event Number	Event channel	Event block name	Event Code	Description
6083	95	NOV3	3	Trip OFF
6084	95	NOV3	4	Block ON
6085	95	NOV3	5	Block OFF
6144	96	NOV4	0	Start ON
6145	96	NOV4	1	Start OFF
6146	96	NOV4	2	Trip ON
6147	96	NOV4	3	Trip OFF
6148	96	NOV4	4	Block ON
6149	96	NOV4	5	Block OFF

In the register of the NOV function is recorded start, trip or blocked “On” event process data. In the table below is presented the structure of NOV function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 3.72 Register content

Date & Time	Event code	Fault type	Trigger voltage	Fault voltage	Prefault voltage	Trip time remaining	Used SG
dd.mm.yyyy hh:mm:ss.mss	5952-6149 Descr.	L1-G...L1-L2-L3	Start average voltage	Trip -20ms averages	Start -200 ms averages	0ms -1800s	1 - 8

3.3.4 Sequence voltage U1/U2>/<(59P/27P/47)

Sequence voltage function (VUB) is used for instant- and time delayed voltage protection for various feeder, machine, utility and industry applications. It has positive- and negative sequence over- and under voltage protection of which user chooses the needed function. Each IED with voltage protection module has four available instances of the function. Function constantly measures fundamental frequency components of phase to earth voltage magnitudes or line- to line and neutral voltage magnitudes to calculate the positive or negative sequence voltage. Used voltage is user selectable. VUB protection is based on system line- to line voltage level. Protection stages can be set to protect against under- or overvoltage. Blocking signal and setting group selection controls the operating characteristics of the function during normal operation.

Positive sequence voltage calculation

Below is presented the formula for symmetric component calculation and therefore to VUB positive sequence calculation.

$$U1 = {}^{1}/_{3}\,(U_{L1} + aU_{L2} + a^{2}U_{L3})$$

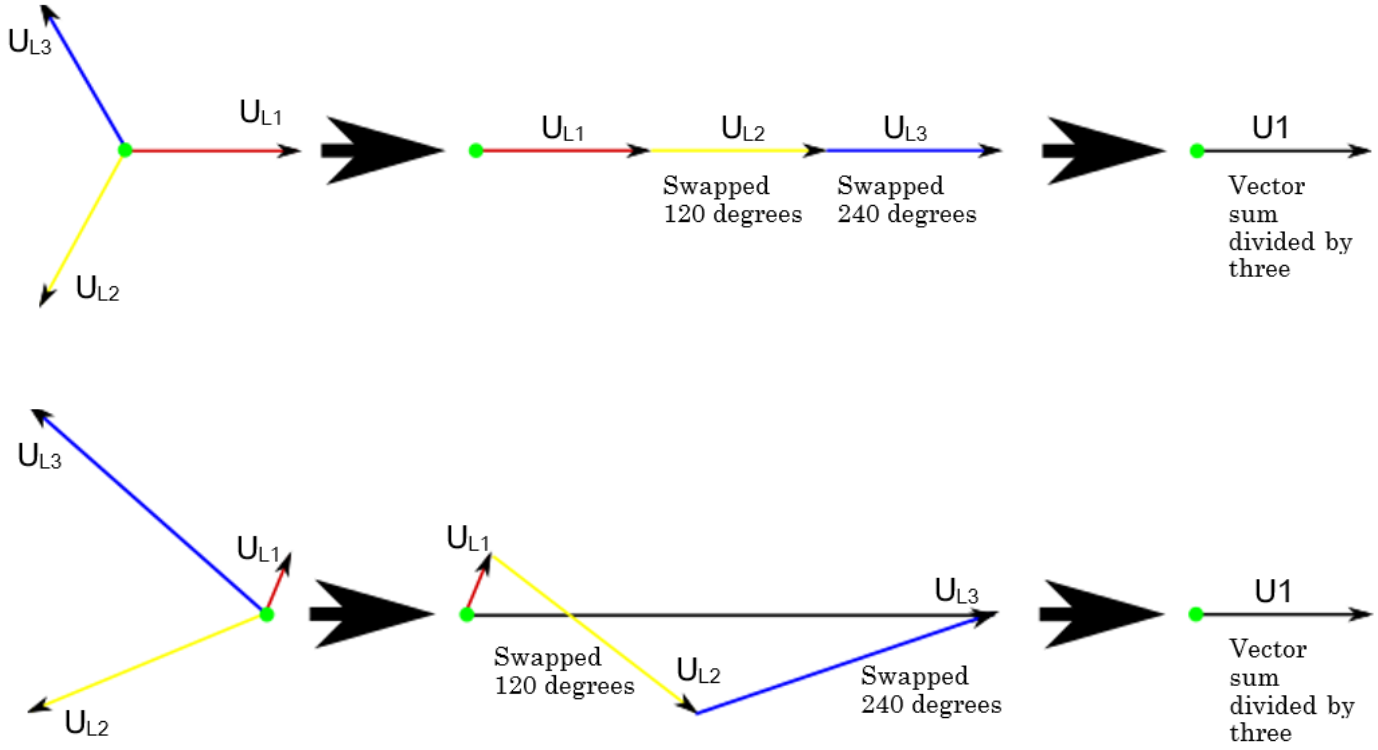
$$a = 1\angle 120°$$

$$a^{2} = 1\angle 240°$$

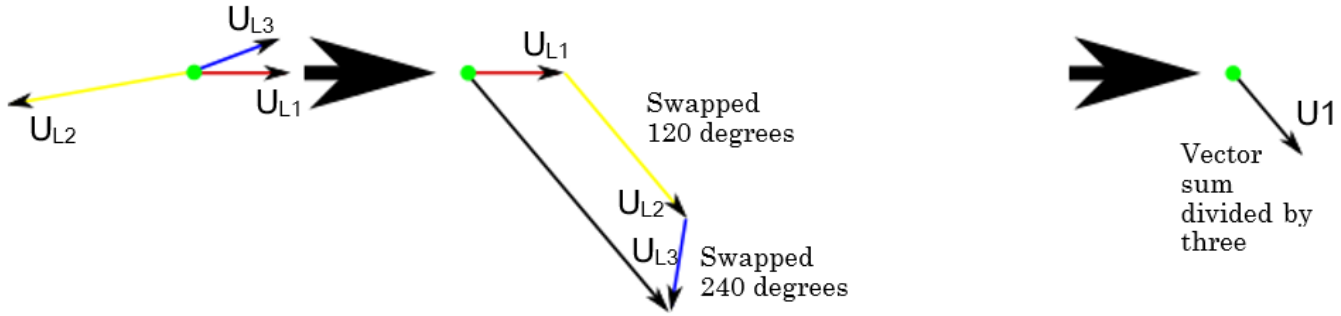
$$U_{L1\ldots3} = Line\ to\ neutral\ voltages$$

See positive sequence calculation examples below.

Figure 3.58 Positive sequence component vector examples.



Earth fault in isolated network.



Close distance short circuit between phases 1 and 3.

Negative sequence calculation

Below is presented the formula for symmetric component calculation and therefore to NSV calculation.

$$U2 = {}^{1}/_{3}\,(U_{L1} + a^2 U_{L2} + a U_{L3})$$

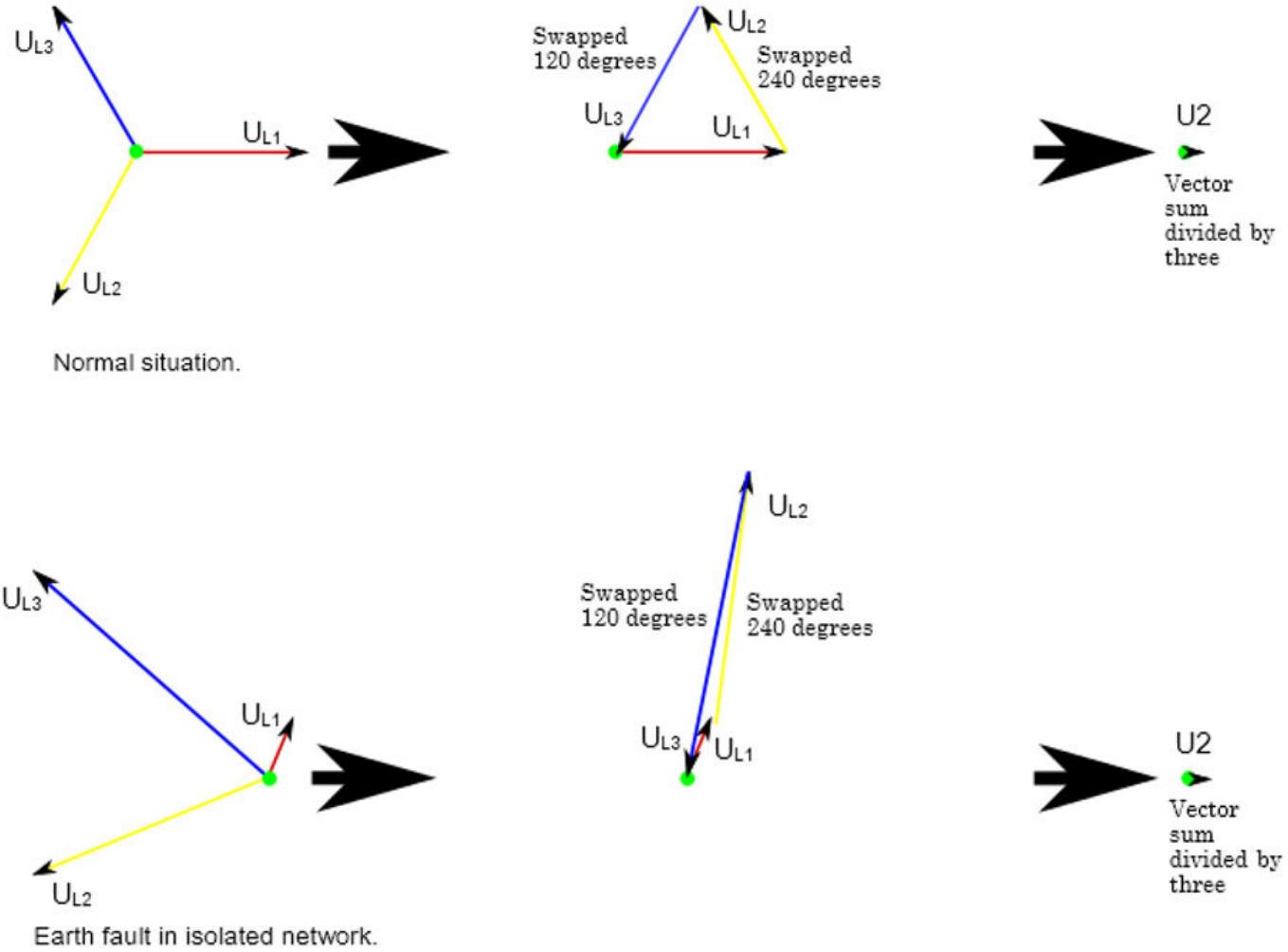
$$a = 1\angle 120°$$

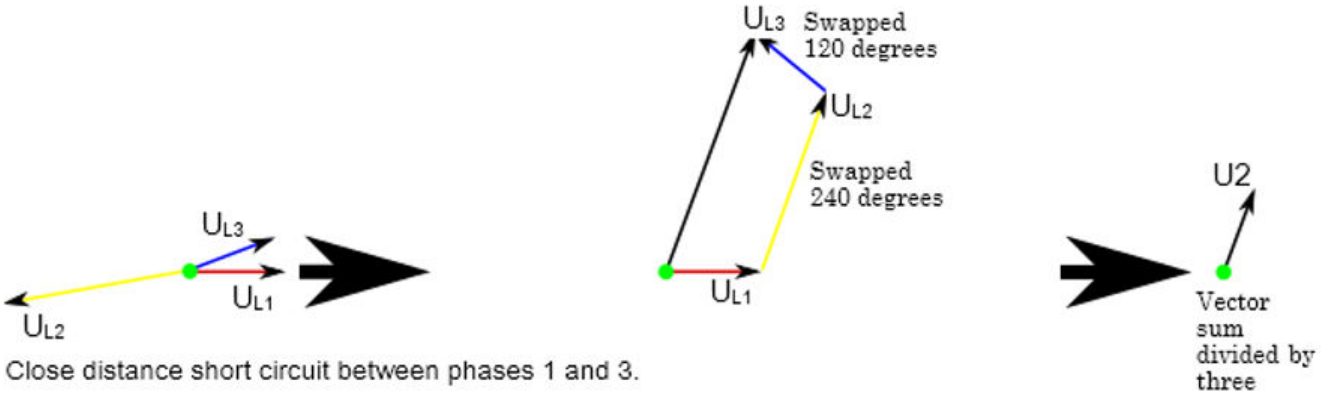
$$a^2 = 1\angle 240°$$

$$U_{L1\ldots3} = Line\ to\ neutral\ voltages$$

See negative sequence calculation examples below.

Figure 3.59 Negative sequence component vector examples.





Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. Sequence voltage function utilizes total of eight separate setting groups which can be selected from one common source.

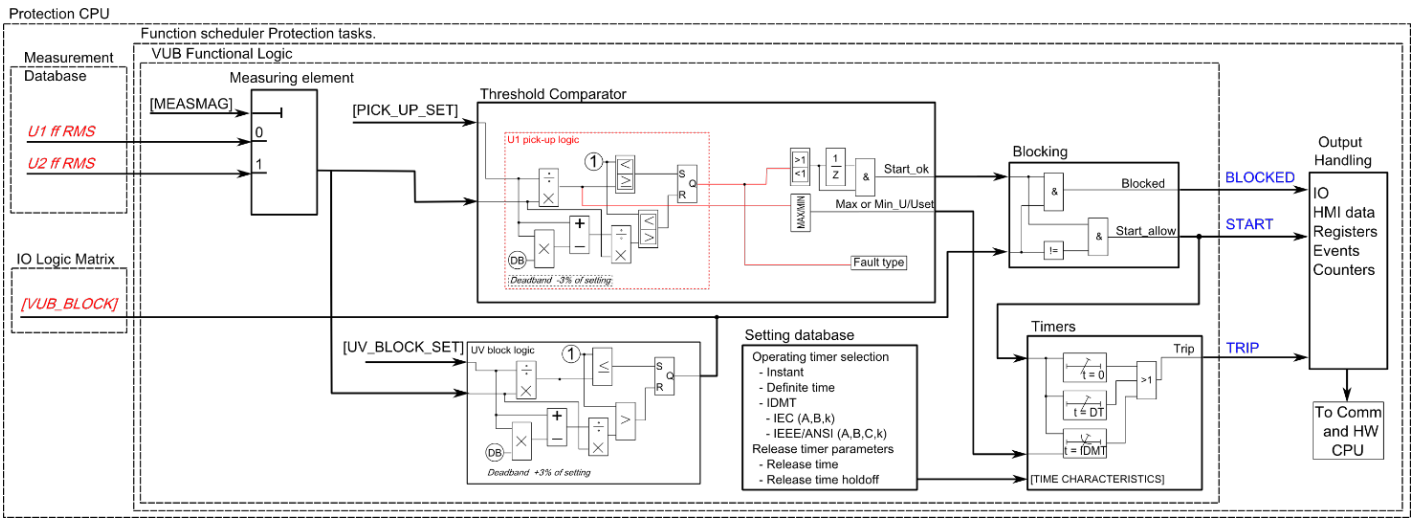
The function can be operating on instant or time delayed mode. In time delayed mode the settable operation modes are either definite time or IDMT.

The operational logic consists of input magnitude processing, input magnitude selection, threshold comparator, block signal check, time delay characteristics and output processing.

Inputs for the function are the operating mode selections, setting parameters and measured and pre-processed voltage magnitudes and binary input signals. Function outputs are START, TRIP and BLOCKED signals which can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the three output signal. In instant operating mode the function outputs START and TRIP events simultaneously with equivalent time stamp. Time stamp resolution is 1ms. Function provides also cumulative counters for START, TRIP and BLOCKED events.

Simplified function block diagram of the positive sequence protection is presented in the following figure.

Figure 3.60 Simplified function block diagram of the sequence voltage function.



Measured input values

The function block uses analog voltage measurement values. Function block always utilizes fundamental frequency RMS values. -20 ms averaged value of the selected magnitude is used for the pre-fault data registering.

Table 3.73 Analog magnitudes used by the VUB function.

Signal	Description	Time base
U_1RMS	Fundamental RMS measurement of voltage U_1/V	5 ms
U_2RMS	Fundamental RMS measurement of voltage U_2/V	5 ms
U_3RMS	Fundamental RMS measurement of voltage U_3/V	5 ms

In fundamental frequency RMS value the pre-fault condition is presented with 20 ms averaged history value from -20 ms of Start or Trip event.

Pick-up characteristics

Pick-up of the VUB function is controlled by Uset setting parameter, which defines the maximum or minimum allowed calculated U1 or U2 voltage before action from the function. The function constantly calculates the ratio in between of Uset and calculated U1 or U2 magnitude (Uc). The monitored voltage is chosen in the INFO-page with the parameter Measured magnitude.

Table 3.74 Measured magnitude selection.

Name	Description	Range	Default
Measured magnitude	Decision which calculated voltage is supervised	U1 Pos seq.Volt U2 Neg seq.Volt	U1 Pos seq.Volt

Reset ratio of 97% in over voltage applications is inbuilt in the function and is always related to the *Uset* value. Reset ratio of 103 % in under voltage applications is inbuilt in the function and is always related to the Uset value. When Uc exceed/ decrease above/below the Uset value will cause pick-up operation of the function.

Table 3.75 Pick-up characteristics setting

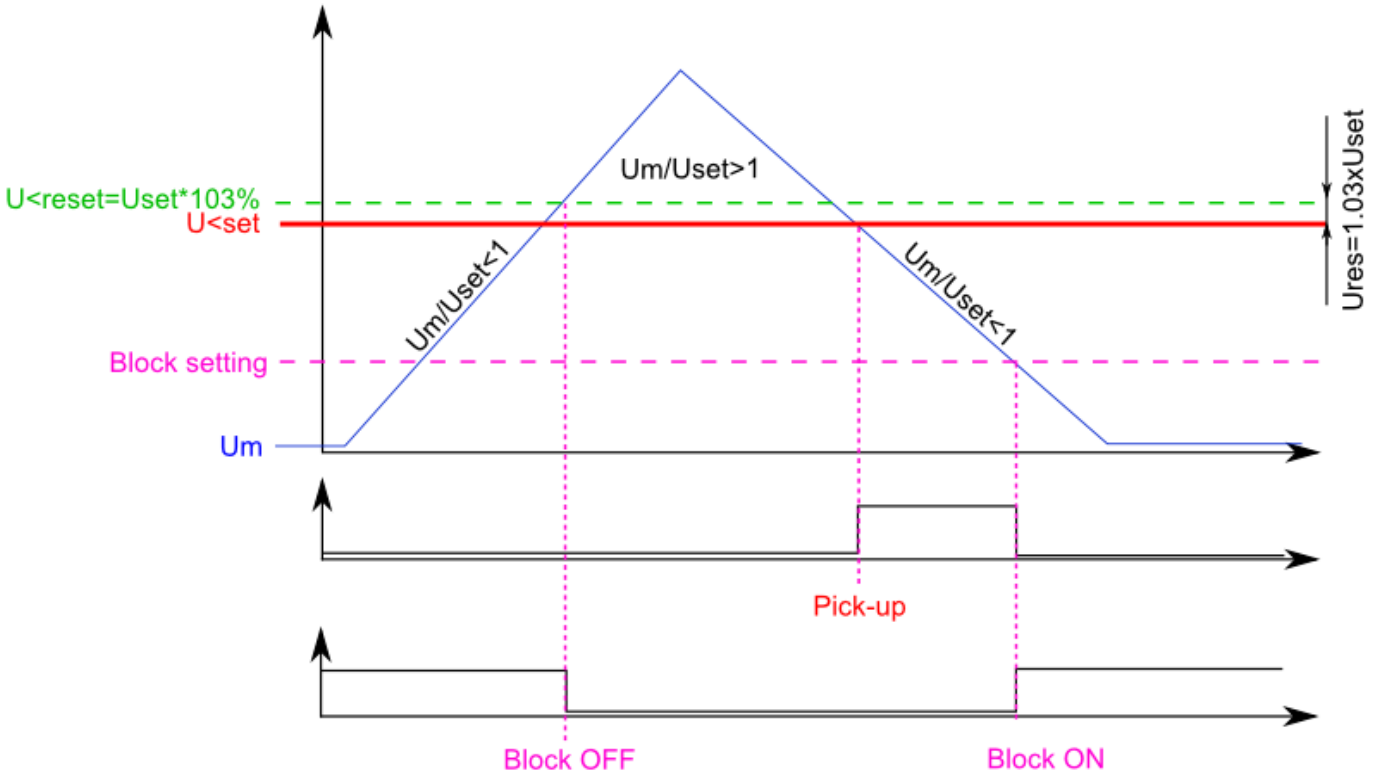
Name	Description	Range	Step	Default
Pick-up terms	Decision if the function will pick-up when the monitored voltage is under or over the set pick-up value.	Over > Under<	-	Over>
Uset	Pick-up setting	5.00...150.00%Un	0.01%Un	105%Un
Ublk	Under voltage blocking (visible when Pick-up term is Under<)	0.00...80.00%Un	0.01%Un	5%Un

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Using Block setting to prevent nuisance trips

In case “Under <” is the chosen tripping condition to prevent the relay from tripping in a situation where the network is de-energized it is advised to use the *Under block setting Ublk* parameter. When the measured voltage drops below the set value relay will not give a tripping signal. If the measured voltage has dropped below the *Under block setting Ublk* the blocking will persist until all of the line voltages have risen over the U< pick-up setting. Please see the image for a visualization of this function. If block level is set to zero, blocking is not in use.

Figure 3.61 Block setting operation example. If Block setting is set to zero blocking is not in use.



Real-time info displayed by the function

The relays Info-page displays useful information in real time of the state of the protection function either through relays HMI display or with MVR utility software when connection there is a connection to relay and Live Edit-mode is activated.

Table 3.76 Info displayed by the function

Name	Unit	Description
U1/2 >/< Pick-up setting	V	Primary voltage required for tripping. The displayed pick-up voltage level depends on the pick-up setting and the voltage transformer settings.
Expected operating time	s	Displays the expected operating time in case a fault occurs
Time remaining to trip	s	When the relay has picked up and is counting time towards pick-up
Umeas/Uset at the moment	Um/Uset	Ratio between measured voltage and the pick-up value.

Function blocking

In the blocking element the block signal is checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup voltage values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Operating time characteristics for trip and reset

This function supports definite time delay (DT) and inverse definite minimum time (IDMT) delay types. For detailed information on these delay types refer to chapter General properties of a protection function.

Events and registers

The VUB function generates events and registers from the status changes of start, trip and blocked. To main event buffer is possible to select status “On” or “Off” messages. The VUB function offers four independent instances which events are segregated for each instance operation.

In the function is available 12 last registers where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values.

Table 3.77 Event codes of VUB function instances 1-4

Event Number	Event channel	Event block name	Event Code	Description
8320	130	VUB1	0	Start ON
8321	130	VUB1	1	Start OFF
8322	130	VUB1	2	Trip ON
8323	130	VUB1	3	Trip OFF
8324	130	VUB1	4	Block ON
8325	130	VUB1	5	Block OFF
8384	131	VUB2	0	Start ON
8385	131	VUB2	1	Start OFF
8386	131	VUB2	2	Trip ON
8387	131	VUB2	3	Trip OFF
8388	131	VUB2	4	Block ON
8389	131	VUB2	5	Block OFF
8448	132	VUB3	0	Start ON
8449	132	VUB3	1	Start OFF
8450	132	VUB3	2	Trip ON
8451	132	VUB3	3	Trip OFF
8452	132	VUB3	4	Block ON
8453	132	VUB3	5	Block OFF
8512	133	VUB4	0	Start ON
8513	133	VUB4	1	Start OFF
8514	133	VUB4	2	Trip ON
8515	133	VUB4	3	Trip OFF
8516	133	VUB4	4	Block ON
8517	133	VUB4	5	Block OFF

In the register of the VUB function is recorded start, trip or blocked “On” event process data. In the table below is presented the structure of VUB function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 3.78 Register content.

Date & Time	Event code	Trigger voltage	Fault voltage	Prefault voltage	Trip time remaining	Used SG
dd.mm.yyyy hh:mm:ss.mss	8320 - 8517 Descr.	Start average voltage	Trip -20ms averages	Start -200ms averages	0ms - 1800s	1 - 8

3.3.5 Vector jump protection (78)

Distribution systems may include different kind of distributed power generation sources such as wind farms and diesel/fuel generators. When a fault occurs in the distribution system, it is usually detected and isolated by the protection system closest to the faulty point, resulting in the shutdown of a part or whole electrical power system. The remaining distributed generators try to deliver the power to the part of the distribution system that has been disconnected from the grid, and in most cases an overload condition can be expected. Under such overload condition, it is normal to have a drop in voltage and frequency. This overload results in the final system disconnection of the islanding generator(s).

The disconnection depends in a great deal in the ratio between power generation and demand of the islanded system. When any power is supplied to a load only from distributed generators, due to the opening of the main switch, the situation is called isolated island operation or islanded operation of the electrical distribution network.

The vector jump (or vector shift) protection is suitable to detect most islanding situation and switch off the mains breaker in order to let the generator supply only loads under their rated power value. Therefore overload won't cause any mechanical stress to the generator unit(s).

The vector jump relay should be issued ether on the mains side of the operated breaker or the islanding generator side. Vector jump function (VJP) is used for instant tripping and has only one operating instance VJP1. Vector jump function has algorithm which follows the samples of chosen measured voltages (64samples/cycle). Used reference voltage can be all or any phase- to phase or phase- to neutral voltage.

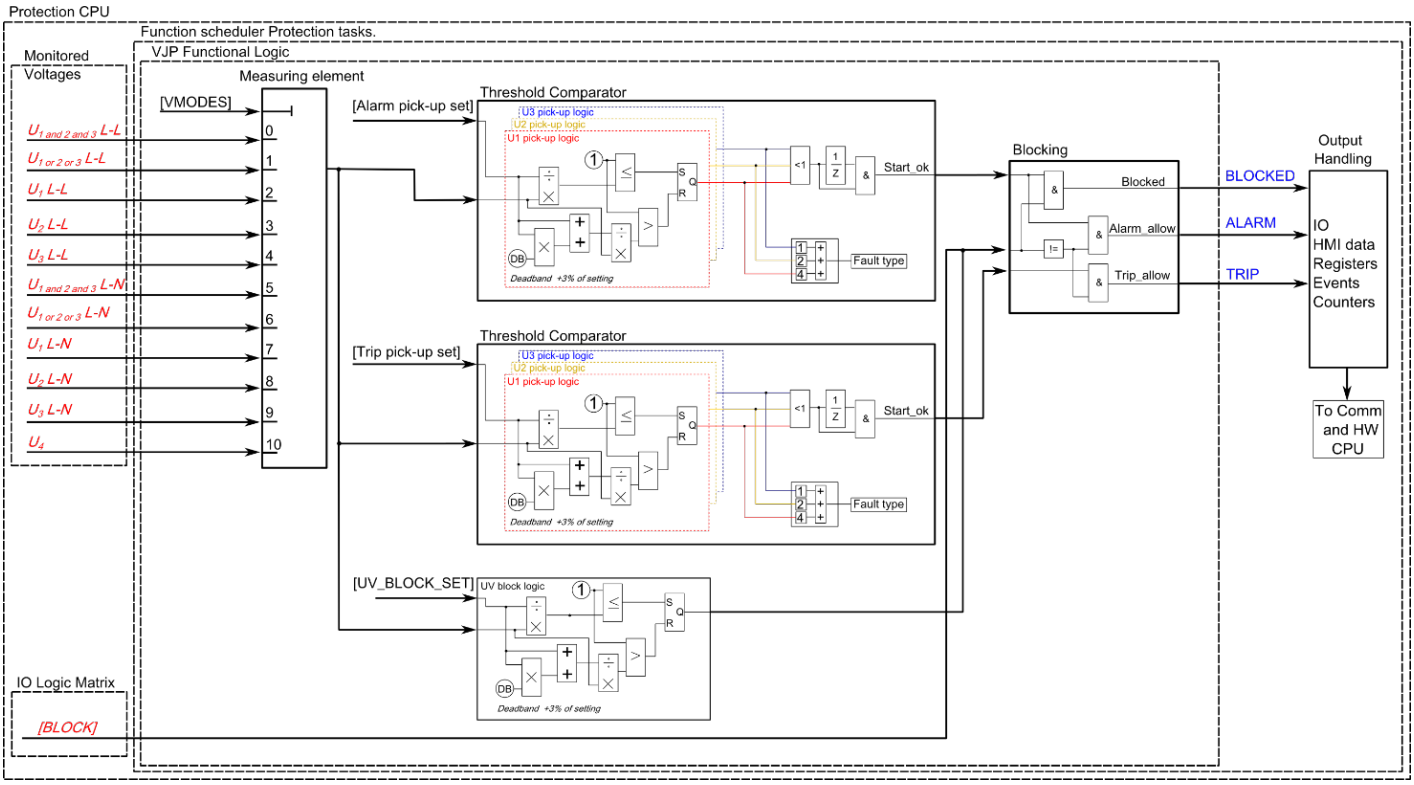
VJP outputs are Δα> Alarm, Trip and Blocked signals. Both alarm and trip signals do have an individual pick-up setting. Blocking signal and setting group selection controls the operating characteristics of the function during normal operation. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. Vector jump function utilizes total of eight separate setting groups which can be selected from one common source.

The operational logic consists of input magnitude processing, input magnitude selection, threshold comparator, two block signal checks (undervoltage block or stage external signal), time delay characteristics and output processing.

Inputs for the function are the available stages, setting parameters and measured and pre-processed voltage magnitudes and binary input signals. Function outputs ALARM, TRIP and BLOCKED signals can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the three output signals. When tripping, the function outputs ALARM and TRIP events simultaneously with equivalent time stamp. Time stamp resolution is 1ms. Function provides also cumulative counters for ALARM, TRIP and BLOCKED events.

In the following figure is presented the simplified function block diagram of the VJP function.

Figure 3.62 Simplified function block diagram of the VJP function.



Measured input values

Analog voltage measurement values are used for the function block. Function block utilizes always complex measurement from samples. For the pre-fault data registering, -20 ms averaged value of the selected magnitude is used.

Table 3.79 Analogic magnitudes used by the VJP function.

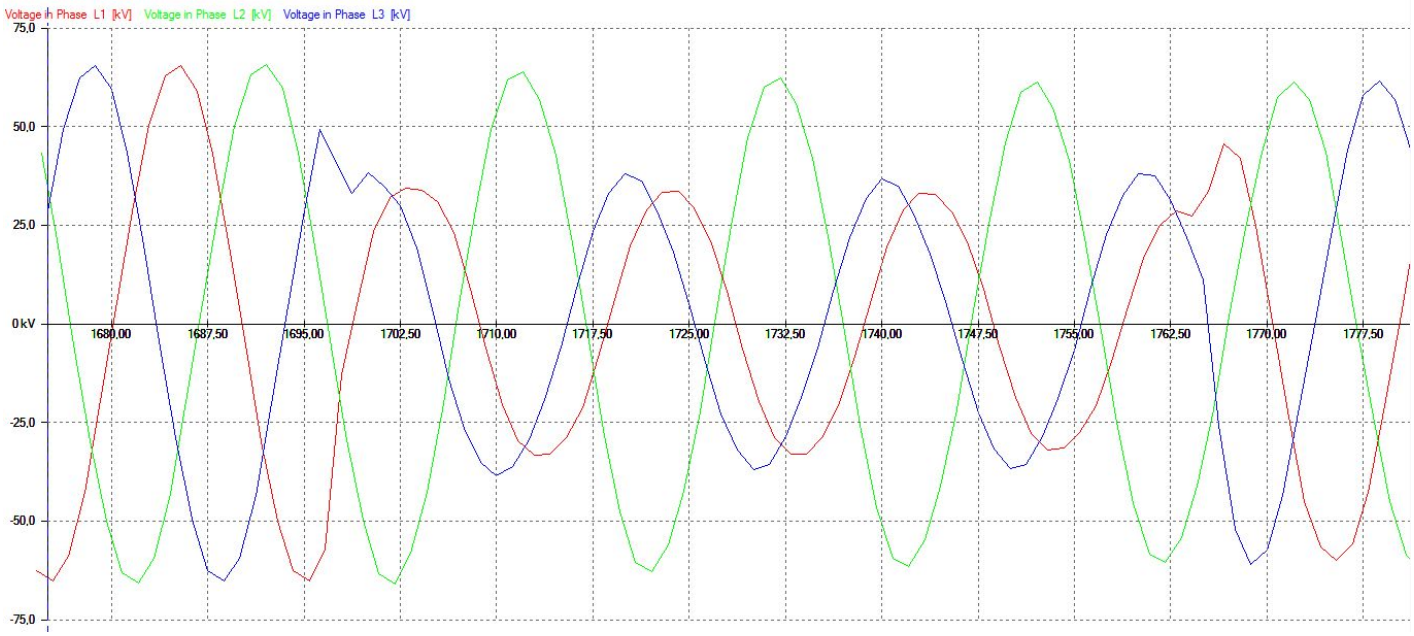
Signal	Description	Time base
U_1L-L	Measured Line-to-Line voltage U_1/V	5 ms
U_2L-L	Measured Line-to-Line voltage U_2/V	5 ms
U_3L-L	Measured Line-to-Line voltage U_3/V	5 ms
U_1L-N	Measured Line-to-Neutral voltage U_1/V	5 ms
U_2L-N	Measured Line-to-Neutral voltage U_2/V	5 ms
U_3L-N	Measured Line-to-Neutral voltage U_3/V	5 ms
U_4	Measured voltage U_4/V	5 ms

Selection of the used AI channel is made with a setting parameter. In all possible input channel variations pre-fault condition is presented with 20 ms averaged history value from -20 ms of Alarm or Trip event.

Pick-up characteristics

When a fault appears in the power system and some areas are disconnected, the remaining generators connected to the network normally must supply the area which has been disconnected from utility side supply and there is an instantaneous demand of power that the generators must tackle. The excitation and the mechanical systems are not so quick to deliver such huge demand of power even if there is enough reserve. The worst situation is suffered by the rotors of the generator units. They suffer a torsion torque that can even break it with the subsequent damage not only for the generator but for the entire power plant too.

Figure 3.63 Generator islanding occurs.



In example case above, only phase-to-phase voltages L1-L2 and L3-L1 have been reduced and the voltage L2-L3 remains the same. This means that the problem happened in phase L1 in the network. The voltage level is not reduced to zero or either the voltage in any phase is totally lost. Phases without fault condition normally remain with the same value. On the other hand, the frequency can sag as it can be seen in the figure below.

Pick-up of the VJP function alarm/trip is controlled by Δα setting parameter, which defines the minimum allowed rapid measured voltage angle change before action from the function. The function constantly calculates the ratio in between of the Δαset and measured magnitude (Δαm) per all selected voltages. VJP stage trip signal lasts for 20 milliseconds and resets automatically after the time has passed. The setting value is common for all measured amplitudes those are used.

Figure 3.64 Vector jump in the relay point of view.

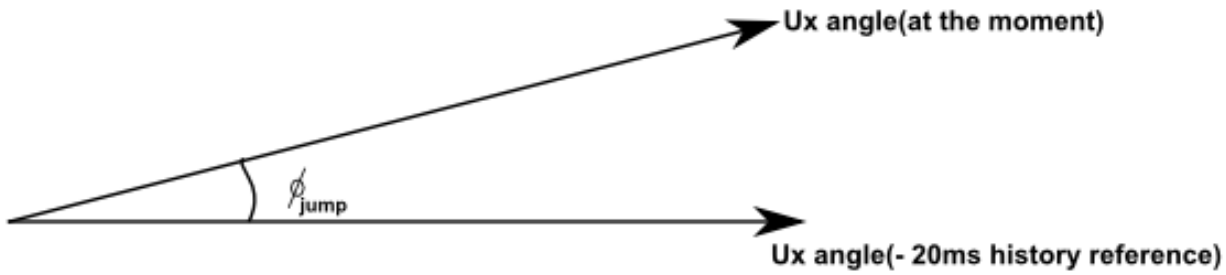


Table 3.80 Pick-up characteristics setting

Name	Description	Range	Step	Default
Δα	Pick-up setting	0.05 ... 30.00deg	0.01deg	5deg
U Block setting	Block setting. If set to zero blocking is not in use. Operation explained in the next chapter.	0.00 ... 100.00%Un	0.01%Un	10%Un

The pick-up activation of the function is not directly equal to start –or trip signal generation of the function. Start signal is allowed if blocking condition is not active.

Function blocking

In the blocking element the block signal is checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, an ALARM or TRIP signal is generated.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup voltage values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Events and registers

The VJP function generates events and registers from the status changes of start, trip and blocked. To main event buffer is possible to select status “On” or “Off” messages.

In the function, there are 12 last registers available. The triggering event of the function (alarm, trip or blocked) is recorded with time stamp and process data values.

Table 3.81 Event codes of the VJP

Event Number	Event channel	Event block name	Event Code	Description
9920	155	VJP1	0	Block On
9921	155	VJP1	1	Block Off
9922	155	VJP1	2	Trip On
9923	155	VJP1	3	Trip Off
9924	155	VJP1	4	Alarm On
9925	155	VJP1	5	Alarm Off

In the register of the VJP function, is recorded start, trip or blocked “On” event process data. In the table below is presented the structure of VJP function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 3.82 Register content.

Date & Time	Event code	Fault type	Trip da meas / dataset	Trip da meas / dataset	Used SG
dd.mm.yyyy hh:mm:ss.mss	9920-9925 Descr.	L1(2), L2(3), L3(1) and U4	Trip angle difference	Alarm angle difference	1 - 8

3.4 Frequency protections

3.4.1 Over- and underfrequency f>/< (81O/81U)

Frequency protection function can be used for both under frequency and over frequency situations and it has four stages for both. Frequency protection can be applied to protect feeder, bus, transformer, motor and generator applications.

Difference between generated power and load demand can cause the frequency to drop below or rise above the allowed level. When the consumption is larger than the generated power the frequency may drop. When more power is generated than is consumed over frequency can occur.

In generator applications too big load or malfunction in power controller can cause frequency to decrease. Under frequency causes damage to turbine wings through vibration, heating due to increased iron losses, dropped cooling effectivity and over magnetization in step-up transformer. Over frequency protection prevents the generator from running too fast which can cause damage to the generator turbine.

Under frequency and over frequency protection can be used as an indicator of accidental island operation of distributed generation and some consumers since it is unlikely that the consumed and generated power are the same. Over frequency is also often used to control power generation to keep the system frequency consistent.

Activation and deactivation of each individual stage can be done inside the protection function menus info-tab.

Outputs of the function are Start Trip and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. Frequency protection utilizes total of eight separate setting groups which can be selected from one common source.

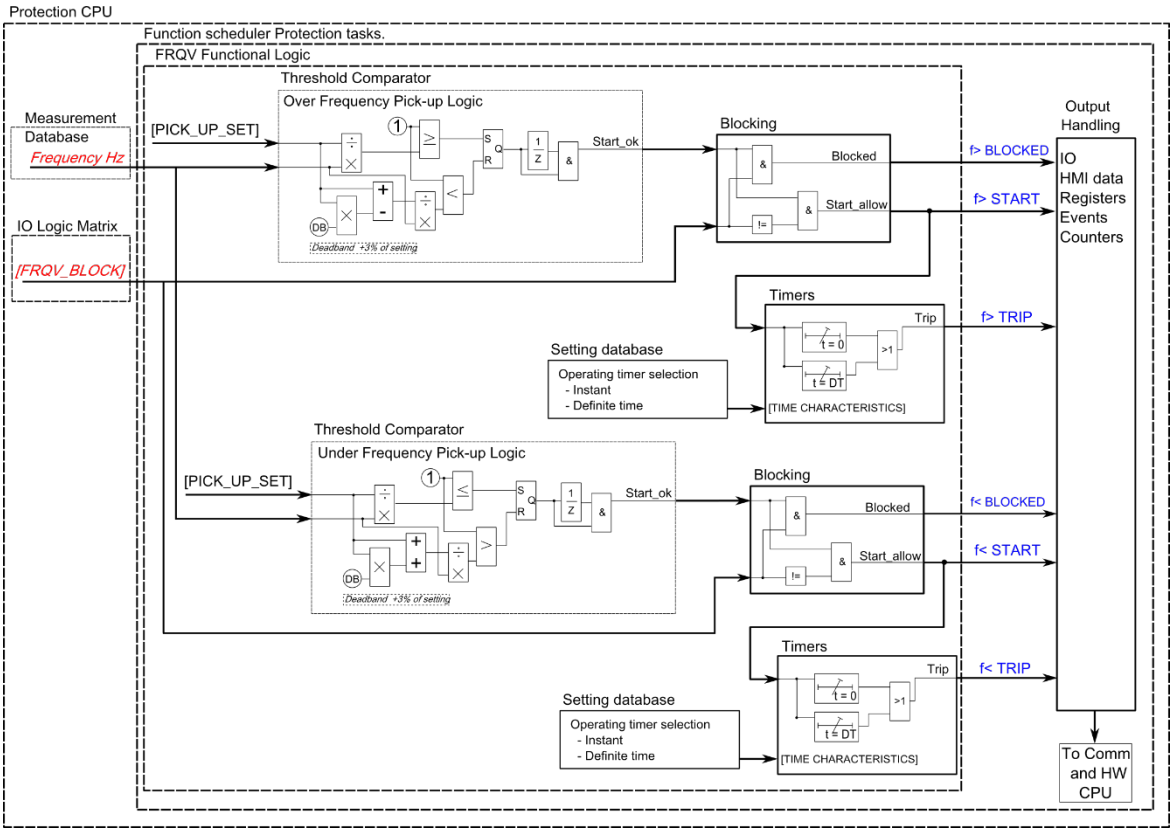
The function can operate on instant or time delayed mode.

The operational logic consists of input magnitude processing, threshold comparator, two block signal check, time delay characteristics and output processing.

Inputs for the function are the operating mode selections, setting parameters and measured and pre-processed frequency magnitudes and binary input signals. Function outputs START, TRIP and BLOCKED signals which can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the three output signal. In instant operating mode the function outputs START and TRIP events simultaneously with equivalent time stamp. Time stamp resolution is 1ms. Function provides also cumulative counters for START, TRIP and BLOCKED events.

In the following figure is presented the simplified function block diagram of the FRQV function.

Figure 3.65 Simplified function block diagram of the FRQV function.



Measured input values

Frequency protection function compares measured frequency to pick-up setting given in Hz. Source of measured frequency depends on the factory defined tracking reference which can be checked from frequency tab behind measurements-menu.

Table 3.83 Measurement magnitudes used by the FRQV function (depends on factory defined)

Signals	Description	Time base
VT1 U1,U2,U3	L-N voltages of first voltage transformer	5 ms
VT2 U1,U2,U3	L-N voltages of second voltage transformer	5 ms

Pick-up characteristics and time delay

Pick-up of each stage of FRQV functions stage is controlled by fset>, fset>> etc.setting parameter, which defines the maximum or minimum allowed measured frequency before action from the function. The function constantly calculates the ratio in between of the pick-up setting and measured frequency. Reset ratio of 97 % is inbuilt in the function and is always related to the pick-up value.

Table 3.84 Pick-up characteristics setting

Name	Description	Range	Step	Default
fset> fset>> fset>>> fset>>>>	Pick-up setting	10.00...80.00Hz	0.01Hz	51Hz
fset< fset<<	Pick-up setting	5.00...75.00Hz	0.01Hz	49Hz

Name	Description	Range	Step	Default
fset<<< fset<<<<				

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Operating time characteristics for trip and reset

This function supports definite time delay (DT). For detailed information on this delay type refer to chapter General properties of a protection function.

Function blocking

In the blocking element the block signal is checked at the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup voltage values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Events

The FRQV function generates events and registers from the status changes of start, trip and blocked. To main event buffer it’s possible to select status “On” or “Off” messages.

In the function is available 12 last registers where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values.

Table 3.85 Event codes of FRQV function.

Event Number	Event channel	Event block name	Event Code	Description
6336	99	FRQV1	0	f> Start ON
6337	99	FRQV1	1	f> Start OFF
6338	99	FRQV1	2	f> Trip ON
6339	99	FRQV1	3	f> Trip OFF
6340	99	FRQV1	4	f>> Start ON
6341	99	FRQV1	5	f>> Start OFF
6342	99	FRQV1	6	f>> Trip ON
6343	99	FRQV1	7	f>> Trip OFF
6344	99	FRQV1	8	f>>> Start ON
6345	99	FRQV1	9	f>>> Start OFF
6346	99	FRQV1	10	f>>> Trip ON
6347	99	FRQV1	11	f>>> Trip OFF

Event Number	Event channel	Event block name	Event Code	Description
6348	99	FRQV1	12	f>>>> Start ON
6349	99	FRQV1	13	f>>>> Start OFF
6350	99	FRQV1	14	f>>>> Trip ON
6351	99	FRQV1	15	f>>>> Trip OFF
6352	99	FRQV1	16	f< Start ON
6353	99	FRQV1	17	f< Start OFF
6354	99	FRQV1	18	f< Trip ON
6355	99	FRQV1	19	f< Trip OFF
6356	99	FRQV1	20	f<< Start ON
6357	99	FRQV1	21	f<< Start OFF
6358	99	FRQV1	22	f<< Trip ON
6359	99	FRQV1	23	f<< Trip OFF
6360	99	FRQV1	24	f<<< Start ON
6361	99	FRQV1	25	f<<< Start OFF
6362	99	FRQV1	26	f<<< Trip ON
6363	99	FRQV1	27	f<<< Trip OFF
6364	99	FRQV1	28	f<<<< Start ON
6365	99	FRQV1	29	f<<<< Start OFF
6366	99	FRQV1	30	f<<<< Trip ON
6367	99	FRQV1	31	f<<<< Trip OFF
6368	99	FRQV1	32	f> Block ON
6369	99	FRQV1	33	f> Block OFF
6370	99	FRQV1	34	f>> Block ON
6371	99	FRQV1	35	f>> Block OFF
6372	99	FRQV1	36	f>>> Block ON
6373	99	FRQV1	37	f>>> Block OFF
6374	99	FRQV1	38	f>>>> Block ON
6375	99	FRQV1	39	f>>>> Block OFF
6376	99	FRQV1	40	f< Block ON
6377	99	FRQV1	41	f< Block OFF
6378	99	FRQV1	42	f<< Block ON
6379	99	FRQV1	43	f<< Block OFF
6380	99	FRQV1	44	f<<< Block ON
6381	99	FRQV1	45	f<<< Block OFF
6382	99	FRQV1	46	f<<<< Block ON
6383	99	FRQV1	47	f<<<< Block OFF

In the table below is presented the structure of FSP function register content. This information is available in 12 last recorded events.

Table 3.86 Register content.

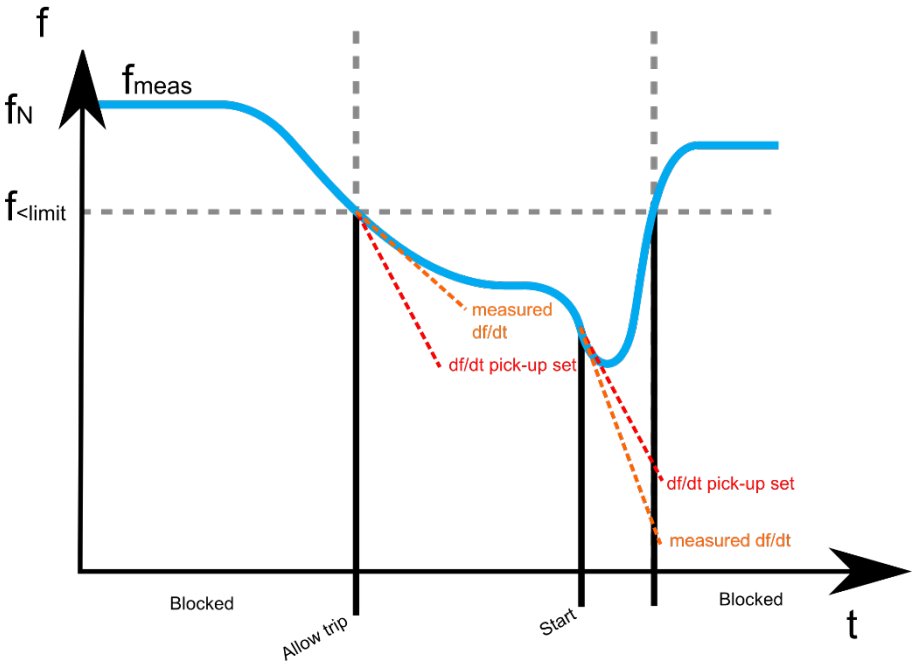
Date & Time	Event code	f Pretrig (Hz)	f Fault (Hz)	Setting group in use
dd.mm.yyyy hh:mm:ss.mss	6336-6383 Descr.	Start –20ms averages	Fault frequency	Starts used at the triggering moment

3.4.2 Rate-of-change of frequency protection df/dt (81R)

Rate of change of frequency (df/dt or ROCOF) is used to detect fast drops or increases of frequency. If the load changes fast df/dt protection will detect and clear the frequency based faults faster than conventional under- and over frequency protections. One of the most common causes for the frequency to deviate from nominal value is unbalance between generated power and the load demand. If the unbalance is big frequency will change rapidly.

Rate of change of frequency protection can also be applied to detect loss of mains situation. Loss of mains is a situation where part of the network (incorporating generation) loses connection with the rest of the system (i.e. islanded network). If the generator is not disconnected from the network as well it can cause safety hazards. Generator can also be automatically reconnected to the network which can cause damage to the generator and the network.

Figure 3.66 Operation of df/dt function when the frequency starts but doesn't trip.



In the figure above is presented an example case of df/dt function operation when the frequency is decreasing. If the f_{limit} is activated df/dt doesn't trip no matter how fast the measured frequency changes if it's over the $f_{<limit}$ or under $f_{>limit}$. In the figure above when the frequency decreases under the $f_{<limit}$ tripping of the function is allowed but change of frequency isn't yet fast enough for the df/dt function to trip. Later the frequency makes a fast dip and as a result the change of the frequency is faster than the set pick-up value which causes the relay to operate.

Activation and deactivation of each individual stage can be done inside the protection function menus info-tab.

Outputs of the function are Start Trip and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. Frequency protection utilizes total of eight separate setting groups which can be selected from one common source.

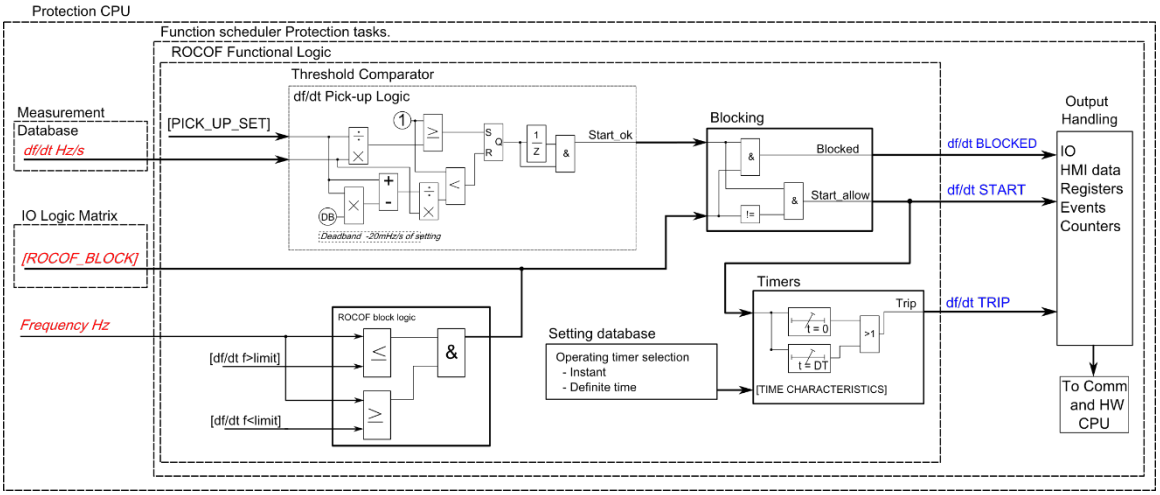
The function can operate on instant or time delayed mode.

The operational logic consists of input magnitude processing, threshold comparator, two block signal check, time delay characteristics and output processing.

Inputs for the function are the operating mode selections, setting parameters and measured and pre-processed frequency magnitudes and binary input signals. Function outputs START, TRIP and BLOCKED signals which can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the three output signal. In instant operating mode the function outputs START and TRIP events simultaneously with equivalent time stamp. Time stamp resolution is 1ms. Function provides also cumulative counters for START, TRIP and BLOCKED events.

In the following figure is presented the simplified function block diagram of the ROCOF function.

Figure 3.67 Simplified function block diagram of the ROCOF function.



Measured input values

Rate of change of frequency protection function compares measured df/dt to pick-up setting given in Hz/s. Source of measured frequency depends on the factory defined tracking reference which can be checked from frequency tab behind measurements-menu.

Table 3.87 Measurement magnitudes used by the ROCOF function (depends on factory definition)

Signals	Description	Time base
VT1 U1,U2,U3	L-N voltages of first voltage transformer	5 ms
VT2 U1,U2,U3	L-N voltages of second voltage transformer	5 ms

Pick-up characteristics and time delay

Pick-up of each stage of ROCOF functions stage is controlled by *df/dt>/< (1) pick-up*, *df/dt>/< (2) pick-up* etc.setting parameter, which defines the maximum allowed change of frequency before action from the function. The function constantly calculates the ratio in between of the pick-up setting and measured df/dt. Reset ratio of 20mHz is inbuilt in the function and is always related to the pick-up value. The f>/< limit value is used to block the operation of the function near the nominal frequency.

Table 3.88 Pick-up characteristics setting

Name	Description	Range	Step	Default
df/dt>/<(1...8)pick-up	Pick-up setting	0.01...10.00Hz/s	0.01Hz/s	0.2 Hz/s
df/dt>/<(1...8) f< limit	f< limit	7.00...65.00Hz/s	0.01Hz/s	49.95 Hz/s
df/dt>/<(1...8) f> limit	f> limit	10.00...70.00Hz/s	0.01Hz/s	51Hz/s

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Operating time characteristics for trip and reset

This function supports definite time delay (DT). For detailed information on this delay type refer to chapter General properties of a protection function.

Function blocking

In the blocking element, the block signal is checked at the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function an HMI display event as well as time stamped blocking event with information of the startup voltage values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Events and registers

The ROCOF function generates events and registers from the status changes of start, trip and blocked. To main event buffer it's possible to select status "On" or "Off" messages.

Function includes 12 last registers where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values.

Table 3.89 Event codes of ROCOF function.

Event Number	Event channel	Event block name	Event Code	Description
6592	103	DFT1	0	df/dt </> (1) Start ON
6593	103	DFT1	1	df/dt </> (1) Start OFF
6594	103	DFT1	2	df/dt </> (1) Trip ON
6595	103	DFT1	3	df/dt </> (1) Trip OFF
6596	103	DFT1	4	df/dt </> (2) Start ON
6597	103	DFT1	5	df/dt </> (2) Start OFF
6598	103	DFT1	6	df/dt </> (2) Trip ON
6599	103	DFT1	7	df/dt </> (2) Trip OFF
6600	103	DFT1	8	df/dt </> (3) Start ON
6601	103	DFT1	9	df/dt </> (3) Start OFF
6602	103	DFT1	10	df/dt </> (3) Trip ON
6603	103	DFT1	11	df/dt </> (3) Trip OFF
6604	103	DFT1	12	df/dt </> (4) Start ON
6605	103	DFT1	13	df/dt </> (4) Start OFF
6606	103	DFT1	14	df/dt </> (4) Trip ON
6607	103	DFT1	15	df/dt </> (4) Trip OFF
6608	103	DFT1	16	df/dt </> (5) Start ON

Event Number	Event channel	Event block name	Event Code	Description
6609	103	DFT1	17	df/dt </> (5) Start OFF
6610	103	DFT1	18	df/dt </> (5) Trip ON
6611	103	DFT1	19	df/dt </> (5) Trip OFF
6612	103	DFT1	20	df/dt </> (6) Start ON
6613	103	DFT1	21	df/dt </> (6) Start OFF
6614	103	DFT1	22	df/dt </> (6) Trip ON
6615	103	DFT1	23	df/dt </> (6) Trip OFF
6616	103	DFT1	24	df/dt </> (7) Start ON
6617	103	DFT1	25	df/dt </> (7) Start OFF
6618	103	DFT1	26	df/dt </> (7) Trip ON
6619	103	DFT1	27	df/dt </> (7) Trip OFF
6620	103	DFT1	28	df/dt </> (8) Start ON
6621	103	DFT1	29	df/dt </> (8) Start OFF
6622	103	DFT1	30	df/dt </> (8) Trip ON
6623	103	DFT1	31	df/dt </> (8) Trip OFF
6624	103	DFT1	32	df/dt </> (1) Block ON
6625	103	DFT1	33	df/dt </> (1) Block OFF
6626	103	DFT1	34	df/dt </> (2) Block ON
6627	103	DFT1	35	df/dt </> (2) Block OFF
6628	103	DFT1	36	df/dt </> (3) Block ON
6629	103	DFT1	37	df/dt </> (3) Block OFF
6630	103	DFT1	38	df/dt </> (4) Block ON
6631	103	DFT1	39	df/dt </> (4) Block OFF
6632	103	DFT1	40	df/dt </> (5) Block ON
6633	103	DFT1	41	df/dt </> (5) Block OFF
6634	103	DFT1	42	df/dt </> (6) Block ON
6635	103	DFT1	43	df/dt </> (6) Block OFF
6636	103	DFT1	44	df/dt </> (7) Block ON
6637	103	DFT1	45	df/dt </> (7) Block OFF
6638	103	DFT1	46	df/dt </> (8) Block ON
6639	103	DFT1	47	df/dt </> (8) Block OFF

In the table below is presented the structure of FSP function register content. This information is available in 12 last recorded events.

Table 3.90 Register content.

Date & Time	Event code	df/dt Pretrig (Hz/s)	f Pretrig (Hz)	df/dt Fault (Hz/s)	f Fault (Hz)	Setting group in use
dd.mm.yyyy hh:mm:ss.mss	6592-6639 Descr.	Start –20ms averages	Start –20ms averages	Fault df/dt	Fault frequency	1-8

3.5 Power protections

3.5.1 Over power P> (32O)

Over power function (OPW) is used for instant- and time delayed active over power protection. In applications like feeder-, generator- and motor protection it is used to detect overload situations by measuring three phase active power.

Outputs of the function are Start Trip and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. Over power function utilizes total of eight separate setting groups which can be selected from one common source.

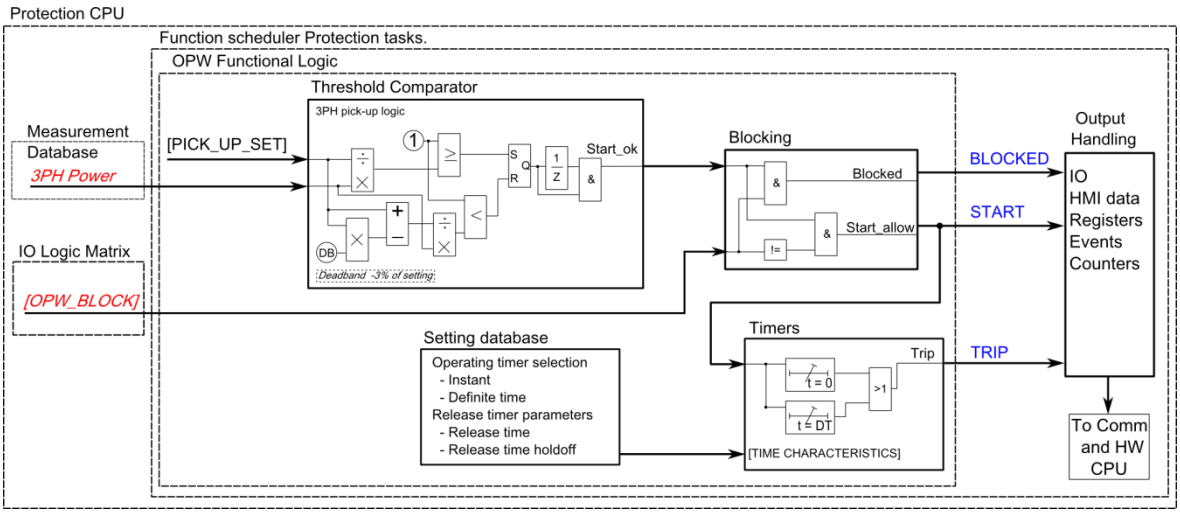
The function can operate on instant or time delayed mode.

The operational logic consists of input magnitude processing, threshold comparator, two block signal check, time delay characteristics and output processing.

Inputs for the function are the operating mode selections, setting parameters and measured and pre-processed power magnitudes and binary input signals. Function outputs START, TRIP and BLOCKED signals which can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the three output signal. In instant operating mode the function outputs START and TRIP events simultaneously with equivalent time stamp. Time stamp resolution is 1ms. Function provides also cumulative counters for START, TRIP and BLOCKED events.

In the following figure is presented the simplified function block diagram of the OPW function.

Figure 3.68 Simplified function block diagram of the OPW function.



Measured input values

Three phase active power value is used for the function block. For pre-fault data registering -20ms averaged value is used. If the protection relay has more than one CT module parameter *Measured side* determines which current measurement is used for the power measurement.

Table 3.91 Measurement magnitudes used by the OPW function.

Signal	Description	Time base
3PH Active power (P)	Total 3 phase active power	5 ms

Pick-up characteristics

Pick-up of the OPW function is controlled by *Pset>* setting parameter, which defines the maximum allowed measured three phase active power before action from the function. The function constantly calculates the ratio in between of the *Pset>* and measured magnitude (Pm). Reset ratio of 97 % is inbuilt in the function and is always related to the *Pset>* value.

Table 3.92 Pick-up characteristics setting

Name	Description	Range	Step	Default
Pset>	Pick-up setting	0.0 ... 100000kW	0.01kW	100kW

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Function blocking

In the blocking element the block signal is checked at the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup voltage values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Operating time characteristics for trip and reset

This function supports definite time delay (DT). For detailed information on this delay type refer to chapter General properties of a protection function.

Events and registers

The OPW function generates events and registers from the status changes of start, trip and blocked. To main event buffer is possible to select status “On” or “Off” messages. The OPW function offers four independent instances which events are segregated for each instance operation.

In the function is available 12 last registers where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values.

Table 3.93 Event codes of the OPW function.

Event Number	Event channel	Event block name	Event Code	Description
6400	100	OPW1	0	Start ON
6401	100	OPW1	1	Start OFF
6402	100	OPW1	2	Trip ON
6403	100	OPW1	3	Trip OFF
6404	100	OPW1	4	Block ON
6405	100	OPW1	5	Block OFF

In the register of the OPW function is recorded start, trip or blocked “On” event process data. In the table below is presented the structure of OPW function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 3.94 Register content.

Date & Time	Event code	Trigger power	Fault power	Prefault power	Trip time remaining	Used SG
dd.mm.yyyy hh:mm:ss.mss	6400-6405 Descr.	Start average power	Trip -20ms averages	Start -200 ms averages	0ms -1800s	1 - 8

3.5.2 Under power P< (32U)

Under power function (UPW) is used for instant- and time delayed active under power protection. Under power function detects loss-of-load conditions when there is no significant loss of current.

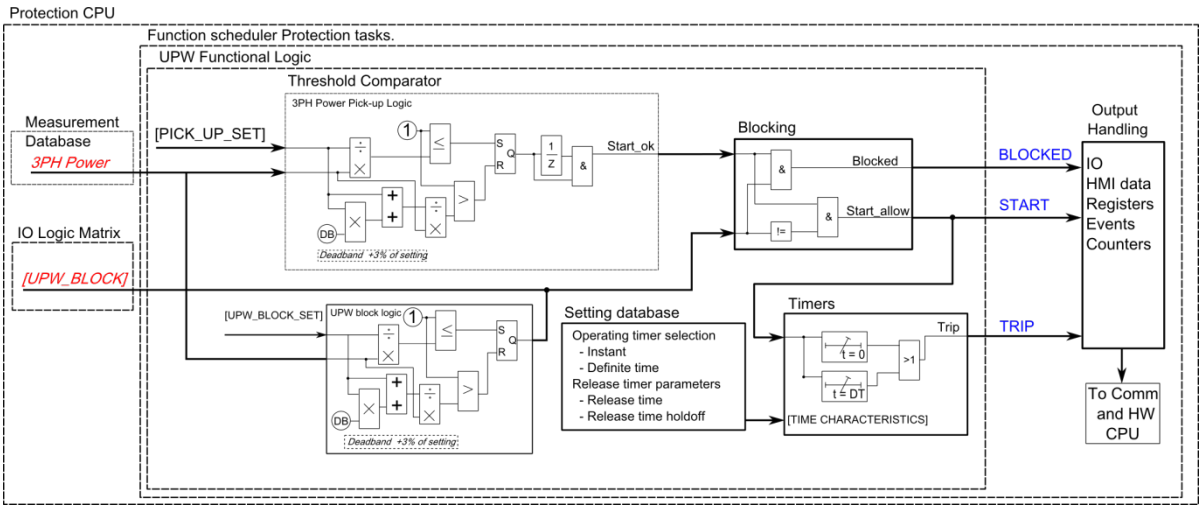
Outputs of the function are Start Trip and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. Under power function utilizes total of eight separate setting groups which can be selected from one common source.

The operational logic consists of input magnitude processing, threshold comparator, two block signal check, time delay characteristics and output processing.

Inputs for the function are the operating mode selections, setting parameters and measured and pre-processed power magnitudes and binary input signals. Function outputs START, TRIP and BLOCKED signals which can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the three output signal. In instant operating mode the function outputs START and TRIP events simultaneously with equivalent time stamp. Time stamp resolution is 1ms. Function provides also cumulative counters for START, TRIP and BLOCKED events.

In the following figure is presented the simplified function block diagram of the UPW function.

Figure 3.69 Simplified function block diagram of the UPW function.



Measured input values

Three phase active power value is used for the function block. For pre-fault data registering -20ms averaged value is used. If the protection relay has more than one CT module parameter Measured side determines which current measurement is used for the power measurement.

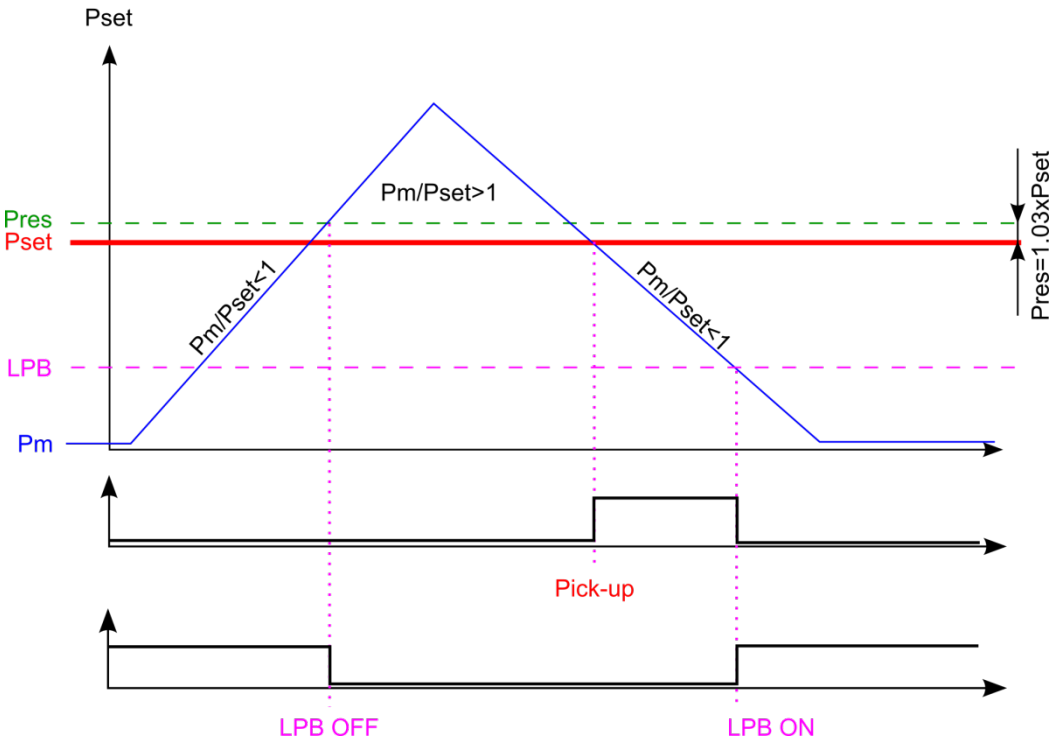
Table 3.95 Measurement magnitudes used by the UPW function.

Signal	Description	Time base
3PH Active power (P)	Total 3 phase active power	5 ms

Pick-up characteristics

Pick-up of the UPW function is controlled by *Pset<* setting parameter, which defines the maximum allowed measured three phase active power before action from the function. The function constantly calculates the ratio in between of the Pset< and measured magnitude (Pm). Reset ratio of 97 % is inbuilt in the function and is always related to the Pset< value.

Figure 3.70 Activation and deactivation characteristics of the Under Power functions Low Power Blocking.



To prevent accidental tripping before active power exceeds under powers pick-up setting, low power block-setting can be used. LPB-signal deactivates when measured active power exceeds pick-up settings reset value (1.03xPset).

Table 3.96 Pick-up characteristics settings

Name	Description	Range	Step	Default
Pset<	Pick-up setting	0.0 ... 100000kW	0.01kW	100kW
Pset<	Low power block	0.0 ... 100000kW	0.01kW	50kW

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Function blocking

In the blocking element the block signal is checked at the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup voltage values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Operating time characteristics for trip and reset

This function supports definite time delay (DT). For detailed information on this delay type refer to chapter General properties of a protection function.

Events and registers

The UPW function generates events and registers from the status changes of start, trip and blocked. To main event buffer is possible to select status “On” or “Off” messages. The UPW function offers four independent instances which events are segregated for each instance operation.

12 last registers are available in the function where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values.

Table 3.97 Event codes of the UPW function.

Event Number	Event channel	Event block name	Event Code	Description
6464	101	UPW1	0	Start ON
6465	101	UPW1	1	Start OFF
6466	101	UPW1	2	Trip ON
6467	101	UPW1	3	Trip OFF
6468	101	UPW1	4	Block ON
6469	101	UPW1	5	Block OFF

In the register of the UPW function is recorded start, trip or blocked “On” event process data. In the table below is presented the structure of UPW function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 3.98 Register content.

Date & Time	Event code	Trigger power	Fault power	Prefault power	Trip time remaining	Used SG
dd.mm.yyyy hh:mm:ss.mss	6464-6469 Descr.	Start average power	Trip -20ms averages	Start -200ms averages	0ms -1800s	1 - 8

3.5.3 Reverse power Pr (32R)

Reverse power function (RPW) is used for instant- and time delayed active reverse power protection. In generator protection applications reverse power protection function is used to prevent damage in situations where synchronous generator is running like a motor when the generator draws active power. Reverse power protection isn’t used to protect the generator itself but to protect the generators turbine.

Outputs of the function are Start Trip and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. Reverse power function utilizes total of eight separate setting groups which can be selected from one common source.

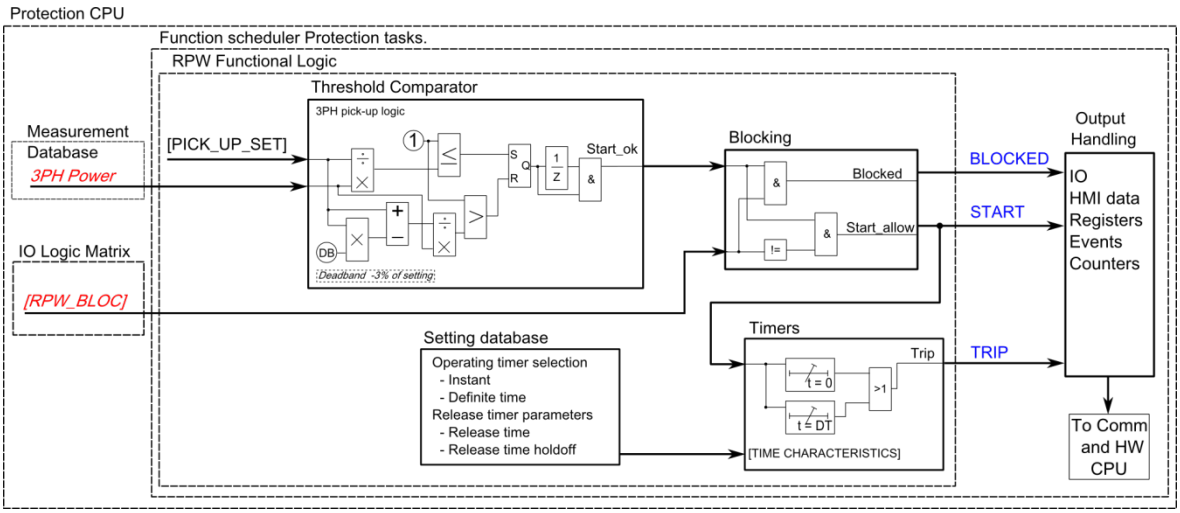
The function can operate on instant or time delayed mode.

The operational logic consists of input magnitude processing, threshold comparator, two block signal check, time delay characteristics and output processing.

Inputs for the function are the operating mode selections, setting parameters and measured and pre-processed power magnitudes and binary input signals. Function outputs START, TRIP and BLOCKED signals which can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the three output signal. In instant operating mode the function outputs START and TRIP events simultaneously with equivalent time stamp. Time stamp resolution is 1ms. Function provides also cumulative counters for START, TRIP and BLOCKED events.

In the following figure is presented the simplified function block diagram of the RPW function.

Figure 3.71 Simplified function block diagram of the RPW function.



Measured input values

Three phase active power value is used for the function block. For pre-fault data registering -20ms averaged value is used. If the protection relay has more than one CT module parameter Measured side determines which current measurement is used for the power measurement.

Table 3.99 Measurement magnitudes used by the RPW function.

Signal	Description	Time base
3PH Active power (P)	Total 3 phase active power	5 ms

Pick-up characteristics

Pick-up of the RPW function is controlled by Pset rev. setting parameter, which defines the maximum allowed measured three phase active power before action from the function. The function constantly calculates the ratio in between of the Pset rev. and measured magnitude (Pm). Reset ratio of 97 % is inbuilt in the function and is always related to the Pset rev. value.

Table 3.100 Pick-up characteristics setting

Name	Description	Range	Step	Default
Pset rev.	Pick-up setting	0.0...100000kW	0.01kW	100kW

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Function blocking

In the blocking element the block signal is checked at the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup voltage values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Operating time characteristics for trip and reset

This function supports definite time delay (DT). For detailed information on this delay type refer to chapter General properties of a protection function.

Events and registers

The RPW function generates events and registers from the status changes of start, trip and blocked. To main event buffer is possible to select status “On” or “Off” messages. The RPW function offers four independent instances which events are segregated for each instance operation.

In the function is available 12 last registers where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values.

Table 3.101 Event codes of the RPW function.

Event Number	Event channel	Event block name	Event Code	Description
6528	102	RPW1	0	Start ON
6529	102	RPW1	1	Start OFF
6530	102	RPW1	2	Trip ON
6531	102	RPW1	3	Trip OFF
6532	102	RPW1	4	Block ON
6533	102	RPW1	5	Block OFF

In the register of the RPW function is recorded start, trip or blocked “On” event process data. In the table below is presented the structure of RPW function register content. This information is available in 12 last recorded events for all provided instances separately.

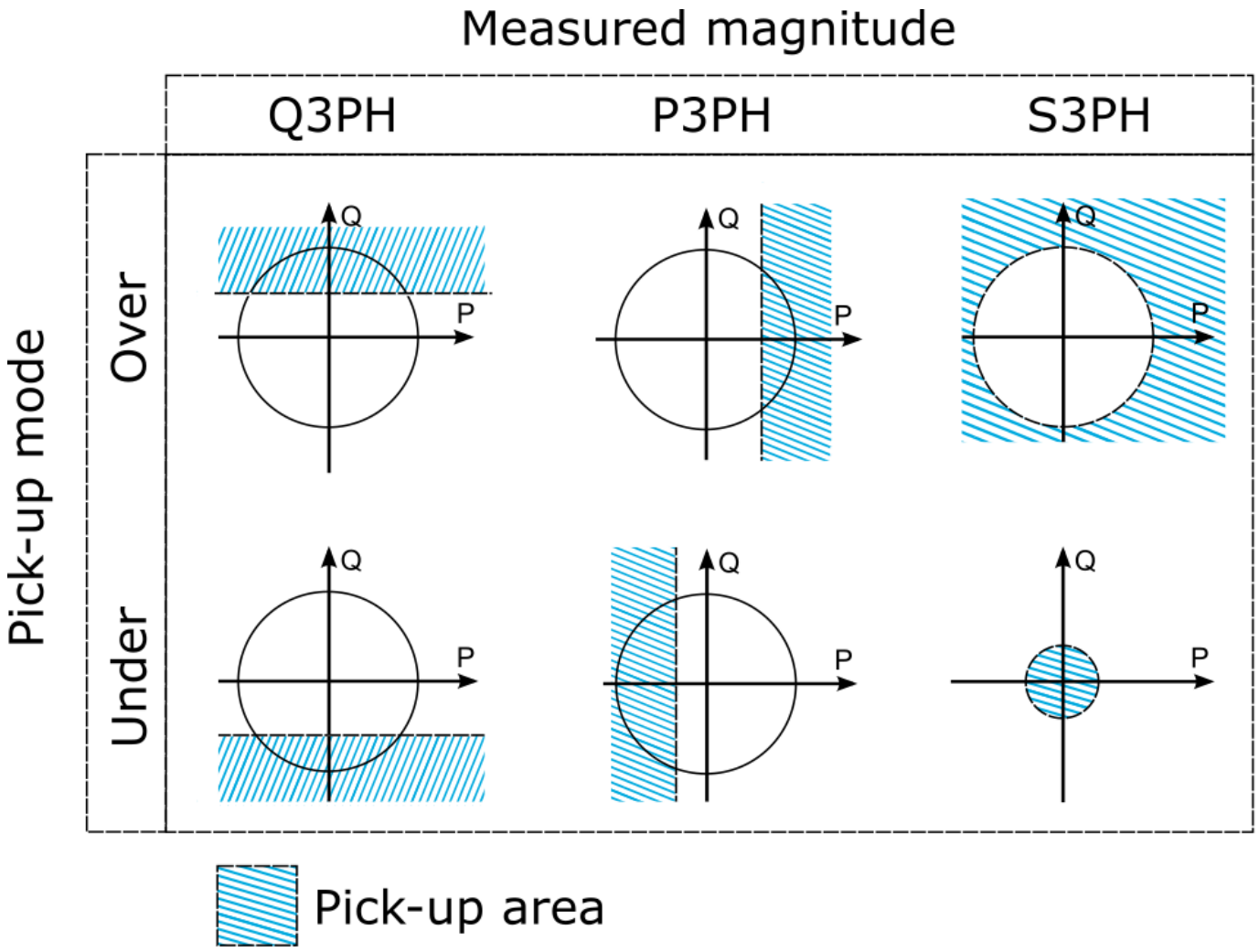
Table 3.102 Register content.

Date & Time	Event code	Trigger power	Fault power	Prefault power	Trip time remaining	Used SG
dd.mm.yyyy hh:mm:ss.mss	6528-6533 Descr.	Start average power	Trip -20ms averages	Start -200ms averages	0ms -1800s	1 - 8

3.5.4 Power protection (32)

PQS power protection function is for instant- and time delayed active, reactive or apparent three phase over or under power protection. Operation mode is selected by user with parameter settings.

Figure 3.72 Pick-up areas of the different modes in PQS power protection function displayed in a PQ diagram.



Outputs of the function are Start Trip and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. PQS power protection function utilizes total of eight separate setting groups which can be selected from one common source.

The function can operate on instant or time delayed mode.

The operational logic consists of input magnitude processing, threshold comparator, two block signal check, time delay characteristics and output processing.

Inputs for the function are the operating mode selections, setting parameters and measured and pre-processed power magnitudes and binary input signals. Function outputs START, TRIP and BLOCKED signals which can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the three output signal. In instant operating mode the function outputs START and TRIP events simultaneously with equivalent time stamp. Time stamp resolution is 1ms. Function provides also cumulative counters for START, TRIP and BLOCKED events.

Measured input values

Function block uses three phase active, reactive or apparent power values. -20ms averaged value is used for pre-fault data registering. Used power measurement value depends on user input. If the protection relay has more than one CT module parameter Measured side determines which current measurement is used for the power measurement.

Table 3.103 Measurement magnitudes used by the PQS function.

Signal	Description	Time base
3PH Active power (P)	Total 3 phase active power	5 ms
3PH Reactive power (Q)	Total 3 phase reactive power	5 ms
3PH Apparent power	Total 3 phase apparent power	5 ms

Pick-up characteristics

Pick-up of the PQS function is controlled by PQS>/< setting parameter, which defines the maximum or minimum allowed measured three phase power (active/reactive/apparent) before action from the function. The function constantly calculates the ratio in between of the PQS>/< and measured power magnitude. Reset ratio of 97% is inbuilt in the function for Over pick-up mode and 103% forUnder pick-up mode and is always related to the pick-up value.

Table 3.104 Pick-up characteristics setting

Name	Description	Range	Step	Default
Pick-up mode	Defines if function will operate in under or over power protection mode	0: > Over 1: < Under	-	0; Over
Pick-up	Pick-up setting. Related to user set nominal power.	-500.000 ... 500.000%	0.005%	0%

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Function blocking

In the blocking element the block signal is checked at the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup voltage values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Operating time characteristics for trip and reset

This function supports definite time delay (DT). For detailed information on this delay type refer to chapter General properties of a protection function.

Events and registers

The PQS function generates events and registers from the status changes of start, trip and blocked. To main event buffer is possible to select status “On” or “Off” messages. The PQS function offers four independent instances which events are segregated for each instance operation.

In the function is available 12 last registers where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values.

Table 3.105 Event codes of the PQS function.

Event Number	Event channel	Event block name	Event Code	Description
6400	100	PQS1	0	Start ON
6401	100	PQS1	1	Start OFF
6402	100	PQS1	2	Trip ON
6403	100	PQS1	3	Trip OFF
6404	100	PQS1	4	Block ON
6405	100	PQS1	5	Block OFF

In the register of the PQS function is recorded start, trip or blocked “On” event process data. In the table below is presented the structure of PQS function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 3.106 Register content.

Date & Time	Event code	Trigger power	Fault power	Prefault power	Trip time remaining	Used SG
dd.mm.yyyy hh:mm:ss.mss	6400-6405 Descr.	Start average power	Trip -20 ms averages	Start -200 ms averages	0ms -1800s	1 - 8

3.6 Feeder protections

3.6.1 Line thermal overload protection TF> (49F)

Line thermal overload function (TOLF) is used for cables and overhead lines thermal capacity monitoring and protection. Also this function can be used for any single time constant application like inductor chokes, certain types of transformers and any other static units which don’t have active cooling in addition to the cables and overhead lines.

TOLF function constantly monitors phase TRMS currents (including harmonics up to 31st) instant values and calculates the set thermal replica status in 5 ms cycles. TOLF function includes total memory function of the load-current conditions according to IEC 60255-8

TOLF function is based on thermal replica, which represents the protected object or cable thermal loading in relation to the current going through the object. Thermal replica includes the calculated thermal capacity used in the “memory” since it is integral function which tells apart this function from normal overcurrent function operating principle for the overload protection applications.

Thermal image for the TOLF function is calculated according to equation described below:

$$\theta_{t\%} = \left(\left(\theta_{t-1} - \left(\frac{I_{MAX}}{I_N \times k_{SF} \times k_{AMB}} \right)^2 \times e^{-\frac{t}{\tau}} \right) + \left(\frac{I_{MAX}}{I_N \times k_{SF} \times k_{AMB}} \right)^2 \right) \times 100\%$$

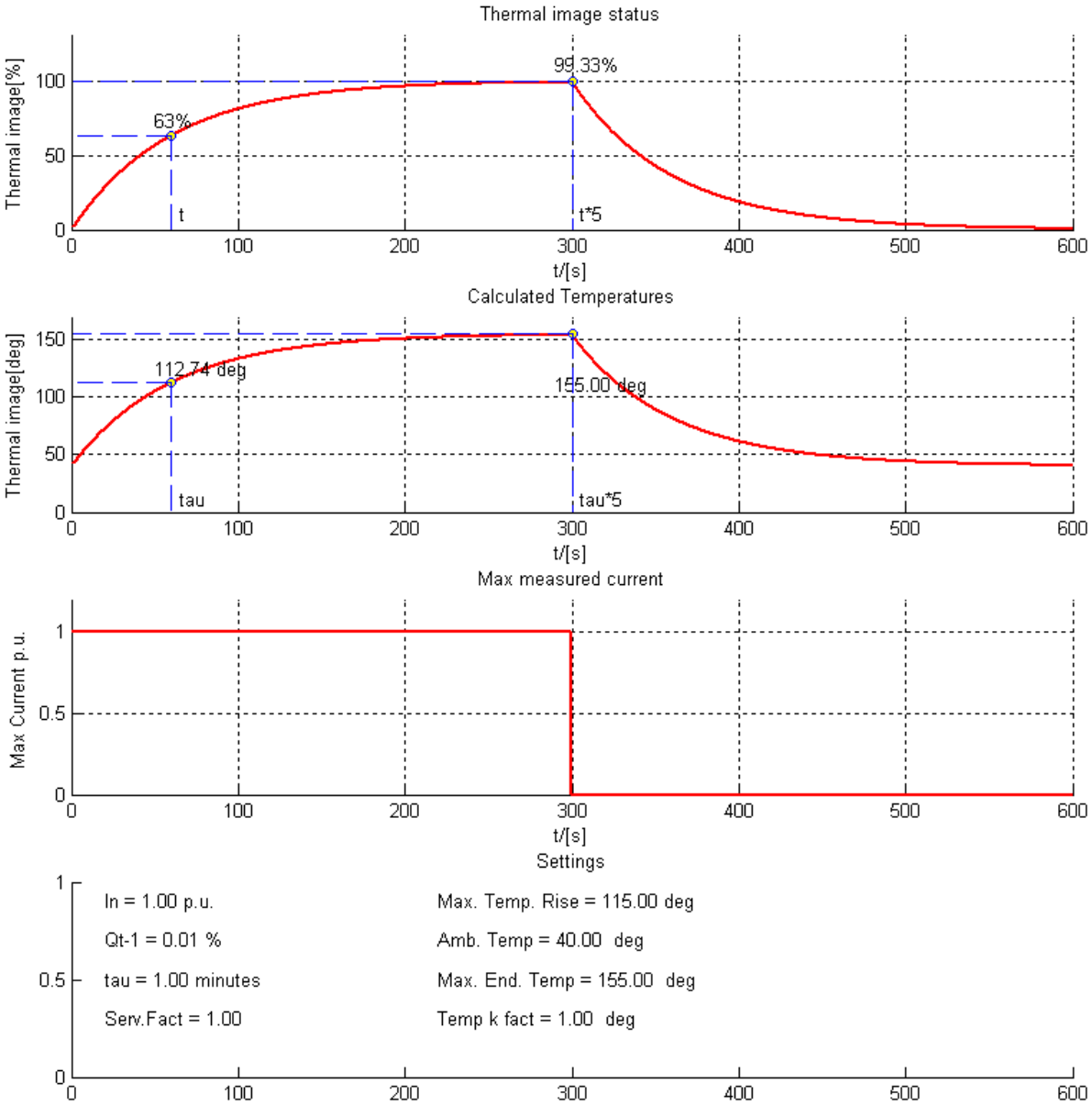
, where

- $q_{t\%}$ = Thermal image status in percent of the maximum thermal capacity available

- q_{t-1} = Thermal image status in previous calculation cycle (the memory of the function)
- I_{MAX} = Measured maximum of the three TRMS phase currents
- I_N = Current for the 100 % thermal capacity to be used (pick-up current in p.u., with this current t_{max} will be achieved in time τ x 5)
- k_{SF} = Loading factor (service factor) coefficient, maximum allowed load current in per unit value depend of the protected object or cable/line installation
- k_{AMB} = Temperature correction factor either from linear approximation or settable 10 point thermal capacity curve.
- τ = Thermal time constant of the protected object (in minutes)
- e = Euler's number
- t = Calculation time step in seconds (0.005s)

The basic operating principle of the thermal replica is based on that the nominal temperature rise is achieved when the protected object is loaded with nominal load in nominal ambient temperature. When the object is loaded with nominal load for time equal its heating constant tau (τ), 63% of the nominal thermal capacity is used. When the loading continues until five times this given constant the used thermal capacity indefinitely approaches to 100% but never exceeds it. With a single time constant model cooling of the object follows this same behavior reversible to the heating when the current feeding is completely zero.

Figure 3.73 Thermal image calculation with nominal conditions, example.



This described behavior is based on that assumption that the monitored object, whether cable, line or electrical device has a homogenous body which is generating and dissipating heat with a rate which is proportional to temperature rise caused by current squared. This usually is the case with cables and objects while overhead lines heat dissipation is dependent of current weather conditions. Weather conditions considering the prevailing conditions in the thermal replica are compensated with ambient temperature coefficient which is constantly calculated and changing when using RTD sensor for the measurement. When the ambient temperature of the protected object is stable it can be set manually (e.g. in case of ground dug cables).

Ambient temperature compensation takes into account the set minimum and maximum temperature and load capacity of the protected object and measured or set ambient temperature. The calculated coefficient is linear correction factor which is presented with following formulas:

$$t_{Amb<t_{min}} = k_{min}$$

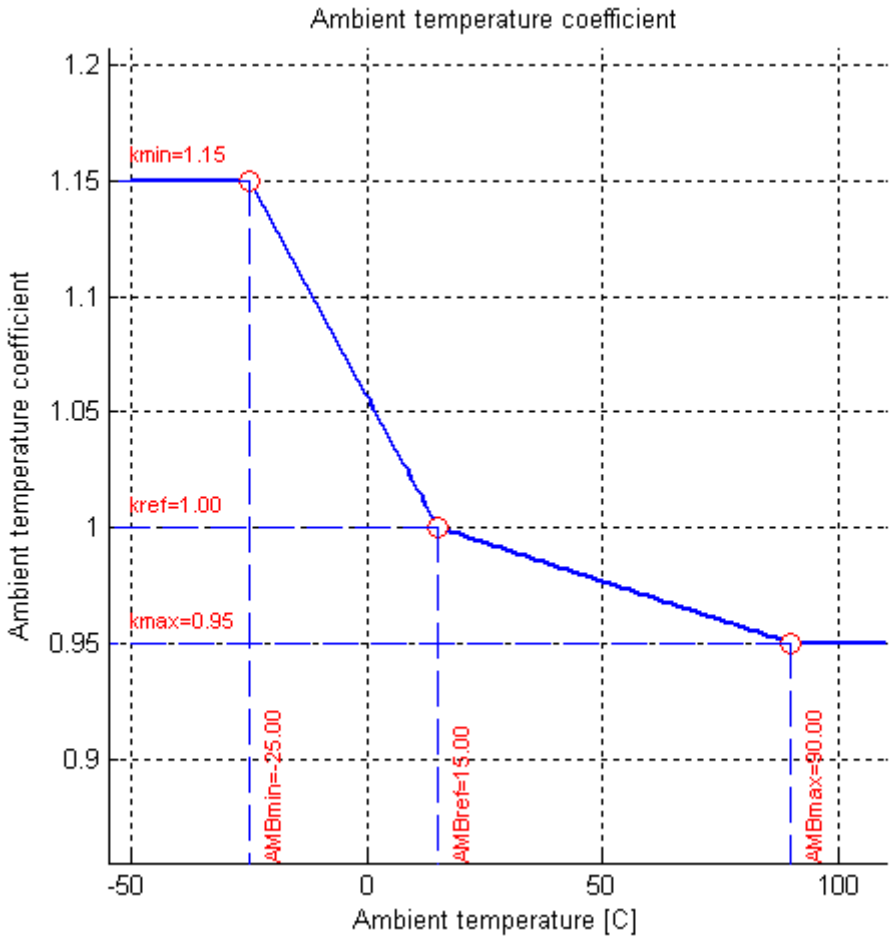
$$t_{Amb<t_{ref}} = \left(\frac{1 - k_{min}}{t_{ref} - t_{min}} \times (t_{AMB} - t_{min})\right) + k_{min}$$

$$t_{Amb>t_{ref}} = \left(\frac{k_{max} - 1}{t_{max} - t_{ref}} \times (t_{AMB} - t_{ref})\right) + 1.0$$

$$t_{Amb>t_{max}} = k_{max}$$

- t_{amb} = Measured (set) ambient temperature (can be set in˚C or˚F)
- t_{max} = Maximum temperature (can be set in˚C or˚F) for the protected object
- k_{max} = Ambient temperature correction factor for the maximum temperature
- t_{min} = Minimum temperature (can be set in˚C or˚F) for the protected object
- k_{min} = Ambient temperature correction factor for the minimum temperature
- t_{ref} = Ambient temperature reference (can be set in˚C or˚F, the temperature in which the given manufacturer presumptions apply and the temperature correction factor is 1.0)

Figure 3.74 Ambient temperature coefficient calculation examples when reference temperature is +15 C with 3 point linear approximation and settable correction curve.



This mentioned ambient temperature coefficient relates to nominal temperature reference. By default is used +15 C (ground dug cables) which gives coefficient value of 1.00 for the thermal replica.

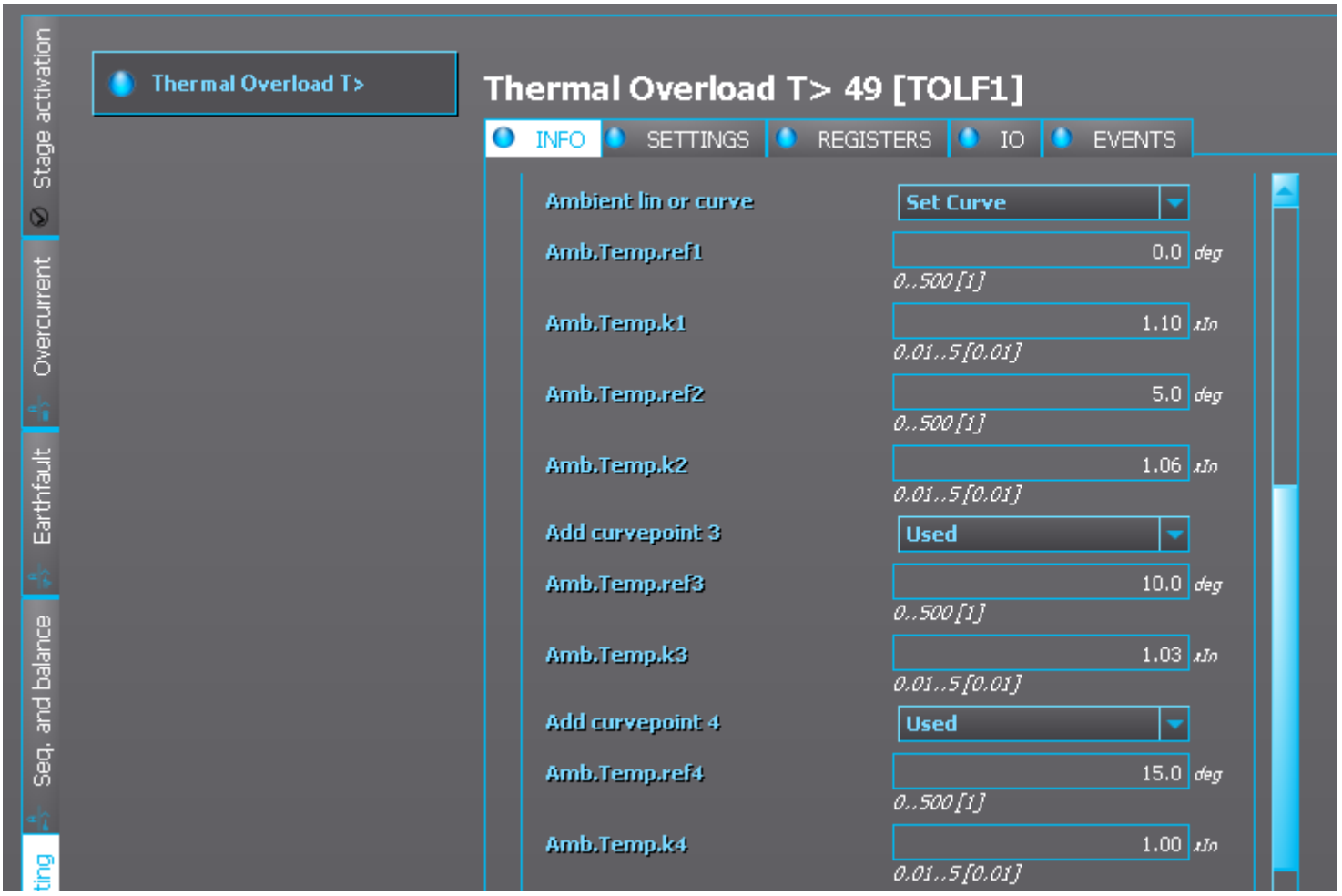
Settable thermal capacity curve uses linear interpolation for ambient temperature correction with maximum 10 pairs of temperature – correction factor pairs.

Figure 3.75 Example of the ground temperature and correction coefficient.

Conductor temperature	Ground temperature, C°										
C°	-5	0	5	10	15	20	25	30	35	40	45
90	1.13	1.10	1.06	1.03	1.00	0.96	0.93	0.89	0.86	0.82	0.77

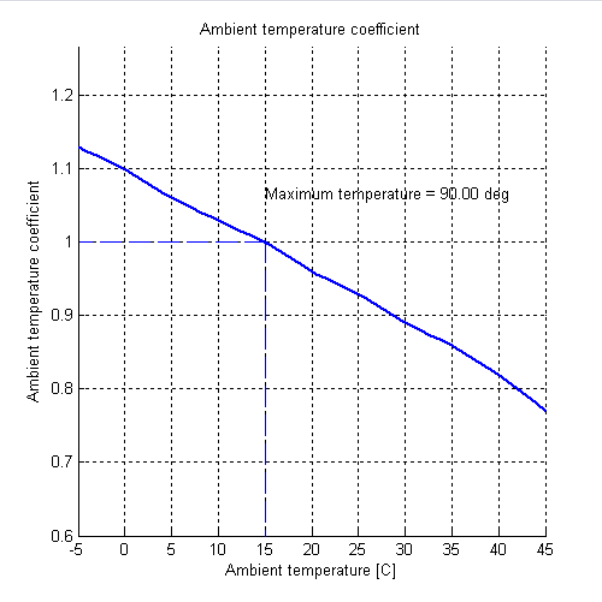
In the manufacturer given data the temperature coefficient may be informed as in figure above.

Figure 3.76 Settings of the TOLF function ambient temperature coefficient curve.



Temperature and coefficient pairs are set to the TOLF function settable curve.

Table 3.107 Set correction curve for ambient temperature.

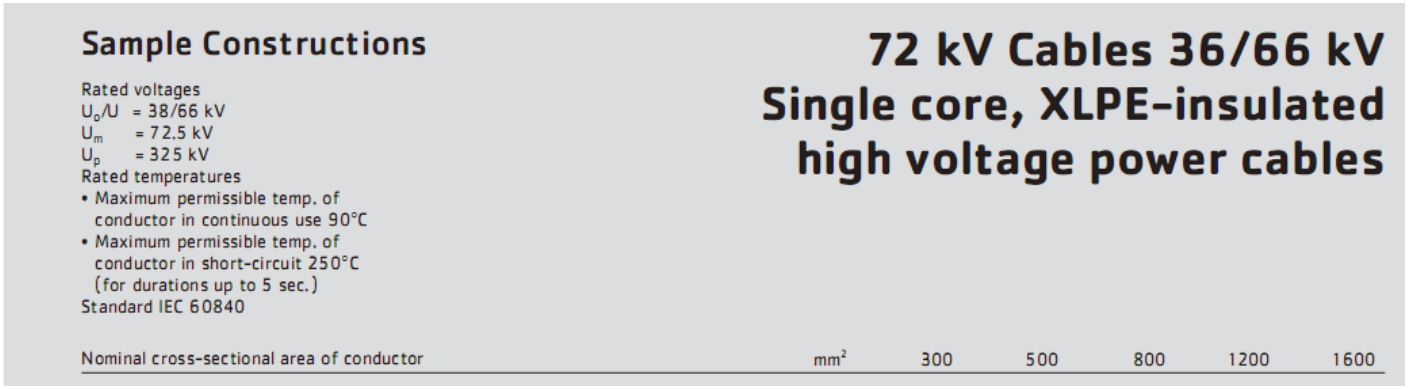


The correction coefficient curve for ambient temperature is shown in the figure.
The reference temperature for ground dug cables usually is 15˚C which gives correction coefficient of 1.00 which can referred as nominal temperature in this case.
The curve does not need to be set as many points as there is available. Minimum setting is two pairs and the result will be straight line.

For the cables this ambient temperature correction is just one correction parameter. For the non-changing corrections are used k_{SF} correction factor which calculation is explained in following part. To calculate the correction factors for the cable or overhead installation, there is need to consult the technical specification for the initial data of the cable used. This information is usually provided by the cable manufacturer.

For cable the initial data may be as follows (example data from Prysmian cables datasheet).

Figure 3.77 Initial data of the cable temperature characteristics and current ratings with different installations and copper or aluminium conductors.



Sample Constructions

Rated voltages
U_o/U = 38/66 kV
U_m = 72.5 kV
U_p = 325 kV
Rated temperatures
- Maximum permissible temp. of conductor in continuous use 90°C
- Maximum permissible temp. of conductor in short-circuit 250°C (for durations up to 5 sec.)

Standard IEC 60840

72 kV Cables 36/66 kV
Single core, XLPE-insulated high voltage power cables

Nominal cross-sectional area of conductor	mm²	300	500	800	1200	1600

Continuous current-carrying capacities

Conductor	Cables laid	Conductor temperature	Laying formation	Screen circuit						
Aluminium	In ground of 15°C	65°C	Flat	Open	A	435	575	750	910	1040
				Closed	A	415	525	640	710	750
			Trefoil	Open	A	415	545	700	830	930
				Closed	A	410	535	680	790	870
		90°C	Flat	Open	A	515	680	890	1080	1235
				Closed	A	490	625	770	860	920
			Trefoil	Open	A	490	645	830	990	1110
				Closed	A	485	635	805	945	1045
	In air of 25°C	90°C	Flat	Open	A	685	930	1265	1555	1815
				Closed	A	660	865	1105	1270	1390
			Trefoil	Open	A	605	820	1095	1335	1535
				Closed	A	600	810	1085	1320	1515
Copper	In ground of 15°C	65°C	Flat	Open	A	560	730	940	1200	1390
				Closed	A	520	635	740	820	855
			Trefoil	Open	A	535	685	860	1095	1240
				Closed	A	525	670	820	1005	1105
		90°C	Flat	Open	A	660	865	1115	1415	1645
				Closed	A	620	765	900	1005	1055
			Trefoil	Open	A	630	815	1025	1305	1485
				Closed	A	620	795	980	1205	1335
	In air of 25°C	90°C	Flat	Open	A	880	1185	1585	2040	2420
				Closed	A	830	1065	1305	1505	1620
			Trefoil	Open	A	775	1035	1355	1765	2065
				Closed	A	770	1025	1340	1685	1940

Maximum permissible short-circuit currents for short-circuit duration of one second

Aluminium conductor	kA	28.3	47.2	75.6	113.4	151.2
Copper conductor	kA	42.8	71.4	114.2	171.4	228.5

Based on the given data can be seen the currents which in given installation and construction methods will achieve the given temperature in given standard conditions.

Cable current and where it is installed are the most important parameters for setting the thermal image to work properly. In addition to this current carrying capacity table also manufacturer should provide additional data for fine tune the thermal image. In addition to the ampere-temperature values equally important information is the continuous current capacity presumptions (e.g. in which conditions the given values apply). In following figure the presumptions are given for example to Prysmian cables.

Figure 3.78 General presumptions of the high voltage cables.

Continuous current-carrying capacity

A separate group of three single core cables can be continuously loaded according to the tables on pages 8 to 14 if the presumptions below are fulfilled. Correction factors for other installations are given in tables 1-7.
The current-carrying capacities are calculated in accordance with the IEC Publication 60287 and under the presumptions given below.

Presumptions

- One three-phase group of single core cables
- Maximum permissible temperature of inner conductor in continuous use:
- XLPE insulated cables 90°C
- Ambient air temperature 25°C
- Ground temperature 15°C
- Depth of laying of cables 1.0 m
- Distance between single core cables:
  - in case of flat formation = one cable diam.
  - in case of trefoil formation = cables touching each other
- Thermal resistivity of soil 1.0 K m/W
- Cable in air = heat dissipation conditions same as if cables in free air.
- Open screen circuit in single core cable group = circuit of metal sheaths, concentric conductors or metallic screens connected to each other and earthed at one point only = screens bonded at a single point. In addition, screen circuit is considered open when cross-bonded at equal interval.
- Closed screen circuit in single core cable group = circuit of metal sheaths, concentric conductors or metallic screens connected to each other at both ends of the group and earthed at least at one end = screens bonded at both ends.

XLPE-insulated cables buried directly in ground

XLPE-insulated cables can continuously be loaded to a conductor temperature of 90°C.
In underground installations, if a cable in the ground is continuously operated at this highest rated conductor temperature, the thermal resistivity of the soil surrounding the cable may in the course of time increase from its original value as a result of the drying-out processes. As a consequence, the conductor temperature may greatly exceed the highest rated value.

Using single-point bonding or cross-bonding instead of both-end bonding results in considerable increase in current carrying capacity.

If the installation conditions vary from the presumption conditions, manufacturers may give additional information of how the current carrying capacity should be corrected in order to match changed conditions.

Figure 3.79 Correction coefficients for the current carrying capacity given by the manufacturer (Prysmian).

Correction factors for the current-carrying capacity

The following tables of correction factors are to be applied to the current-carrying capacity when installation conditions vary from the presumptions above.

The rating for most conditions can be quickly estimated by multiplying the continuous current-carrying capacity value by the correction factors given in the appropriate tables 1-7.

Table 1. Correction factors for groups of cables buried directly in ground

Spacing between groups of cables, mm	Numbers of groups of single core cables beside each other						
	2	3	4	5	6	8	10
0 (touching)	0.79	0.69	0.63	0.58	0.55	0.50	0.46
70	0.85	0.75	0.68	0.64	0.60	0.56	0.53
250	0.87	0.79	0.75	0.72	0.69	0.66	0.64

The values apply to groups of three single core cables (in trefoil or flat formation) without or with spacing between the cable groups horizontally placed.

Table 2. Correction factors for different thermal resistivities of soil

Thermal resistivity of soil Km/W	0.7	1.0	1.2	1.5	2.0	2.5	3.0
Correction factor	1.10	1.00	0.92	0.85	0.75	0.69	0.63

Examples of thermal resistivities of soil:

- dry sand (moisture content 0%) 3.0 K m/W
- dry gravel and clay 1.5 K m/W
- semi-dry gravel and sand (moisture content 10%) 1.2 K m/W
- semi-dry and moist gravel 1.0 K m/W
- moist clay and sand (moisture content 25%) 0.7 K m/W

Table 3. Correction factors for different installation depths in ground

Depth of laying, m	0.50-0.70	0.71-0.90	0.91-1.10	1.11-1.30	1.31-1.50
Rating factor	1.05	1.02	1.00	0.97	0.95

Table 4. Correction factors for different ground temperatures

Conductor temperature	Ground temperature, C°										
C°	-5	0	5	10	15	20	25	30	35	40	45
90	1.13	1.10	1.06	1.03	1.00	0.96	0.93	0.89	0.86	0.82	0.77
80	1.14	1.11	1.07	1.04	1.00	0.96	0.92	0.88	0.83	0.78	0.73
70	1.17	1.13	1.09	1.04	1.00	0.95	0.90	0.85	0.80	0.73	0.67
65	1.18	1.14	1.10	1.05	1.00	0.95	0.89	0.84	0.77	0.71	0.63

Table 5. Correction factors for different cables in unfilled plastic pipes

Spacing between the tubes, mm	Numbers of tubes beside each other							
	1	2	3	4	5	6	8	10
0 (touching)	0.80	0.75	0.65	0.60	0.60	0.55	0.55	0.50
70		0.75	0.70	0.65	0.60	0.60	0.55	0.55
250		0.75	0.70	0.70	0.70	0.65	0.65	0.65

For parallel ducts with a group of three single core cables in each and with the cables equally loaded the current-carrying capacity indicated on pages 8 to 14 for cables buried directly in ground shall be reduced by correction factors given above.

The reduction in current carrying capacity can be avoided if the pipes after cable pulling are filled with material thermally equal to the ambient ground.

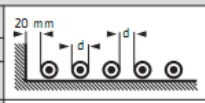
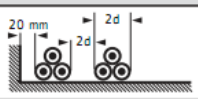
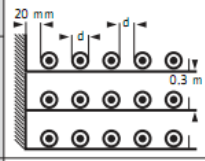
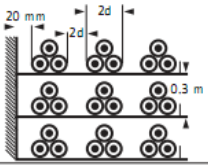
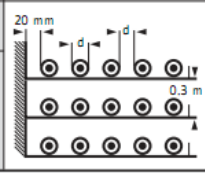
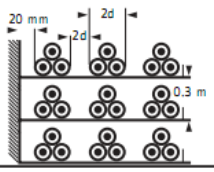
If factors in table 5 are used, factors in table 1 are not applicable.

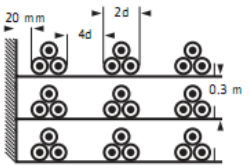
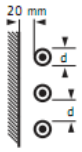
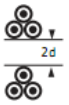
Table 6. Correction factors for different ambient air temperatures

Conductor temperature	Ambient air temperature, C°									
C°	10	15	20	25	30	35	40	45	50	55
90	1.12	1.08	1.04	1.00	0.95	0.90	0.85	0.80	0.74	0.68
80	1.14	1.09	1.05	1.00	0.95	0.89	0.84	0.77	0.69	0.61
70	1.18	1.12	1.06	1.00	0.93	0.86	0.79	0.71	0.62	0.52
65	1.20	1.14	1.07	1.00	0.93	0.85	0.77	0.68	0.57	0.45

Table 7. Correction factors for different groups of three single core cables laid in the air

This applies only when the cable temperature does not affect the ambient air temperature.

Type of laying		Cables laid in flat formation Spacing = One cable diameter (d). Distance from the wall not less than 20 mm.				Cables laid in trefoil formation Spacing = Two cable diameters (2d). Distance from the wall not less than 20 mm.			
Number of groups		1	2	3		1	2	3	
		Correction factor				Correction factor			
On floor		0.92	0.89	0.88		0.95	0.90	0.88	
	Number of trays								
On metal trays (restricted air circulation)	1	0.92	0.89	0.88		0.95	0.90	0.88	
	2	0.87	0.84	0.83		0.90	0.85	0.83	
	3	0.84	0.82	0.81		0.88	0.83	0.81	
	6	0.82	0.80	0.79		0.86	0.81	0.79	
	Number of ladders								
On metal ladders	1	1.00	0.97	0.96		1.00	0.98	0.96	
	2	0.97	0.94	0.93		1.00	0.95	0.93	
	3	0.96	0.93	0.92		1.00	0.94	0.92	
	6	0.94	0.91	0.90		1.00	0.93	0.90	

Arrangements where reduction of current is not necessary	The cooling of cables in flat formation by increased spacing will get better while the losses in metallic screens and sheaths will increase reducing the current-carrying capacity. Each case must be calculated separately.							
Systems placed on top of each other								
	1	2	3		1	2	3	
	Correction factor				Correction factor			
On structures or on wall	0.94	0.91	0.89		0.89	0.86	0.84	

As an example of the k_{SF} (service factor, current carrying capacity) factor importance let's calculate cable installation with correct k factor and without setting it to correct value.

Initial data for the set-up of the thermal image:

500 mm^2 cross sectional 66 kV copper cable is installed into ground. Its 1s permissible short circuit current is 71.4 kA and its insulation is XLPE. The cables screen circuit is open and the laying of the cable is flat. Its current carrying capacity is 575A in 65˚C and 680A in 90˚C. Reference temperature for ground installation is 15˚C.

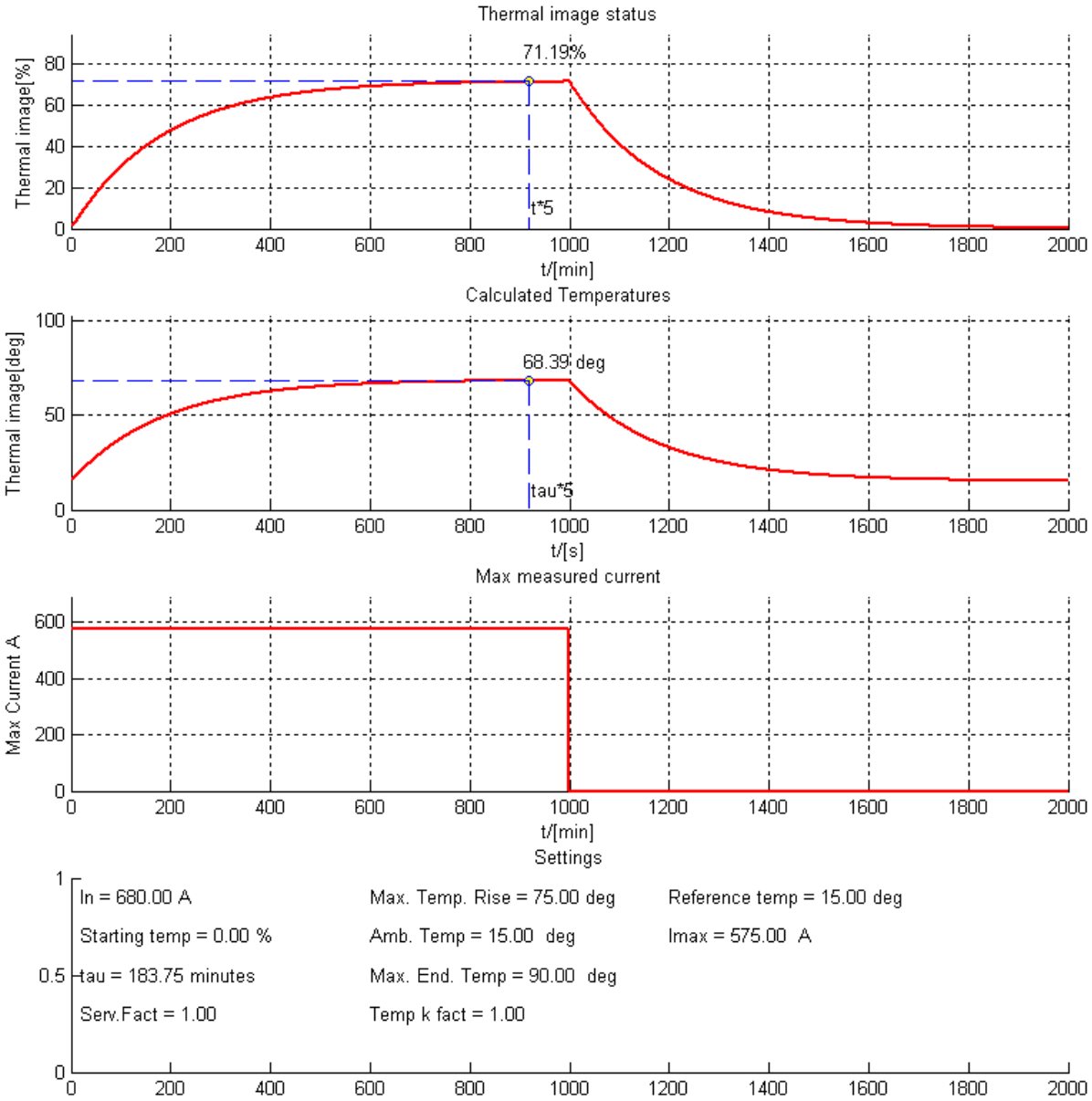
First let's calculate estimate of the time constant t from the known 1s short circuit current related to In. (If manufacturer has not informed the time constant it can be estimated from given short circuit withstandability current, which is usually 1s value). TOLF function uses this same method for estimating the heating time constant.

$$\tau_{Cable} = \frac{1s}{60s} \times \left(\frac{I_{1s}}{I_N}\right)^2 = \frac{1s}{60s} \times \left(\frac{71400A}{680A}\right)^2 = 183.75\,min$$

Rest of the settings are found from the initial data for the cable:

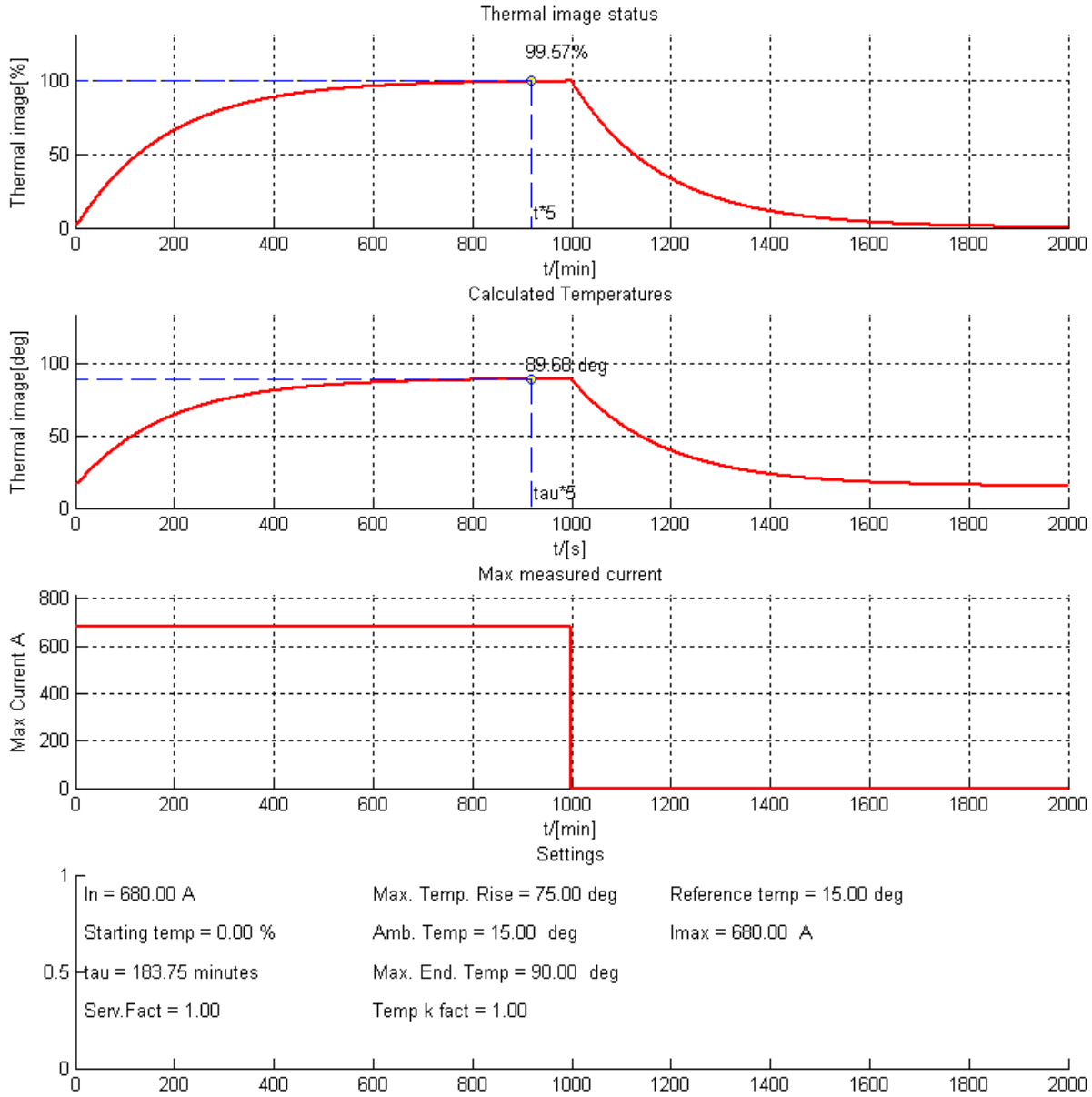
In = 680 A, Tmax = 90˚C, Tamb = 15˚C, Tref = 15˚C and k_{SF} = 1.0

Figure 3.80 Thermal image response with nominal load when the installation is according to the presumptions.



As can be noted from the results, when the cable has been loaded with stable current for time which is five times of the time constant t end temperature of 68.35˚C is reached. This represents 71 % of the thermal capacity used. According to the data sheet with this current temperature should be around 65˚C and can be seen that the model is now 3 degrees overprotecting.

Figure 3.81 Thermal image response with maximum load when the installation is according to the presumptions.



With maximum allowed load the end temperature 89˚C has been reached with thermal capacity 99.6% used. From this result can be noted that the thermal image matches perfectly into the expectations.

Cable alarm from the overheating could be set securely.

When comparing the result to fully tuned model in the application let's include all of the installation correction factors to the image.

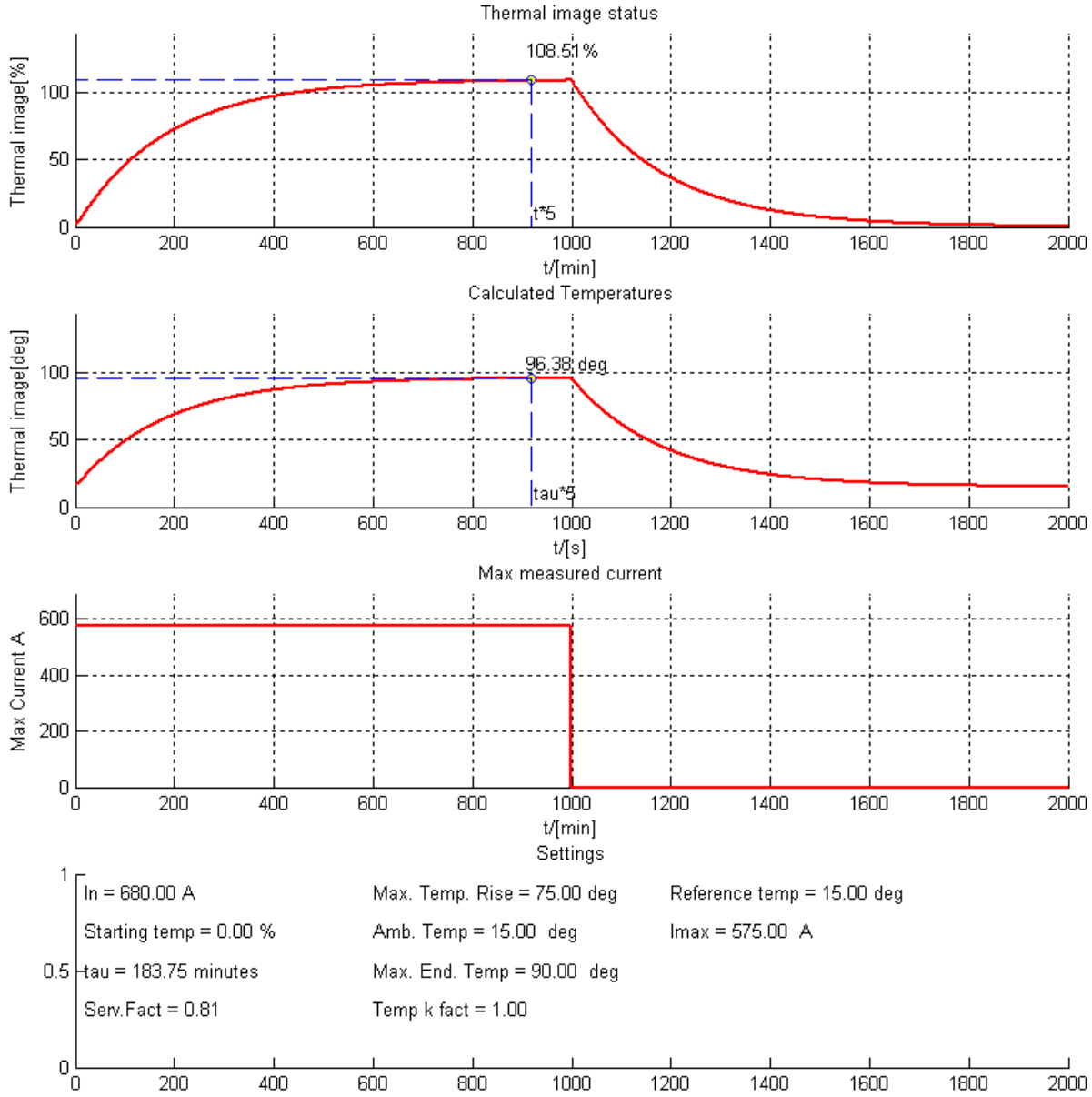
500 mm^2 cross sectional 66 kV copper cable is installed with no adjacent cables (k=1) into dry gravel and clay (k=0.85) ground in depth of 1.5 meter (k=0.95). Cable 1s permissible short circuit current is 71.4 kA and its insulation is XLPE. The cables screen circuit is open and the laying of the cable is flat. Its current carrying capacity is 575A in 65˚C and 680A in 90 ˚C. Reference temperature for ground installation is 15˚C. Cable thermal time constant is 183.8 min.

From these given initial data also the k_{SF} correction factor can be calculated by multiplying them together (k factor related information in red color):

$$k_{SF} = 1 \times 0.85 \times 0.95 = 0.81$$

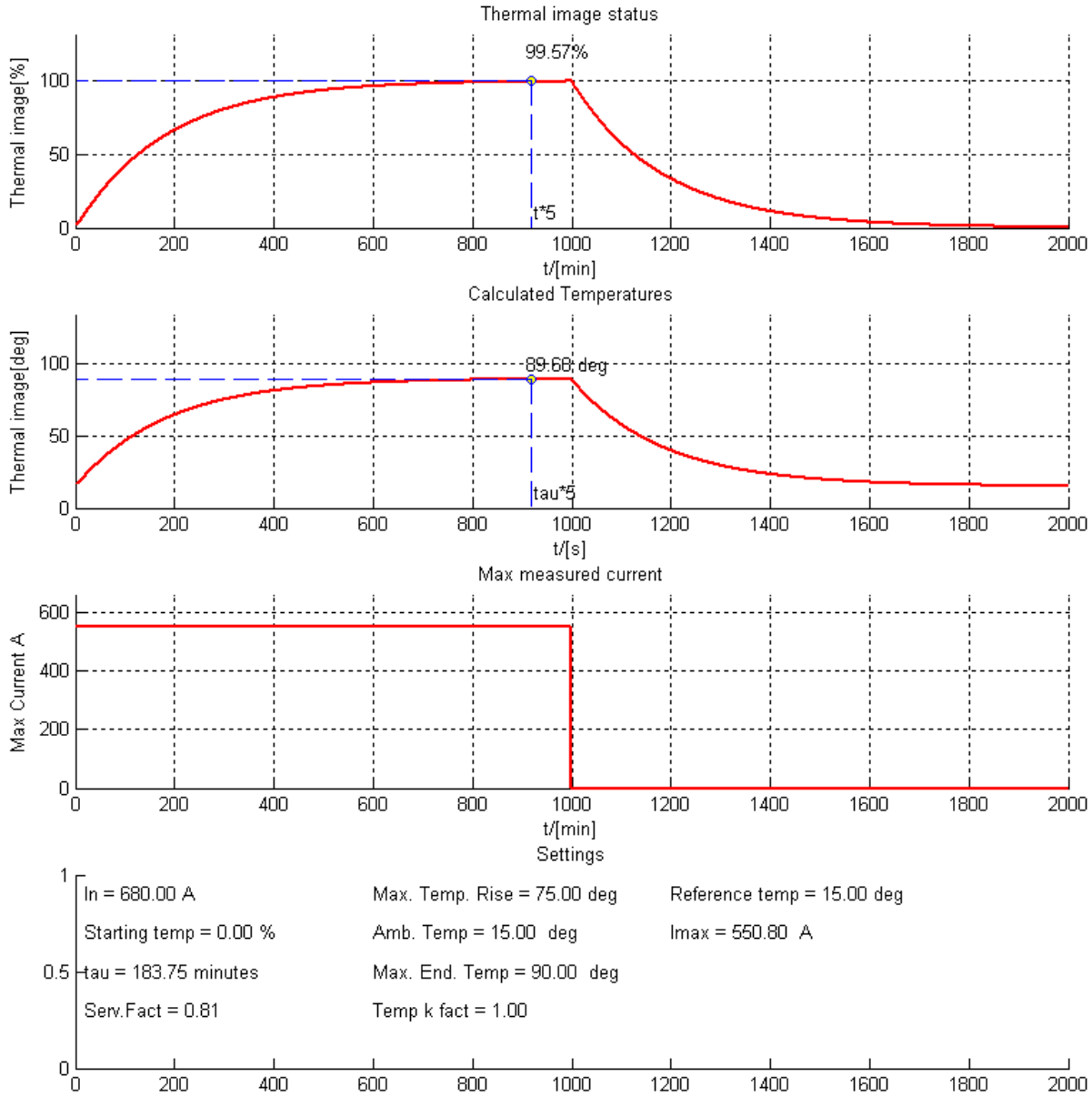
so the settings would be then In = 680 A, Tmax = 90˚C, Tamb = 15˚C, Tref = 15˚C and k_{SF} = 0.81

Figure 3.82 Thermal image response with nominal currents and fine tuned k_{SF} correction factor.



Now when trying to load the cable with the given nominal current can be seen that the actual cable current carrying capacity is much lower than in presumption conditions. Normal loading current can now get the cable too warm and endanger its withstandability. If in this case the k_{SF} factor would not been set the thermal image would show about 68˚C temperature when it in reality would be 96˚C.

Figure 3.83 Thermal response with k_{SF} factor correctly set.



When the installation conditions vary from the presumption conditions like in this example, the current carrying capacity of the cable had been reduced so that 90˚C temperature is achieved already with 550A current instead of the initial data given current of 680A.

Estimating trip time

$$t_{etrip} = ln\left(\frac{{I_{meas}}^2 - \left(k_{fact} \times tamb_{fact} \times \sqrt{\theta_{Calc}} \times I_N\right)^2}{\left({I_{meas}}^2 - {I_N}^2\right)}\right) \times \tau \times 60$$

Calculated effective nominal current:

$I_N = k_{fact} \times tamb_{fact} \times I_{Nom}$, where

- k_{fact} is the service factor
- $tamb_{fact}$ is the ambient temperature factor
- I_{Nom} is the nominal current of the protected device

Calculated end heating:

$\theta_{End} = (I_{meas}/I_N)^2$, where

- I_{meas} is the measured current
- I_N is the previously calculated effective nominal current

Time constant calculation:

$\tau = e^{(-0.005[s] \times (Tc[min] \times 60)[s])}$, where

- e is the Euler's number
- Tc is the user set time constant
- 0.005s is the program cycle time

Active thermal status now is calculated as below:

$\theta_{Calc} = ((\theta_{-1} - \theta_{End}) \times \tau) + \theta_{End}$

- $\theta_{-1}$is previous cycle calculation result (integrating function needs the memory to operate)
- θ_{End} is the calculated end heating (measured current dependent)
- τ is the previously calculated time constant

With this base information the tripping time can be calculated with the formula above (in seconds) when replacing the θ_{Calc} with the value of the thermal level which from the tripping time is wanted to be calculated (in per-unit value).

Thermal overload function IO

Blocking signal and setting group selection controls the operating characteristics of the function during normal operation.

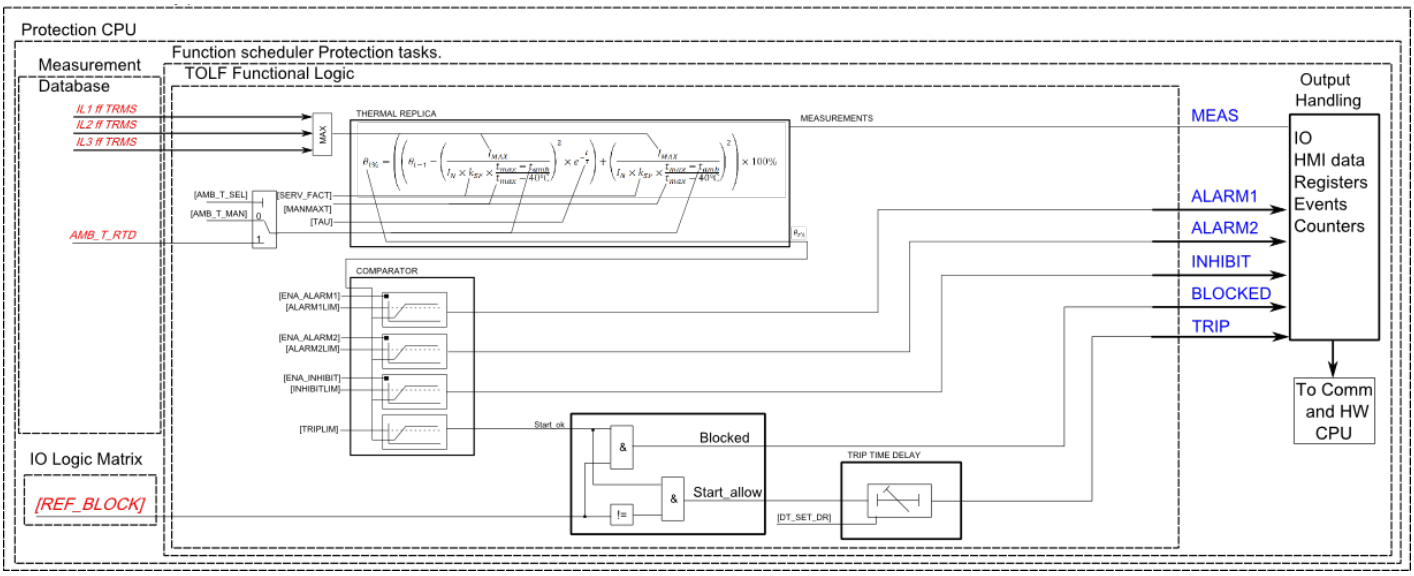
Outputs of the function are TOLF Trip and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. TOLF function utilizes total of eight separate setting groups which can be selected from one common source. Also the operating mode of the TOLF can be changed by setting group selection.

The operational logic consists of input magnitude processing, thermal replica, comparator, block signal check and output processing.

Inputs for the function are setting parameters and measured and pre-processed current magnitudes. Function output signals can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the two output signal. Time stamp resolution is 1ms. Function provides also cumulative counters for TOLF Trip, Alarm 1, Alarm 2, Inhibit and BLOCKED events.

In the following figure is presented the simplified function block diagram of the TOLF function.

Figure 3.84 Simplified function block diagram of the TOLF function.



Measured input value

Function block uses analog current measurement values. Function uses the fundamental frequency magnitude of the current measurement inputs and calculated residual current with residual current measurement. For residual current measurement I01 or I02 can be selected.

Table 3.108 Analogic magnitudes used by the TOLF function.

Signal	Description	Time base
IL1RMS	Fundamental TRMS measurement of phase L1/A current	5 ms
IL2RMS	Fundamental TRMS measurement of phase L2/B current	5 ms
IL3RMS	Fundamental TRMS measurement of phase L3/C current	5 ms
RTD	Temperature measurement for the ambient correction	5 ms

Table 3.109 General settings of the TOLF stage (not SG selectable)

Name	Range	Step	Default	Description
TF> mode	0:Disabled 1:Activated	-	0:Disabled	Selection of the function is activated or disabled in the configuration. Default setting 0:Disabled (Not in use).
Temp C or F deg	0:C 1:F	-	0:C	Selection whether the temperature values of the thermal image and RTD compensation are shown in Celsius or Fahrenheit degrees.

Table 3.110 Thermal replica settings.

Name	Range	Step	Default	Description
IN thermal cap current	0.10... 40.00xIn	0.01xIn	1.00xIn	Current for the 100 % thermal capacity to be used (pick-up current in p.u., with this current t_{max} will be achieved in time t x 5). Default setting is 1.00 xIn.
Set or estimate tau (t const)	0:Set 1:Estimate	-	0:Set	Selection of the timeconstant setting. If selection is “Set” then tau (t const) setting is available and the used time constant can be set there. If the setting is “Estimate”, cable initial data parameters are visible. Default setting is “Set”.

Name	Range	Step	Default	Description
tau (t const)	0.1... 500.0min	0.1min	10.0min	Time constant setting. This time constant is used for heating and cooling of the protected object. Setting is visible if Set or estimate tau setting is selected to “Set”.
Max.Perm.OC.Current(norm ik1s)	1...1000000A	1A	75000A	Maximum rated short circuit current of the protected object (cable). Usually this value is presented as 1 second value. Setting is visible if Set or estimate tau setting is selected to “Estimate”.
Max. OC. time (norm 1s)	0.1...5s	0.1s	1.0s	Time of the maximum rated short circuit current (usually 1 second) of the protected object. Setting is visible if Set or estimate tau setting is selected to “Estimate”.
Rated nominal current	1...1000000A	1A	700A	Rated nominal current in primary value of the protected object in nominal rated conditions. Setting is visible if Set or estimate tau setting is selected to “Estimate”.
Estimated tau	0...1800min	0.005min	191.3min (from defaults)	Estimation result which is used for thermal replica time constant. After the previous three required parameters are set the IED will calculate this value. This value is visible if Set or estimate tau setting is selected to “Estimate”.
kSF (service factor)	0.01...5.00	0.01	1.00	Service factor which corrects the maximum allowed current value according to installation etc. conditions which vary from the presumption conditions.
Cold Reset default theta	0.0...150.0%	0.1%	60.0%	Thermal image status in the restart of the function / IED in percentage of used thermal capacity of the protected object. Default setting is 60% of thermal capacity used. Also, possible to fully reset thermal element. This parameter can be used when testing the function to manually set the current thermal cap to any value.

Table 3.111 Environmental settings

Name	Range	Step	Default	Description
Object max temp (tmax = 100%)	0...500deg	1deg	90deg	Maximum allowed temperature for the protected object. Default setting is +90 degrees and it suits for Celsius range and for PEX insulated cables
Ambient temp sel	0:Manual set 1:RTD	-	0:Manual set	Selection whether fixed or measured ambient temperature should be used for the thermal image biasing.
Man.Amb.Temp.Set	0...500deg	1deg	15deg	Manual fixed ambient temperature setting for the thermal image biasing. For underground cables commonly is used 15 degrees Celsius. Setting is visible if Ambient temp sel is set to “Manual set”.
RTD Amb.Temp.Read	0...500deg	1deg	15deg	RTD ambient temperature reading for the thermal image biasing. Setting is visible if Ambient temp sel is set to “RTD”.
Ambient lin. or curve	0:Linear est. 1:Set curve	-	0:Linear est	Selection of ambient temperature correction either by internally calculated compensation based on end temperatures or user settable curve. Default setting is

Name	Range	Step	Default	Description
				0:Linear corr, which means internally calculated correction for ambient temperature.
Temp.reference (tref) k_{amb}=1.0	-60...500deg	1deg	15deg	Temperature reference setting. In this temperature manufacturer presumptions apply and the thermal correction factor is 1.00 (rated temperature). For ground dug cables this is usually 15˚C and in air 25˚C. Setting is visible if Ambient lin. or curve is set to “Linear est.”
Max ambient temp	0...500deg	1deg	45deg	Maximum ambient temperature setting. If measured temperature is more than maximum set temperature the set correction factor for maximum temperature shall be used. Setting is visible if Ambient lin. or curve is set to “Linear est.”
k at max amb temp	0.01...5.00xIn	0.01xIn	1.00xIn	Temperature correction factor for maximum ambient temperature setting. Setting is visible if Ambient lin. or curve is set to “Linear est.”
Min ambient temp	-60...500deg	1deg	0deg	Minimum ambient temperature setting. If measured temperature is less than minimum set temperature the set correction factor for minimum temperature shall be used. Setting is visible if Ambient lin. or curve is set to “Linear est.”
k at min amb temp	0.01...5.00xIn	0.01xIn	1.00xIn	Temperature correction factor for minimum ambient temperature setting. Setting is visible if Ambient lin. or curve is set to “Linear est.”
Amb.Temp.ref1...10	-50.0... 500.0deg	0.1deg	15deg	Temperature reference points for the user settable ambient temperature coefficient curve. Setting is visible if Ambient lin. or curve is set to “Set curve”.
Amb.Temp.k1...k10	0.01...5.00	1.00	0.01	Coefficient value for the temperature reference point. Coefficient and temperature reference points must be set as pairs. Setting is visible if Ambient lin. or curve is set to “Set curve”.
Add curvepoint 3...10	0:Not used 1:Used	-	0:Not used	Selection whether the curve temperature / coefficient pair is in use. Minimum amount is two pairs to be set for the temperature / coefficient curve and maximum is ten pairs. If measured temperature is less than set minimum temperature reference or more than maximum set temperature reference the used temperature coefficient shall be the first or last value in the set curve. Setting is visible if Ambient lin. or curve is set to “Set curve”.

Operation characteristics

The operating characteristic of the TOLF function is completely controlled by the thermal image. From the thermal image calculated thermal capacity used value can be set IO controls with Alarm 1, Alarm 2, Inhibit and Trip signals.

Table 3.112 Pick-up characteristics setting (SG selectable)

Name	Range	Step	Default	Description
Enable TF> Alarm 1	0:Disabled 1:Enabled	-	0:Disabled	Enabling / Disabling of the Alarm 1 signal and IO
TF> Alarm 1 level	0.0...150.0%	0.1%	40%	Alarm 1 activation threshold. Default setting is 40%.
Enable TF> Alarm 2	0:Disabled 1:Enabled	-	0:Disabled	Enabling / Disabling of the Alarm 2 signal and IO

Name	Range	Step	Default	Description
TF> Alarm 2 level	0.0...150.0%	0.1%	40%	Alarm 2 activation threshold. Default setting is 40%.
Enable TF> Rest Inhibit	0:Disabled 1:Enabled	-	0:Disabled	Enabling / Disabling of the Inhibit signal and IO
TF> Inhibit level	0.0...150.0%	0.1%	80%	Inhibit activation threshold. Default setting is 80%.
Enable TF> Trip	0:Disabled 1:Enabled	-	0:Disabled	Enabling / Disabling of the Inhibit signal and IO
TF> Trip level	0.0...150.0%	0.1%	100%	Inhibit activation threshold. Default setting is 80%.
TF> Trip delay	0.000...3600.000s	0.005s	0.000s	Trip signal additional delay. This delay will prolong the trip signal generation for the set time. Default setting is 0.000s which will not give added time delay for the trip signal.

The pick-up activation of the IO is direct for all other signals except TRIP signal which has also blocking check before the trip signal is generated.

Function blocking

In the blocking element the block signal is checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a Trip signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If Trip function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup current values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Measurements and indications of the function

TOLF function outputs measured process data from following magnitudes:

Table 3.113 General status codes

Name	Range	Description
TF> Condition	0:Normal 1:Alarm1 On 2:Alarm2 On 3:Inhibit On 4:Trip On 5:Blocked	TOLF function operating condition at the moment considering binary IO signal status. When the status is “Normal” no outputs are controlled.
Thermal status	0:Light / No load 1:High overload 2:Overloading 3:Load normal	TOLF function thermal image status. When the measured current is below 1 % of nominal status “Light / No load” will be shown, when the measured current is below trip limit status “Load normal” will be shown, when the measured current is over pick-up limit but under 2 xIn status “Overloading” will be shown and when measured current is over 2 xIn status “High overload” will be shown.

Table 3.114 Measurements

Name	Range	Description / values
Currents	0:Primary A 1:Secondary A 2:Per unit	Active phase current measurement from IL1(A), IL2(B) and IL3(C) phases in given scalings.
Thermal Image	0:Thermal image calc.	- TF> Trip expect mode: No trip expected / Trip expected - TF> time to 100% theta: Time to reach 100% thermal cap - TF> reference T curr.: Reference / pick-up value (IEQ) - TF> Active meas curr.: Measured max TRMS current at the moment - TF> T est.with act curr.: Estimate of used thermal capacity with current at the moment - TF> T at the moment: Thermal capacity used at the moment
	1:Temp estimates	- TF> Used k for amb.temp: Ambient correction factor at the moment - TF> Max.Temp.Rise All: Maximum temperature rise allowed - TF> Temp.Rise atm: Calculated temperature rise at the moment - TF> Hot Spot estimate: Estimated hot spot temperature including the ambient temperature - TF> Hot Spot Max. All: Maximum allowed temperature for the object
	2:Timing status	- TF> Trip delay remaining: Time to reach 100% theta - TF> Trip time to rel.: Time to theta to reach under trip limit when cooling - TF> Alarm 1 time to rel.: Time to theta to reach under Alarm 1 limit when cooling - TF> Alarm 2 time to rel.: Time to theta to reach under Alarm 2 limit when cooling - TF> Inhibit time to rel.: Time to theta to reach under Inhibit limit when cooling

Table 3.115 Counters

Name	Description / values
Alarm1 inits	Times the TOLF function has activated the Alarm 1 output
Alarm2 inits	Times the TOLF function has activated the Alarm 2 output
Restart inhibits	Times the TOLF function has activated the Restart inhibit output
Trips	Times the TOLF function has tripped
Trips Blocked	Times the TOLF function trips has been blocked

Events and registers

The TOLF function generates events and registers from the status changes of the Trip activated and blocked signals. To main event buffer is possible to select status “On” or “Off” messages.

In the function is available 12 last registers where the triggering event of the function (Trip activated or blocked) is recorded with time stamp and process data values.

Table 3.116 Event codes of the TOLF function instance

Event Number	Event channel	Event block name	Event Code	Description
4288	67	TOLF1	0	Alarm1 On
4289	67	TOLF1	1	Alarm1 Off
4290	67	TOLF1	2	Alarm2 On
4291	67	TOLF1	3	Alarm2 Off
4292	67	TOLF1	4	Inhibit On
4293	67	TOLF1	5	Inhibit Off
4294	67	TOLF1	6	Trip On

Event Number	Event channel	Event block name	Event Code	Description
4295	67	TOLF1	7	Trip Off
4296	67	TOLF1	8	Block On
4297	67	TOLF1	9	Block Off

In the register of the TOLF function is recorded activated, blocked etc. “On” event process data. In the table below is presented the structure of TOLF function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 3.117 Register content

Date & Time	Event code	Time to reach 100% theta	Ref. T current	Active meas current	T at the moment
dd.mm.yyyy hh:mm:ss.mss	4288- 4297 Descr.	seconds	xIn	xIn	%
Max temp rise allowed	Temp rise at the moment	Hot Spot estimate	Hot spot max all.	Trip delay rem	Used SG
deg	deg	deg	deg	s	1 - 8

3.6.2 Intermittent earth fault I0Int> (67NT)

Intermittent earth fault is a transient type of single phase to ground fault where the actual fault phenomenon lasts about few hundred microseconds. Intermittent earth fault is commonly seen in Petersen coil grounded (compensated) medium voltage networks. Intermittent earth fault is commonly thought as only cable network problem but it can occur in overhead line networks as well. The key point for this type of fault appearance is the compensation of earth fault currents with Petersen coil.

This phenomenon is coming more frequent as utilities are changing the overhead lines to ground dug cables. Ground dug cables are more reliable than overhead lines considering the possible seasonal storm damages thus this type of distribution network development is very understandable. Maintenance costs and power down time of ground dug cable network per yearly bases is significantly less than with overhead line networks. The problem comes from that the increasing amount of cabling in the network causes dramatic increasing of the capacitive earth fault currents in the distribution networks. When the capacitive earth fault current in the network increases, distinguishing of the earth fault current with Petersen coil comes in to the picture.

Problems caused by intermittent earth fault are normally seen in compensated network substations where during the fault possibly many feeders are tripped simultaneously by earth fault or whole substation is tripped by residual voltage back-up protection from the incomer. This is typical behavior in old-fashioned relay protection which is not capable to differentiate in between of normal consistent earth fault and intermittent earth fault. Since the intermittent earth fault is transient type of fault where the actual fault is only few hundred microseconds causes the traditional directional earth fault protection relays to lose the directional sensitivity. When the directional decision algorithms of traditional relays try to cope with intermittent signals the trip decision result will be totally up to luck. Typical finding from this type of complete black out substation includes from all protection relays logs found multiple directional earth fault starts and releases and finally the incomer relay residual voltage trip. This is the worst case scenario. On the other typical scenario few feeders have tripped in the same fault including, by luck the correct faulty feeder. In this later case also in all of the relays logs can be seen the incorrectly started directional earth fault events and releases.

Previously this kind of behavior was commonly ignored and put to mystery category since it might have happened just once or twice per year and also disturbance recordings were not commonly used in normal medium voltage substations for verification of the fault. When disturbance recorders were introduced as common feature of the protection relay this phenomena got name and characteristics. Its unique characteristics require completely different tools for handling than the traditional directional earth fault protection is capable of handling.

Typical characteristics of intermittent earth fault include high magnitude current spikes which compared to residual voltage are in opposite direction of the current spike in the faulted feeder and same direction in non faulted feeder. Following figures present few intermittent earth fault situations seen by the relays in substation.

Figure 3.85 Close to resonance tuned medium size network intermittent earth fault seen by faulty feeder relay.

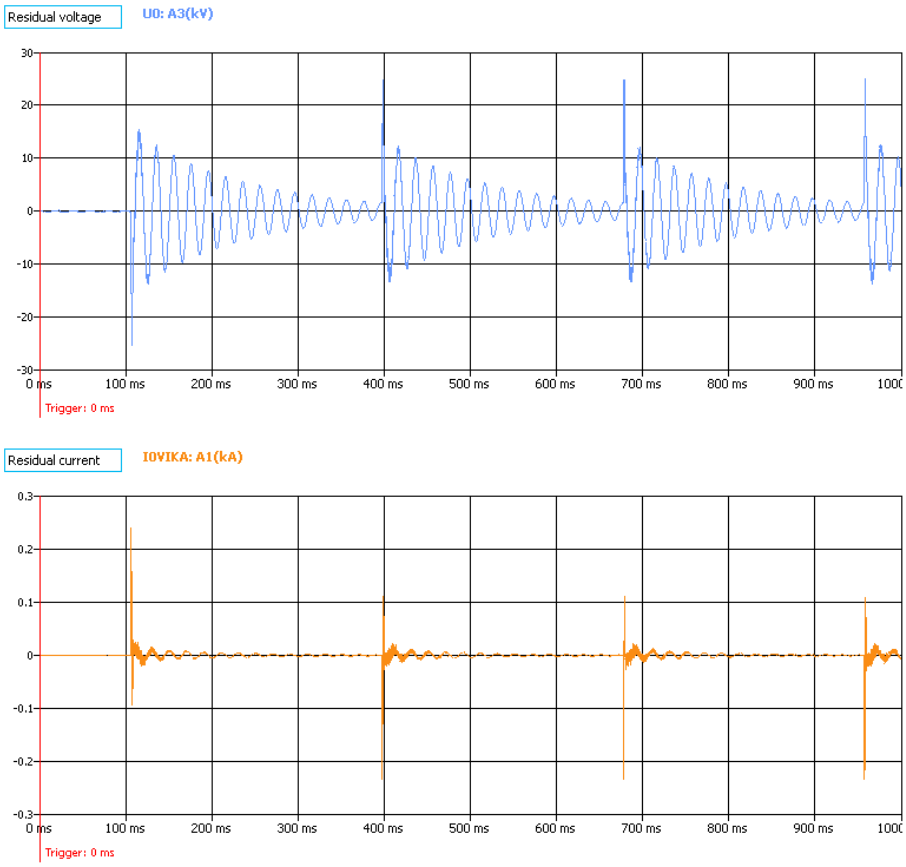


Figure 3.86 Close to resonance tuned network intermittent earth fault seen by healthy feeder relay.

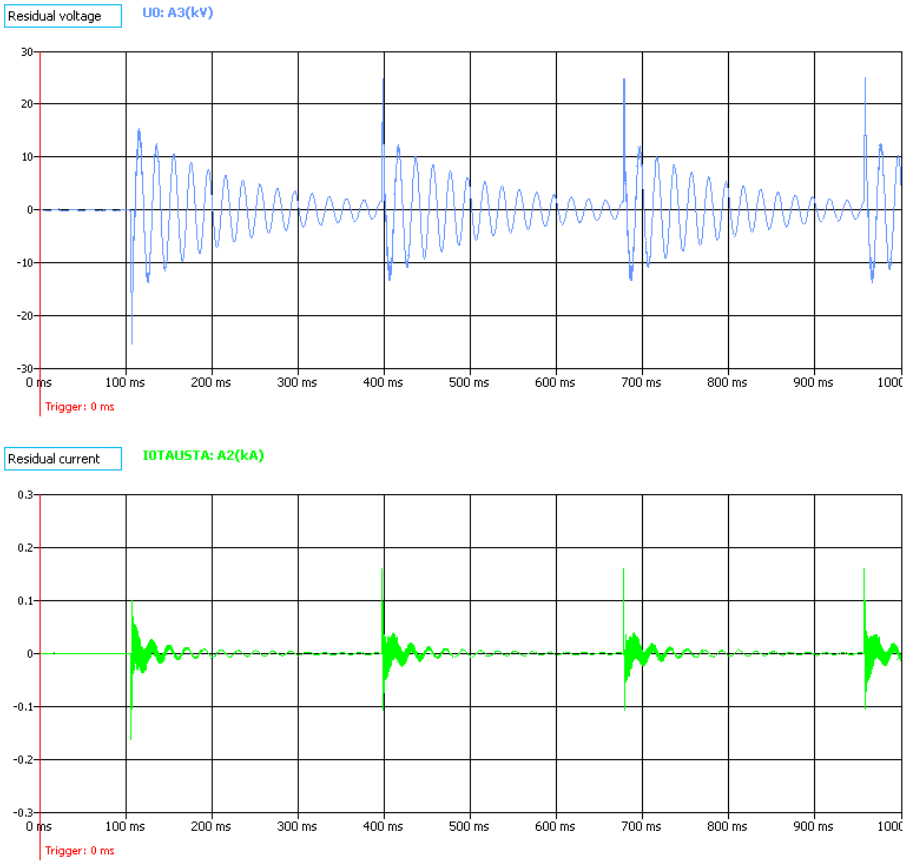


Figure 3.87 Undercompensated medium size network intermittent earth fault seen by faulty feeder relay.

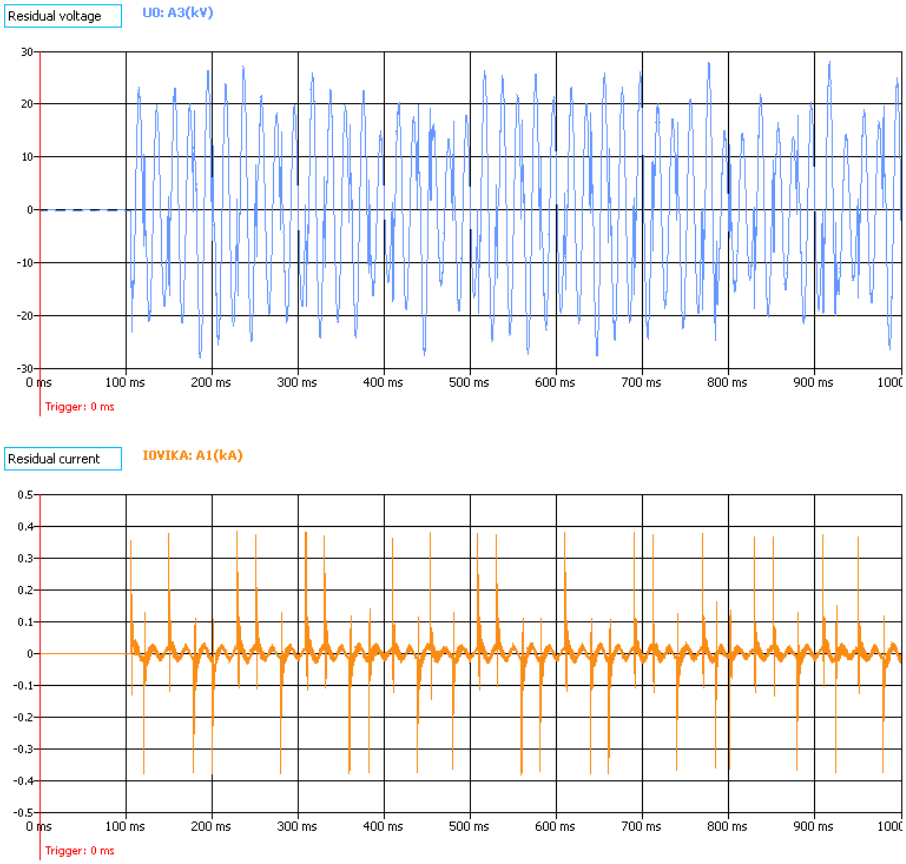
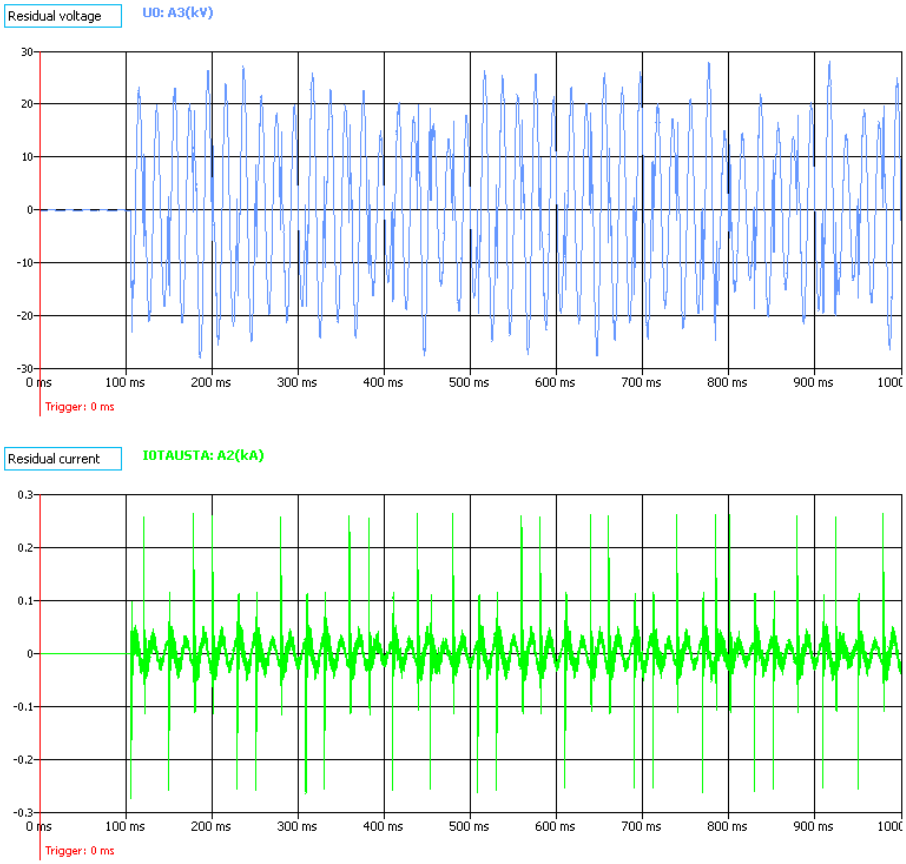


Figure 3.88 Undercompensated medium size network intermittent earth fault seen by healthy feeder relay.



As can be seen from the figures the residual voltage in both cases is high. When considering the normal directional earth fault protection in the close to resonance case most probably directional earth fault may not even pick-up and if it picks up it will surely release before set operating time. Residual voltage still stays on for longer period and most probably in this case it will also release before the set tripping time. This situation may last for long time and cause stress to the network unnecessarily and if let to last long may cause insulator breakdown in other parts of the network.

In the under- / overcompensated network case the residual voltage stays on almost maximum level all the time. In addition to that the current flashover spikes are seen constantly in every power cycle. In this case normal FFT based directional earth fault protection algorithms lose the direction sensing due to FFT processed input signal expects power cycle long stabile data for accurate directional output. In this case the zero crossings during the power cycle are multiple so FFT result may be anything in between of 0 – 180 degrees. When analyzing the situation on the normal directional earth fault protection point of view the result may be no trip at all or trip to non faulted feeder in addition to faulted feeder expected trip. All these three scenarios are equally probable.

Intermittent algorithm description

Patent pending. Further information by request.

Setting principles

The intermittent earth fault protection shall be coordinated with bus bar residual voltage protection in such a way that in case of intermittent earth fault the faulty feeder will be in all cases tripped by intermittent earth-fault protection function prior to residual voltage protection function considering a sufficient safety margin as well. On the other hand, since an intermittent earth fault causes significant network stress the protection trip should be performed as fast as possible.

The strike through time of an intermittent earth fault in a close to resonance tuned network sets the limit for the minimum operate time of an intermittent earth fault protection stage. To ensure a correct protection operation in all cases, the reset time of intermittent earth fault stage shall be set according to the network in question, to such a level that ensures that fault has disappeared and no new strike through is expected after set reset time.

The size of the network is a dominant factor in defining the strike through time interval. In larger network in amperes a less frequent strike troughs can be expected. The following can be presented as a rule of a thumb: in a small / medium size networks (<60A) approximately. 250 - 350ms strike through interval and in a large network (~100A) approximately. 500ms strike through interval is expected. As a recommended practice it can be stated that the reset time of an intermittent earth fault stage should not be set lower than 450ms to obtain a network independent setting. Using this reset set value one can be sure that function will not reset too early even in resonance tuned network.

Typically the maximum operate time of the intermittent earth-fault function is dictated by bus bar residual voltage protection. If the residual voltage protection is set to very fast tripping it may be necessary to prolong the set value of the same. As a recommended practice it can be stated that the operation time of an intermittent earth fault stage should be 500ms counting from the first strike through. In this case the protection tripping requires minimum two strike troughs even in resonance tuned network where strike through happens less frequently. If the residual voltage protection is set to very fast tripping (<1s) it may be necessary to verify the reset value of the residual voltage protection. In no case shall the residual voltage protection operate time be faster than set intermittent earth fault operate time plus circuit breaker operate time added with reset time of residual voltage protection stage.

If an intermittent earth fault protection start is used to block regular non-intermittent directional earth fault protection, the blocking should be applied for both healthy and faulty feeder relays. In general, if intermittent earth fault protection is not used to block directional earth fault protection, it shall be verified that the operate time of regular directional earth fault protection is longer than set intermittent earth fault protection operate time. It is recommended to block regular directional earth fault protection only to avoid start events of directional earth fault protection during intermittent earth faults (if start events are considered disturbing) or if directional non-intermittent earth fault protection is set to faster operate time than intermittent earth fault protection.

If the intermittent earth fault protection should be set for optimal operation, too sensitive pick-up settings should be avoided. General setting parameter values are presented below.

Setting parameter	**Value**
U0 Detect spike >	60 %
I0 Detect spike >	0.5 xI0n
FWD reset time	0.250 s
REV reset time	0.250 s
Definite operating time delay	0.500 s
Spikes to trip >	2

Best verification for the settings is field test with intermittent earth fault capable test system. Each network characteristics may vary significantly from each other. By following basic rules presented in this chapter the correct setting range should be easier to define.

It is also important to check that the reset time settings are never set longer than the desired operating time delay setting.

Measured input values

For the function block is used analog current measurement values from the residual magnitudes. Residual voltage has to be measured for this function to operate. Either I01 or I02 channel can be selected for residual current samples.

Table 3.118 Analogic magnitudes used by the IEF function.

Signal	Description	Time base
U0 samples	U0 residual voltage per unitized samples circular buffer	5 ms
I01 samples	I0 residual current per unitized samples circular buffer	5 ms
I02 samples	I0 residual current per unitized samples circular buffer	5 ms

Selection of the used AI channel is made with a setting parameter.

General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible change them with setting group switching.

Table 3.119 General settings of the function

Name	Description	Range	Step	Default
Meas side	Defines which current measurement module is used by the function.	1:Side1 2:Side2 3:Side3	-	1:Side1
Input selection	Defines which measured residual current is used by the function.	1:I01 2:I02	-	1:I01

Pick-up characteristics

Pick-up of the IEF function is controlled by *U0 Detect spike >* and *I0 Detect spike >* setting parameters, which define the maximum allowed measured residual current and voltage before action from the function. The function constantly calculates the ratio in between of the setting and circular buffer maximum value.

Table 3.120 Pick-up characteristics setting

Name	Range	Step	Default	Description
U0 Detect spike >	1.00...100.00%Un	0.01 %Un	80.00%Un	Pick-up setting U0
I0 Detect spike >	0.05...40.00xI0n	0.01 xI0n	0.50 xI0n	Pick-up setting I0

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active and if the input signal calculated admittance delta exceeds these settings given admittance threshold. I0 Detect spike > / U0 Detect spike > = set admittance delta threshold.

Function blocking

In the blocking element the block signal is checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup current values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Operating time characteristics for trip and reset

The operating timers' behavior of the function can be set for trip signal and also for the release of the function in case the pick-up element is reset before the trip time has been reached. Definite time operation (DT) will give trip signal with user given time delay regardless of the measured current as long as pick-up element is active (independent time characteristics). In the following table are presented the setting parameters for the function time characteristics.

Table 3.121 Operating time characteristics setting parameters.

Name	Range	Step	Default	Description
FWD reset time	0.000... 1800.000s	0.005s	0.300s	Forward start detection reset time. Starts to count from first detected forward (faulty feeder) spike. If in counting another spike is detected resets and starts from beginning. If runs to end resets the function start signals.
REV reset time	0.000... 1800.000s	0.005s	0.300s	Reverse start detection reset time. Starts to count from first detected reverse (healthy feeder) spike. If in counting another spike is detected resets and starts from beginning. If runs to end resets the function start signals.
Definite operating time delay	0.000... 1800.000s	0.005s	0.500s	Operating time counter that starts from beginning of the fault in case if FWD reset time is running and the function has start signal on. If FWD reset time is reached and function releases this timer is reset as well.
Spikes to trip >	1...50	1	2	Calculated cumulative spikes comparator. In order to trip this set amount of spikes must be exceeded. If set operating time is reached but calculated spike amount is below this setting function shall release without trip when the FWD reset time is elapsed.

Events and registers

The IEF function generates events and registers from the status changes of intermittent earth fault detected, normal earth fault detected, FWD start, REV start, trip and blocked. To main event buffer is possible to select status "On" or "Off" messages.

In the function is available 12 last registers where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values.

Table 3.122 Event codes of the IEF function.

Event Number	Event channel	Event block name	Event Code	Description
7296	114	IEF1	0	Start FWD ON
7297	114	IEF1	1	Start FWD OFF
7298	114	IEF1	2	Start REV ON
7299	114	IEF1	3	Start REV OFF
7300	114	IEF1	4	Trip ON
7301	114	IEF1	5	Trip OFF
7302	114	IEF1	6	Block ON
7303	114	IEF1	7	Block OFF
7304	114	IEF1	8	Intermittent EF detected ON
7305	114	IEF1	9	Intermittent EF detected OFF

Event Number	Event channel	Event block name	Event Code	Description
7306	114	IEF1	10	Normal earthfault detected
7307	114	IEF1	11	Intermittent EF Locked

In the register of the IEF function is recorded start, trip or blocked “On” event process data. In the table below is presented the structure of HOC function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 3.123 Register content.

Date & Time	Event code	Trip time remaining	Started FWD	Spikes FWD	Started REV	Spikes REV	Spikes to trip	Used SG
dd.mm.yyyy hh:mm:ss.mss	7296-7307 Descr.	Time remaining from the set operating time	Yes / No indication of forward start in this fault	Calculated cumulative amount of forward (faulty feeder spikes)	Yes / No indication of reverse start in this fault	Calculated cumulative amount of reverse (healthy feeder spikes)	Set spikes to trip subtracted by cumulative forward spikes. If 0 spikes enough for trip.	1 - 8

3.6.3 Auto-reclosing 0 → 1 (79)

Autoreclosing (AR) means coordinated de-energization and energization of transmission or distribution overhead-line with purpose to clear permanent or semi-permanent cause of fault from the line to restore supply automatically to the line.

Autoreclosing can be used in overhead-line networks for clearing transient and semi-permanent faults which present approximately 80-95% of all of the faults found in transmission and distribution networks. Majority of this type of faults can be cleared with high speed autoreclosing and the rest of the faults can be cleared with delayed autoreclosing by de-energizing the faulty line for a longer period of time.

Only minority of the overhead line faults are permanent type which require maintenance or repair in the actual fault location. Faults like lightning in the line, tree branch touching to the overhead line, arc caused by animals or short circuits caused by objects touching to the overhead lines are this type of transient and semi-permanent faults. If the fault is permanent for example tree fall and leaning into the overhead line or broken insulator, autoreclosing will not clear the fault and the faulty feeder shall be locked from closing until the cause of the fault is repaired in the actual fault location. Also close short circuit faults should avoid the autoreclosing to be even initiated in order to avoid unnecessary stress for the lines and circuit breaker in cases when the fault cannot be cleared by autoreclosing the line. Similar situations arise also in the mixed cable and overhead line networks since cable network faults cannot be cleared by autoreclosing. In this category faults the autorecloser should be aware of fault location before autoreclosing is applied to the faulty line.

Auto-reclosing as application

The main principle of autoreclosing is to de-energize the faulty line and fault location so that the cause of the fault can drop out from the line. When the line is energized and object either touches or drops into the line, current will start to flow through the object either to the ground or in between of the phases causing the surrounding air to heat and ionize and start to operate as conductor in between of the energized phase(s) and (or) ground causing arc to ignite.

When the breaker is opened either by command of autorecloser or protection function, voltage in the line will be zero thus extinguishing the arc and letting the object which caused the fault to drop from the line and by this way clearing the cause of the fault. Autorecloser closes the breaker after set time (called Dead Time meaning the time which the line is not-energized) and the supply is restored to the line. If the fault is not cleared by this first autoreclosing cycle (called Shot) then more shots can be applied to the line.

If the fault was not cleared by the time autorecloser closes the breaker and second shot is applied into the line there can be set either time delay (called Arcing time) in order to burn the fault causing object from the line or normal protection operating times can be applied. In autorecloser is selection also if the fault is not present when closing the breaker but

reappears soon after closing the breaker (called Discrimination time, Reclaim time), Autorecloser either arms another shot or gives final trip command and locks-out. In case one shot is applied to the line and if it is not successfully clearing the fault autorecloser will init final trip and will lock out the feeder closing also.

Whether single or multi-shot autoreclosing should be used is matter of the type of protection, switchgear, circuit breaker, stability requirements, network type, consumer loads and also local utility knowledge and practices of the network.

Typical autoreclosing scheme is not easy to define since in distribution and transmission networks these mentioned parameters vary greatly thus affecting directly to the scheme main parameters, how many shots and how long dead times should be set for the reclosing scheme and also which protection functions should init the autorecloser.

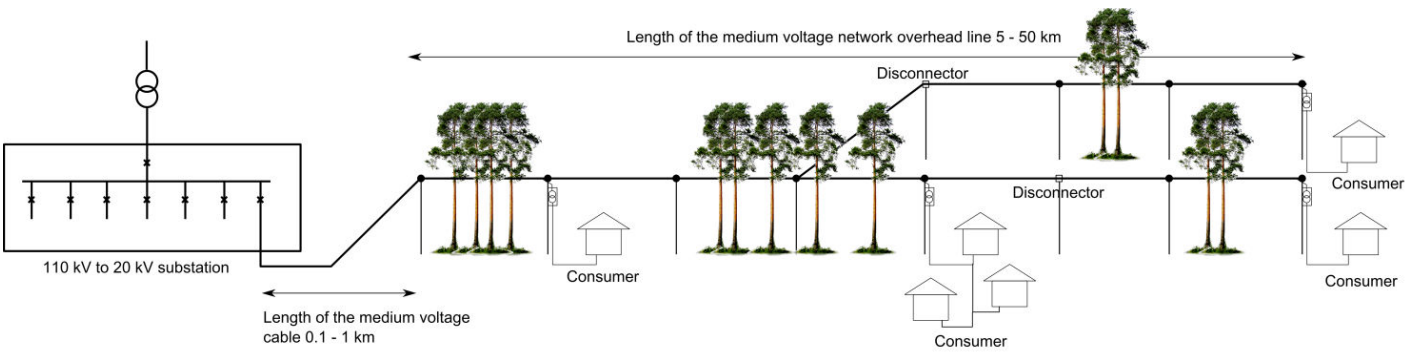
Minimum times for the Dead Time setting is mostly dependent of the voltage level of the protected network in order to give enough time for the air to de-ionize after the circuit breaker is opened. For medium voltage 20 kV to 75 kV Dead Time of 200 ms should be sufficient when for 110 kV requires about 300 ms and 400 kV requires 400-500 ms Dead Time. This minimum time is not this straightforward to define since it is affected by other parameters also like conductor spacing, wind speed, fault type, fault duration etc. The main purpose of the Dead Time is to allow and give time for the fault location surrounding air to return to isolating state before the line is re-energized and inhibit the arc from re-ignite due to heated and ionized air. Also for lower voltage levels the breaker open-close-open cycle capacity gives restrictions for the minimum Dead Time setting while with higher voltage levels the de-ionizing time dictates the minimum Dead Time which makes possible a successful autoreclosing.

In case of evolving faults like transient earth fault turns to multi-phase short circuit or overcurrent fault different schemes can be built by setting the requests into different priorities and behaviors. Autorecloser has five independent priority requests for reclosing and one critical request which halt the recloser in any position it is running when the critical request is received. REQ1 has the highest priority and REQ5 lowest.

Auto-reclosing scheme in radial network

In typical medium voltage overhead network construction is radial type and does not cause any additional requirements for the autoreclosing scheme in addition to the mentioned air de-ionization time and the capacity of the circuit breaker which should be the dictating magnitudes for the autoreclosing scheme. Also typically medium voltage overhead line consists of only consumers and no power generation which leads to that the most stable supply continuity is the main objective.

Figure 3.89 Typical rural radial medium voltage network construction.



Typically rural radial medium voltage network consists of short cable connection from substation to the overhead line and relatively long overhead line which typically ends to consumer. The overhead line part can feed from basically any location residential, farming etc. consumers which connect with 20 kV / 0.4 kV distribution transformers to the medium voltage. Overhead line can have multiple branches and it usually in the countryside goes through forest areas in between of the consumers. In longer lines is possible to isolate areas of the overhead line with line disconnectors at least in branches.

In this type of application is normally used two shot (one high speed and one delayed) autoreclosing which are started by earth fault protection or overcurrent protection. Short circuit protection is used for interlocking of the autorecloser in case of clear short circuit fault in the line.

Figure 3.90 Example of signals assignment for autoreclosing sequences

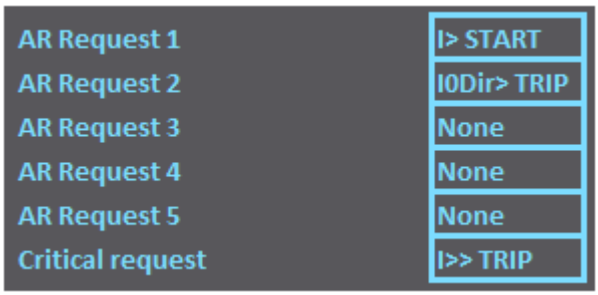
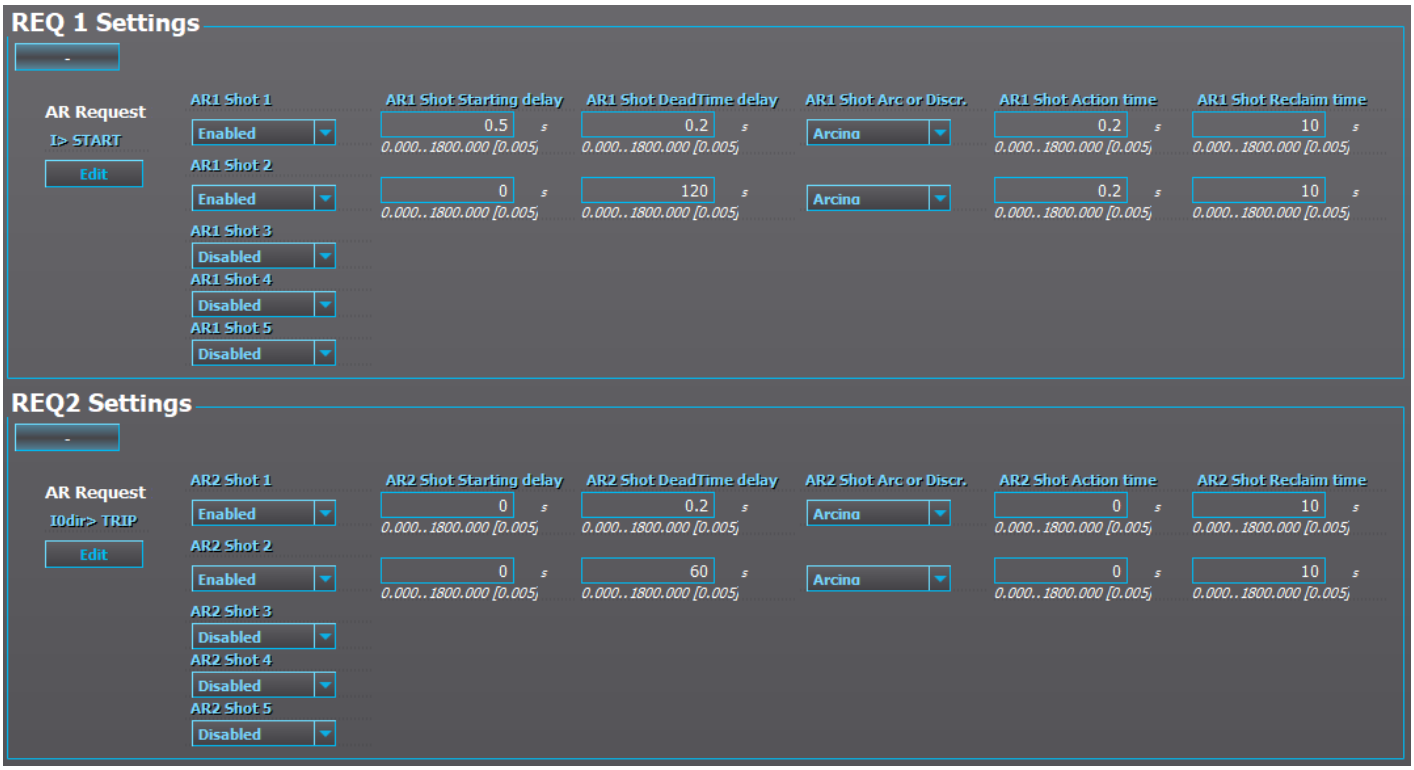


Figure 3.91 Autoreclosing shot settings, two requests and two shots are initialized.



In this example for earth faults its own operating time settings are used and for overcurrent time delay its set from autorecloser. Both fault types can initialize both of the shots with different settings. If the fault evolves from earth fault AR2 to multi-phase fault, auto-recloser will use AR1 settings for the reclosing. In this example the dead time in between of the first and second shot is different due to need for give more time for the air to cool and de-ionize in the case of overcurrent or multi-phase fault. If high set overcurrent stage activates in any situation the autoreclosing sequence is ended. In this case final trip shall be issued and the feeder closing will be locked by autorecloser. Closing of the breaker will require manual reset of the autorecloser lock before attempting to close the breaker. Manual reset can be applied from SCADA or locally from the HMI of the IED.

Following graphs present the principle signaling of the autorecloser in different cases possible for this type of line. The graphs describe the available requests status, autorecloser internal signal statuses, timer statuses, breaker controls from autorecloser and breaker status signals.

Autorecloser operates closely with Object control and all of the breaker status and monitor signals are forwarded from the selected Object to the autorecloser. Also circuit breaker Open and Close signals are controlled through the dedicated Object. In cases when the breaker cannot be closed due to it being not ready or breaker closing is waiting for synchrocheck allowance the wait state is forwarded to autorecloser so that it waits for Object to acknowledge either successful closing or failure timeout. Similar situation can arise in circuit breaker open command e.g. if the open is blocked due to SF6 gas leakage. In the failure acknowledgements situations autorecloser is always put to lock-out state with requirement for reset when the cause of the lock-out is cleared. Reset is done by external input to the function or by closing the breaker.

Auto-reclosing sequence from trip with two shot failure

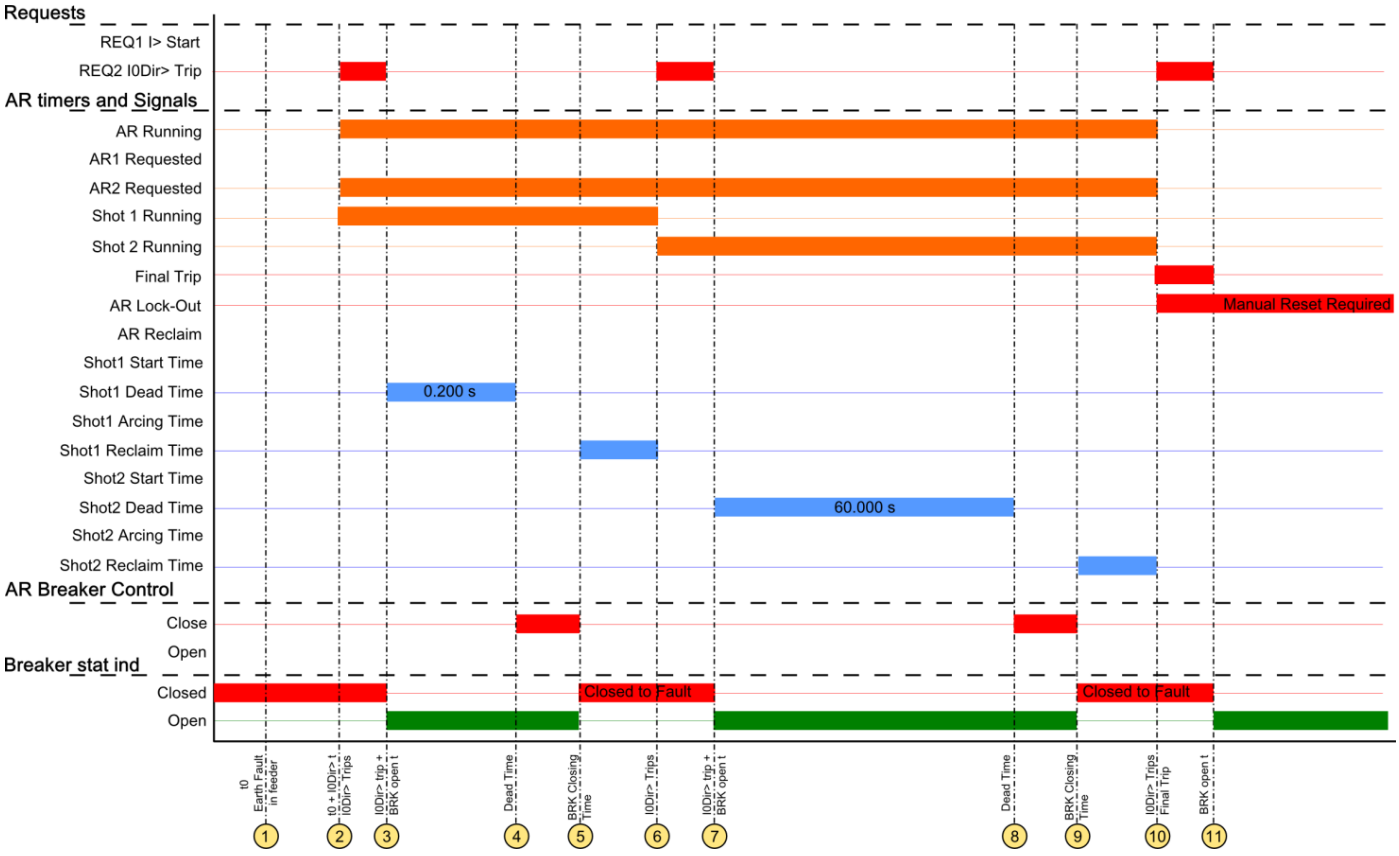
For this earth fault autoreclosing scheme directional earth fault protection Trip signal to operate was set as REQ2 starter which has Shot1 and Shot2 enabled with following settings. One rapid shot followed by time delayed shot is set for this scheme.

Figure 3.92 Settings for earth fault reclosing with two shots.



When Trip signal is used for the autorecloser cycle init then no additional starting or discrimination times are used since the protection stage takes care of the breaker opening timings directly by its own operation. Autorecloser therefore only monitors the status of the directional earth fault stage tripping before initiating request and shots.

Figure 3.93 Signal status graph of the permanent earth fault autoreclosing cycle.



1. Earth fault is found in the protected line which causes directional earth fault protection I0Dir> to start and calculate the operating time for the trip.
2. I0Dir> trips and gives open command to the breaker open coil. Autoreclosing REQ2 is initiated and AR running, AR2 Requested and Shot1 Running signals are activated.

3. Circuit breaker is opened and I0Dir> Trip signal is released and simultaneously REQ2 signal for autorecloser is released. Recloser starts to calculate the Shot1 Dead Time for closing the breaker.
4. Dead Time for Shot1 is exceeded and autorecloser sends close request for the Object breaker, the close conditions are met and the breaker close command is sent to breaker close coil.
5. Circuit Breaker is closed towards the fault which was not cleared by the Shot1 given non-energized time and I0Dir> stage picks up and starts to calculate operating time for trip. Close command is drop off after the breaker closed indication is received and the autorecloser starts to calculate Reclaim time.
6. I0Dir> trips and gives REQ2 request for autorecloser, autorecloser is calculating Reclaim Time for Shot1 and while during this time new request is received recloser will jump to next available Shot for this request. Shot2 is next which is allowed for REQ2 input and Shot2 Running signal is set to active and Shot1 Running is drop off.
7. Circuit breaker is opened and I0Dir> Trip signal is released and simultaneously REQ2 signal for autorecloser is released. Recloser starts to calculate the Shot2 Dead Time for closing the breaker.
8. Dead Time for Shot2 is exceeded and autorecloser sends close request for the Object breaker, the close conditions are met and the breaker close command is sent to breaker close coil.
9. Circuit breaker is closed towards the fault which was not cleared by the Shot2 given non-energized time and I0Dir> stage picks up and starts to calculate operating time for trip. Close command is drop off after the breaker closed indication is received and the autorecloser starts to calculate Reclaim time.
10. I0Dir> trips and gives REQ2 request for autorecloser, autorecloser is calculating Reclaim Time for Shot2 and while during this time new request is received recloser will jump to next available Shot for this request. For this scheme is not anymore available shots so autorecloser initializes Final Trip state and drops AR Running, Shot2 Running and REQ2 Running signals. Autorecloser enters to Lock-out state preventing further requests for reclosing.
11. Circuit breaker is opened and I0Dir> Trip signal is released. Simultaneously REQ2 signal is released and recloser is now in steady Lock-out state waiting for manual reset from user and re-initialization by closing the breaker.

Auto-reclosing sequence from trip with two shot, high speed fails and time delayed succeeds

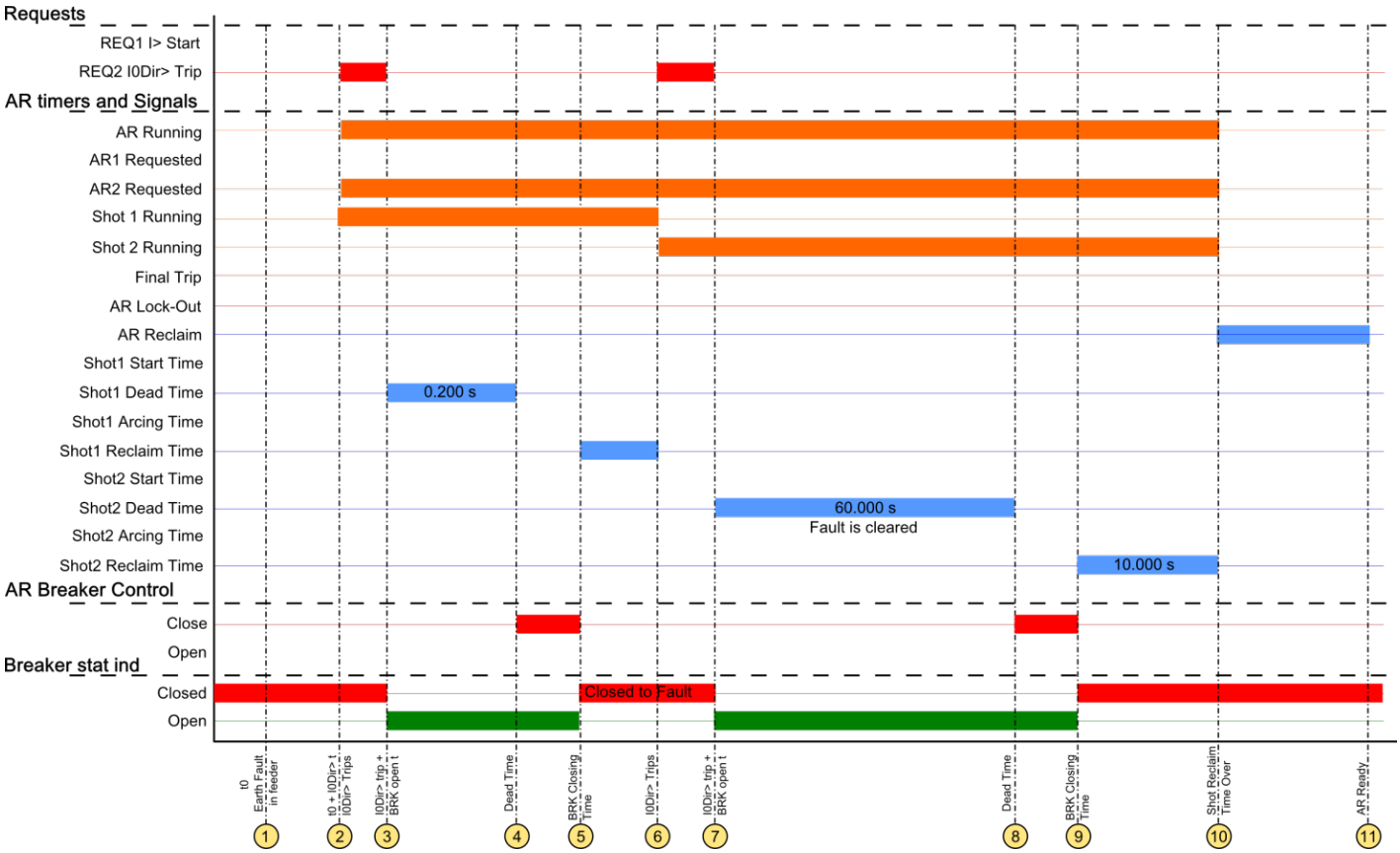
The Scheme for autoreclosing starter and shots is the same than in the previous example with same settings and signals. In this example fault persist for the high speed autoreclosing but is cleared by time delayed autoreclosing.

Figure 3.94 Settings for earth fault reclosing with two shots.



This type of sequence represents 10-15% of all the faults in the medium voltage overhead line network.

Figure 3.95 Signal status graph of the semi-permanent earth fault autoreclosing cycle.



1. Earth fault is found in the protected line which causes directional earth fault protection I0Dir> to start and calculate the operating time for the trip.
2. I0Dir> trips and gives open command to the breaker open coil. Autoreclosing REQ2 is initiated and AR running, AR2 Requested and Shot1 Running signals are activated.
3. Circuit breaker is opened and I0Dir> Trip signal is released and simultaneously REQ2 signal for autorecloser is released. Recloser starts to calculate the Shot1 Dead Time for closing the breaker.
4. Dead Time for Shot1 is exceeded and autorecloser sends close request for the Object breaker, the close conditions are met and the breaker close command is sent to breaker close coil.
5. Circuit Breaker is closed towards the fault which was not cleared by the Shot1 given non-energized time and I0Dir> stage picks up and starts to calculate operating time for trip. Close command is drop off after the breaker closed indication is received and the autorecloser starts to calculate Reclaim time.
6. I0Dir> trips and gives REQ2 request for autorecloser, autorecloser is calculating Reclaim Time for Shot1 and while during this time new request is received recloser will jump to next available Shot for this request. Shot2 is next which is allowed for REQ2 input and Shot2 Running signal is set to active and Shot1 Running is drop off.
7. Circuit breaker is opened and I0Dir> Trip signal is released and simultaneously REQ2 signal for autorecloser is released. Recloser starts to calculate the Shot2 Dead Time for closing the breaker.
8. Dead Time for Shot2 is exceeded and autorecloser sends close request for the Object breaker, the close conditions are met and the breaker close command is sent to breaker close coil.
9. Circuit breaker is closed and since fault cleared by the Shot2 given non-energized time no pick-ups are detected Close command is drop off after the breaker closed indication is received and the autorecloser starts to calculate Reclaim time for Shot2.
10. Reclaim Time for Shot2 is exceeded and the reclosing cycle is ended. AR running, Shot2 Running and REQ2 Running signals are reset and Reclaim Time for the Autorecloser application starts. Difference in between of the autoreclosing and shot specific reclaim times is that if fault is returning in shot specific reclaim time autorecloser jumps to next shot. If a fault return after successful cycle and Autoreclosing reclaim time is running recloser will go directly to final trip state and lock-out state. This behavior can be controlled with settings. Both of these reclaim times can be set to 0 when they are not needed. Autoreclosing will skip all timers set to 0.
11. Autoreclosing Reclaim Time is exceeded and Autorecloser is set to Ready state waiting for next request.

Auto-reclosing sequence from Trip with two shot, high speed succeeds

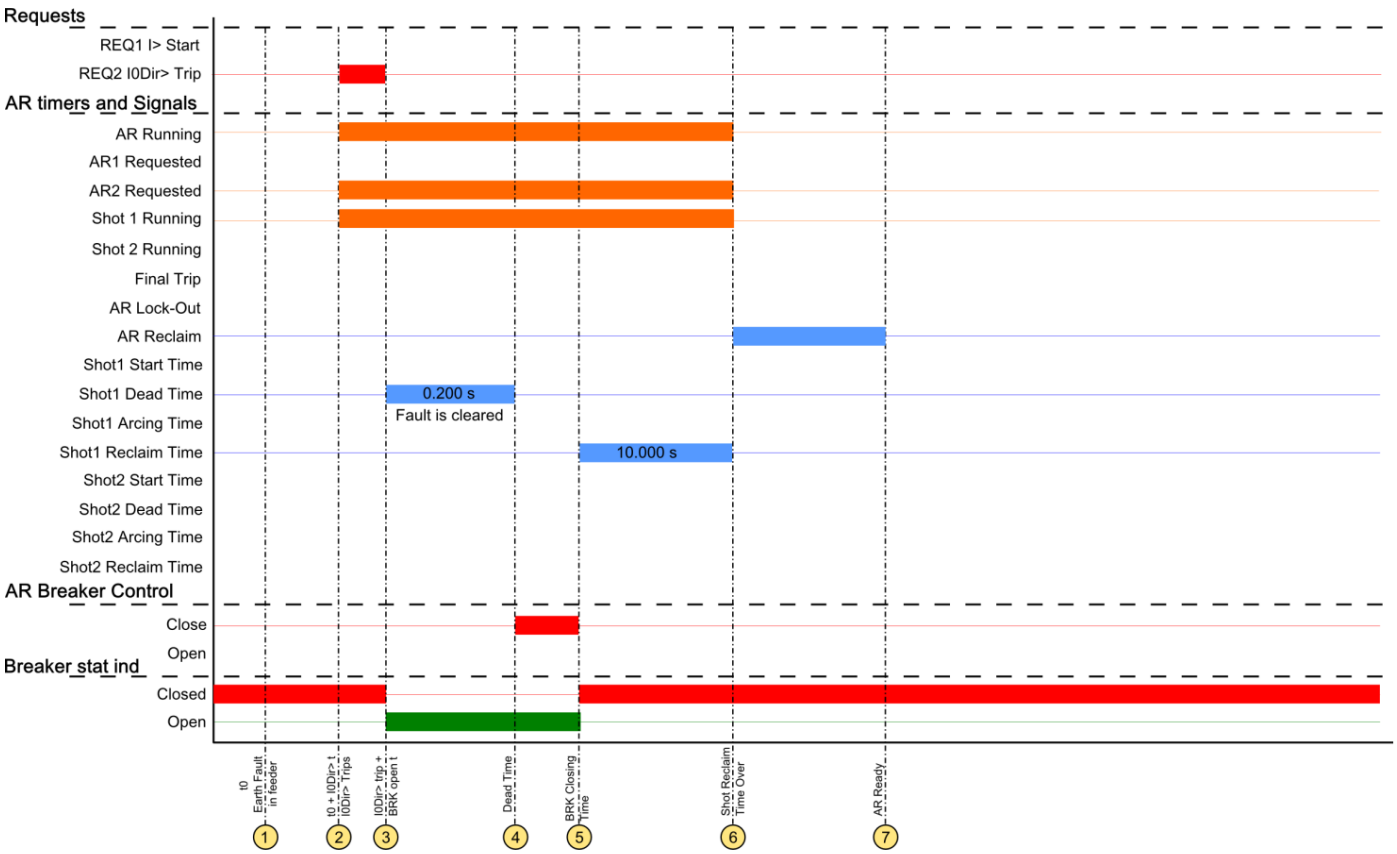
The Scheme for autoreclosing starter and shots is the same than in the previous examples with same settings and signals. In this example fault is cleared by the high speed autoreclosing.

Figure 3.96 Settings for earth fault reclosing with two shots.



This type of sequence represents 75-85% of all the faults in the medium voltage overhead line network.

Figure 3.97 Signal status graph of the transient earth fault autoreclosing cycle.



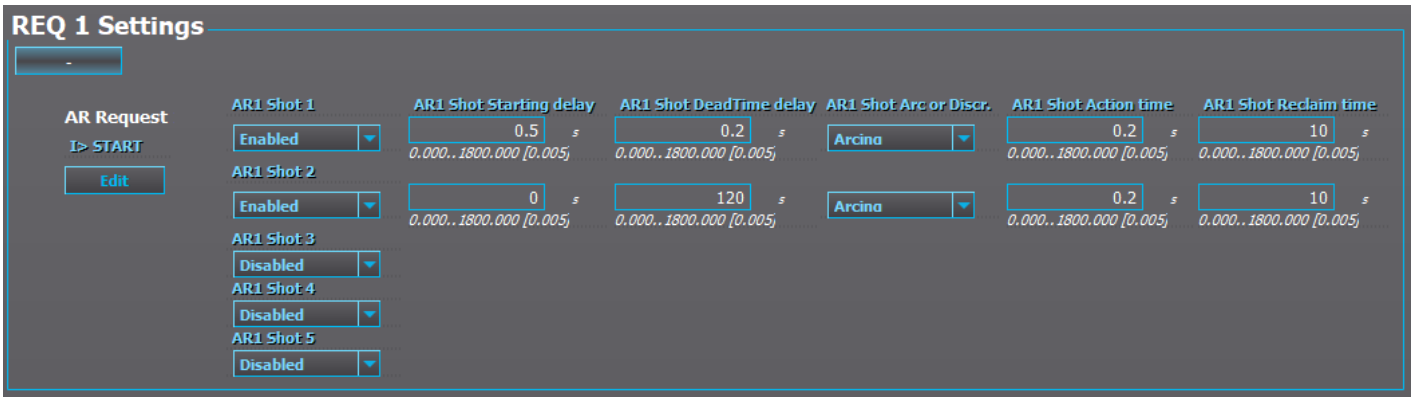
1. Earth fault is found in the protected line which causes directional earth fault protection I0Dir> to start and calculate the operating time for the trip.
2. I0Dir> trips and gives open command to the breaker open coil. Autoreclosing REQ2 is initiated and AR running, AR2 Requested and Shot1 Running signals are activated.
3. Circuit breaker is opened and I0Dir> Trip signal is released and simultaneously REQ2 signal for autorecloser is released. Recloser starts to calculate the Shot1 Dead Time for closing the breaker.

4. Dead Time for Shot1 is exceeded and autorecloser sends close request for the Object breaker, the close conditions are met and the breaker close command is sent to breaker close coil.
5. Circuit breaker is closed and since fault cleared by the Shot1 given non-energized time no pick-ups are detected Close command is drop off after the breaker closed indication is received and the autorecloser starts to calculate Reclaim time for Shot1.
6. Reclaim Time for Shot1 is exceeded and the reclosing cycle is ended. AR running, Shot1 Running and REQ2 Running signals are reset and Reclaim Time for the Autorecloser application starts. Difference in between of the autoreclosing and shot specific reclaim times is that if fault is returning in shot specific reclaim time autorecloser jumps to next shot. If a fault return after successful cycle and Autoreclosing reclaim time is running recloser will go directly to final trip state and lock-out state. This behavior can be controlled with settings of the recloser. Both of these reclaim times can be set to 0 when they are not needed. Recloser function will skip all timers set to 0. Also is possible to set the AR Reclaim not to be used after successful reclosing cycle.
7. Autoreclosing Reclaim Time is exceeded and Autorecloser is set to Ready state waiting for next request.

Auto-reclosing sequence from Start with two shot failure

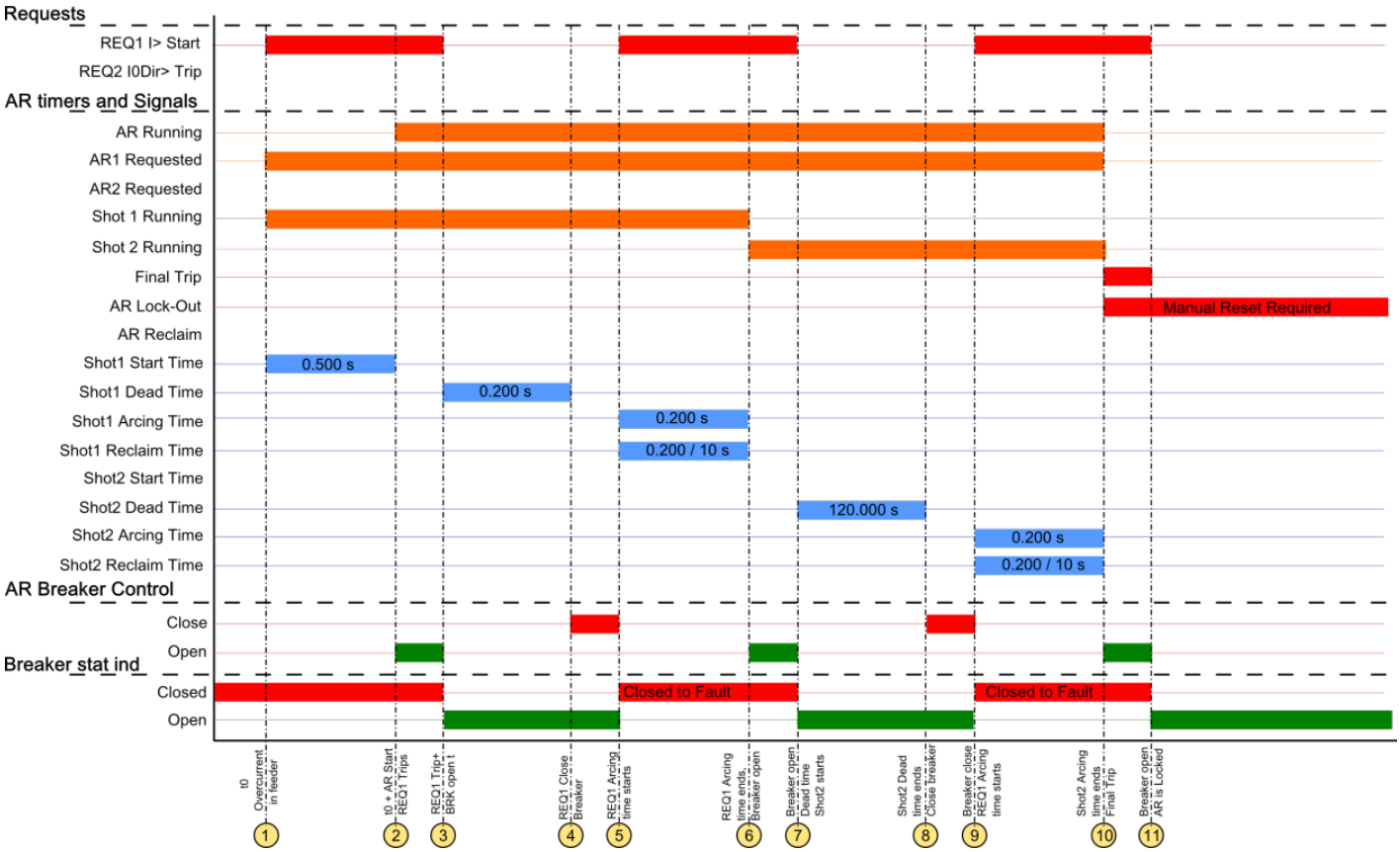
For this overcurrent autoreclosing scheme was set non directional overcurrent protection Start signal to operate as REQ1 starter which was enabled to Shot1 and Shot2 with following settings. One rapid shot followed by time delayed shot are set for this scheme. In this scheme the first start time is set to longer than in the unsuccessful reclose shots arcing time if the fault persists then the allowed towards fault time is reduced.

Figure 3.98 Settings for earth fault reclosing with two shots.



When Start signal is used for the autoreclosing the timings of the fault durations are taken care by the autorecloser function and the starting / arcing times needs to be set accordingly. The main operating time settings of the protection should be longer than the values set to the autorecloser in order the state changes work properly for recloser.

Figure 3.99 Signal status graph of the permanent overcurrent autoreclosing cycle.

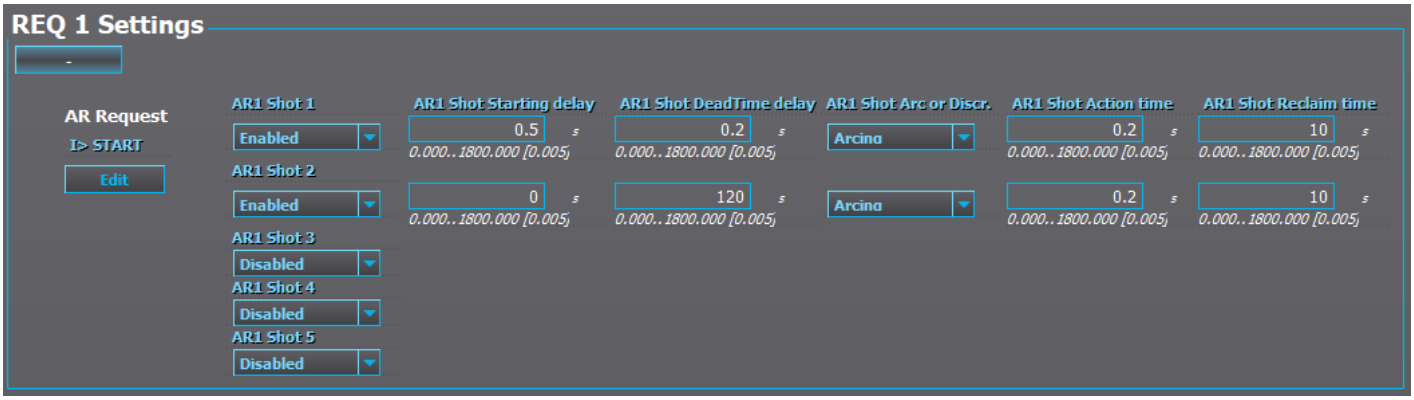


1. Overcurrent is found in the protected line which causes overcurrent protection I> to pick up and activate REQ1 which causes the starting time calculating for the Shot 1. Shot 1 signal is activated simultaneously with corresponding starting time even the autorecloser is still in not running mode.
2. Start time 500 ms for Shot 1 is elapsed and the autorecloser enters to running mode and sends open command to the breaker.
3. Circuit breaker is opened and I> Start signal is released and simultaneously REQ1 signal for autorecloser is released. Recloser starts to calculate the Shot1 Dead Time for closing the breaker.
4. Dead Time for Shot1 is exceeded and autorecloser sends close request for the Object breaker, the close conditions are met and the breaker close command is sent to breaker close coil.
5. Circuit breaker is closed and since fault is not cleared by the Shot1 given non-energized time, pick-up of I> is detected. Close command is drop off after the breaker closed indication is received and the autorecloser starts to calculate Reclaim time for Shot1 simultaneously with the arcing time.
6. Arcing time for the Shot1 is exceeded which means that the fault is not cleared and the recloser sends open command to the breaker. Recloser enters to the Shot2 state.
7. Circuit breaker opens and the Dead time calculation for Shot2 starts.
8. Shot2 Dead time calculation is finished and the recloser sends close command to the breaker.
9. Dead Time for Shot2 is exceeded and autorecloser sends close request for the Object breaker, the close conditions are met and the breaker close command is sent to breaker close coil.
10. Circuit breaker is closed towards the fault which was not cleared by the Shot2 given non-energized time and I> stage picks up and starts to calculate arcing time for final trip. Close command is drop off after the breaker closed indication is received and the autorecloser starts to calculate Reclaim time.
11. Arcing time is finished and REQ1 request is activated for autorecloser, autorecloser is calculating Reclaim Time for Shot2 and while during this time new request is received recloser will jump to next available Shot for this request. For this scheme is not anymore available shots so autorecloser initializes Final Trip state and drops AR Running, Shot2 Running and REQ1 Running signals. Autorecloser enters to Lock-out state preventing further requests for reclosing. Circuit breaker is opened and I> Start signal is released. Simultaneously REQ1 signal is released and recloser is now in steady Lock-out state waiting for manual reset from user and re-initialization by closing the breaker.

Auto-reclosing sequence from Start with two shot, high speed fails and time delayed succeeds

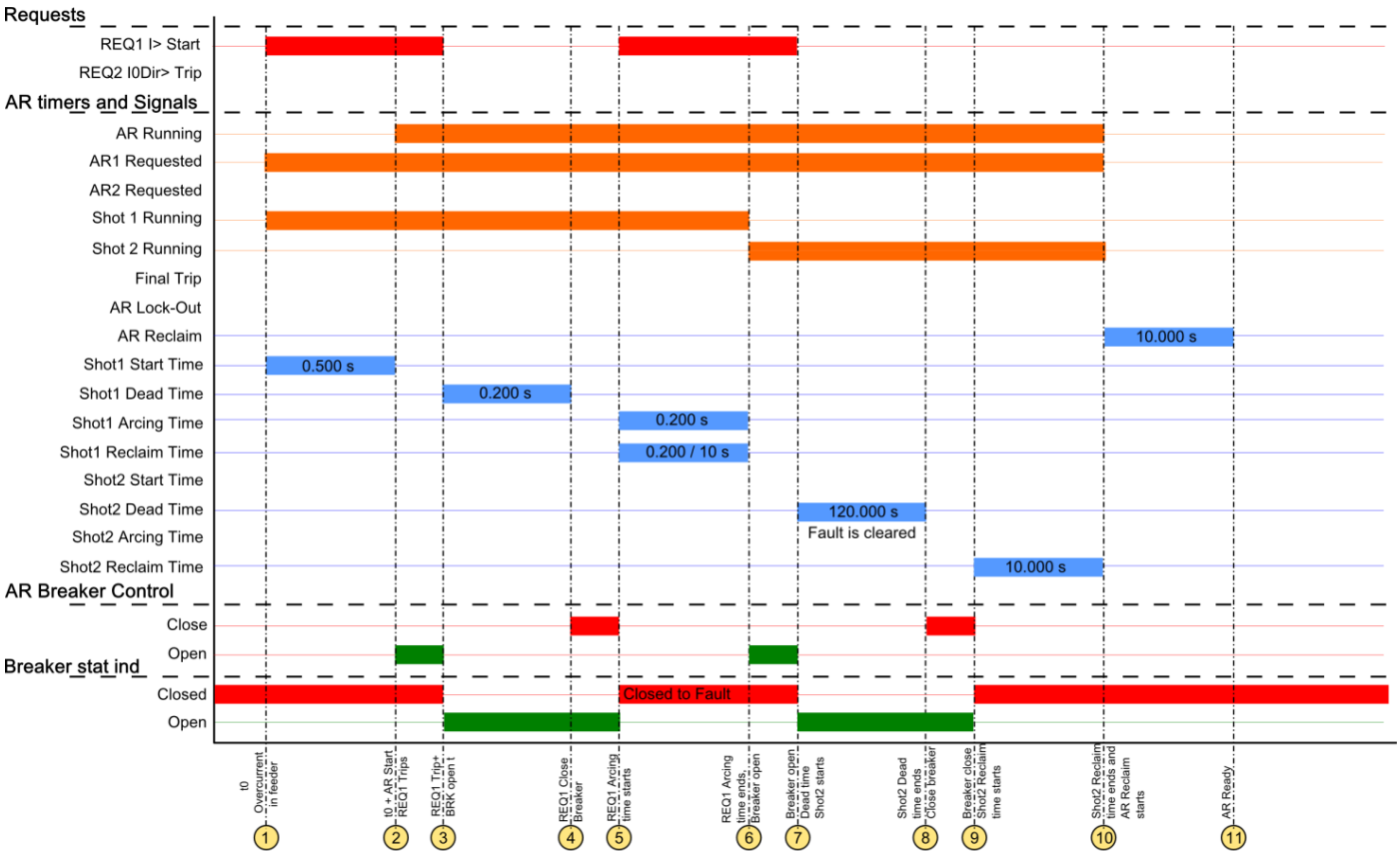
The Scheme for autoreclosing starter and shots is the same than in the previous example with same settings and signals. In this example fault persist for the high speed autoreclosing but is cleared by time delayed autoreclosing.

Figure 3.100 Settings for overcurrent reclosing with two shots.



This type of sequence represents 10-15% of all the faults in the medium voltage overhead line network.

Figure 3.101 Signal status graph of the semi-permanent overcurrent autoreclosing cycle.



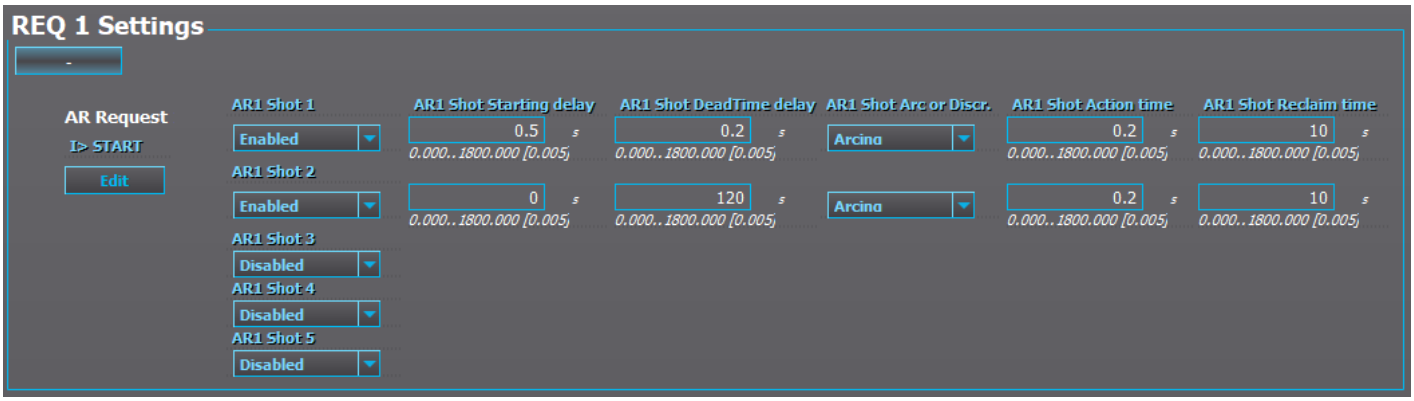
1. Overcurrent is found in the protected line which causes overcurrent protection I> to pick up and activate REQ1 which causes the starting time calculating for the Shot 1. Shot 1 signal is activated simultaneously with corresponding starting time even the autorecloser is still in not running mode.
2. Start time 500 ms for Shot 1 is elapsed and the autorecloser enters to running mode and sends open command to the breaker.
3. Circuit breaker is opened and I> Start signal is released and simultaneously REQ1 signal for autorecloser is released. Recloser starts to calculate the Shot1 Dead Time for closing the breaker.

4. Dead Time for Shot1 is exceeded and autorecloser sends close request for the Object breaker, the close conditions are met and the breaker close command is sent to breaker close coil.
5. Circuit breaker is closed and since fault is not cleared by the Shot1 given non-energized time, pick-up of I> is detected. Close command is drop off after the breaker closed indication is received and the autorecloser starts to calculate Reclaim time for Shot1 simultaneously with the arcing time.
6. Arcing time for the Shot1 is exceeded which means that the fault is not cleared and the recloser sends open command to the breaker. Recloser enters to the Shot2 state.
7. Circuit breaker opens and the Dead time calculation for Shot2 starts.
8. Shot2 Dead time calculation is finished and the recloser sends close command to the breaker.
9. Circuit breaker is closed and since fault cleared by the Shot2 given non-energized time, no pick-ups are detected. Close command is drop off after the breaker closed indication is received and the autorecloser starts to calculate Reclaim time for Shot2.
10. Reclaim Time for Shot2 is exceeded and the reclosing cycle is ended. AR running, Shot2 Running and REQ1 Running signals are reset and Reclaim Time for the Autorecloser application starts. Difference in between of the autoreclosing and shot specific reclaim times is that if fault is returning in shot specific reclaim time autorecloser jumps to next shot. If a fault return after successful cycle and Autoreclosing reclaim time is running recloser will go directly to final trip state and lock-out state. This behavior can be controlled with settings of the recloser. Both of these reclaim times can be set to 0 when they are not needed. Recloser function will skip all timers set to 0. Also is possible to set the AR Reclaim not to be used after successful reclosing cycle.
11. Autoreclosing Reclaim Time is exceeded and Autorecloser is set to Ready state waiting for next request.

Auto-reclosing sequence from Start with two shot, high speed succeeds

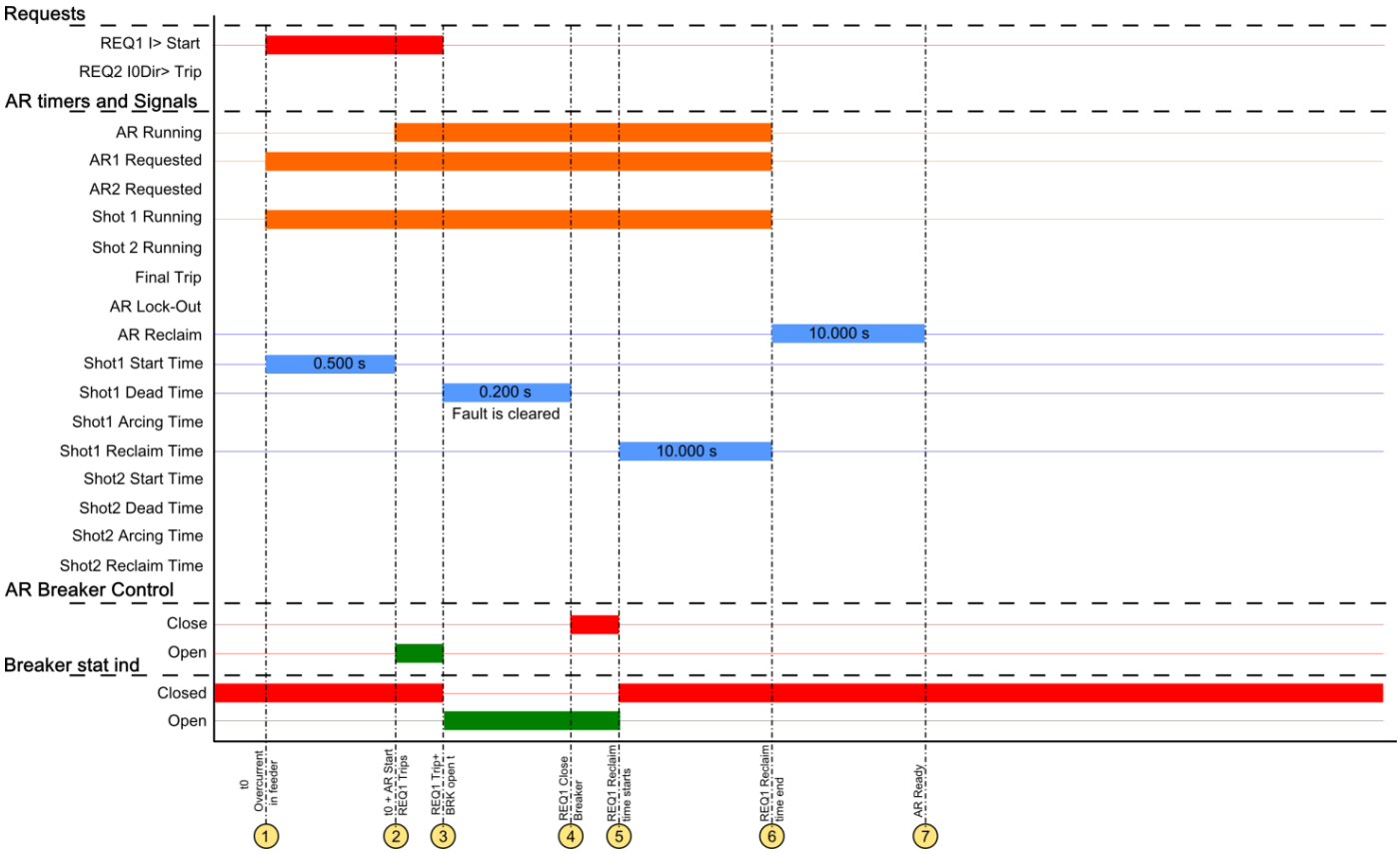
The Scheme for autoreclosing starter and shots is the same than in the previous examples with same settings and signals. In this example fault is cleared by the high speed autoreclosing.

Figure 3.102 Settings for overcurrent reclosing with two shots.



This type of sequence represents 75-85% of all the faults in the medium voltage overhead line network.

Figure 3.103 Signal status graph of the transient overcurrent autoreclosing cycle.



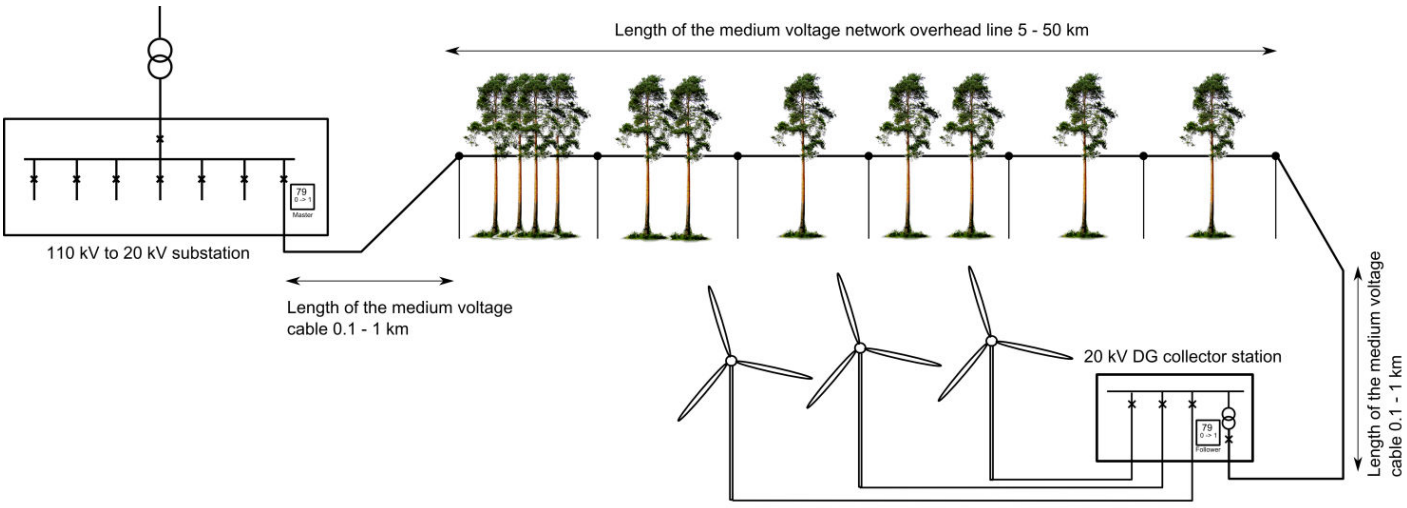
1. Overcurrent is found in the protected line which causes overcurrent protection I> to pick up and activate REQ1 which causes the starting time calculating for the Shot 1. Shot 1 signal is activated simultaneously with corresponding starting time even the autorecloser is still in not running mode.
2. Start time 500 ms for Shot 1 is elapsed and the autorecloser enters to running mode and sends open command to the breaker.
3. Circuit breaker is opened and I> Start signal is released and simultaneously REQ1 signal for autorecloser is released. Recloser starts to calculate the Shot1 Dead Time for closing the breaker.
4. Dead Time for Shot1 is exceeded and autorecloser sends close request for the Object breaker, the close conditions are met and the breaker close command is sent to breaker close coil.
5. Circuit breaker is closed and since fault cleared by the Shot1 given non-energized time, no pick-ups are detected. Close command is drop off after the breaker closed indication is received and the autorecloser starts to calculate Reclaim time for Shot1.
6. Reclaim Time for Shot1 is exceeded and the reclosing cycle is ended. AR running, Shot1 Running and REQ1 Running signals are reset and Reclaim Time for the Autorecloser application starts. Difference in between of the autoreclosing and shot specific reclaim times is that if fault is returning in shot specific reclaim time autorecloser jumps to next shot. If a fault return after successful cycle and Autoreclosing reclaim time is running recloser will go directly to final trip state and lock-out state. This behavior can be controlled with settings of the recloser. Both of these reclaim times can be set to 0 when they are not needed. Recloser function will skip all timers set to 0. Also is possible to set the AR Reclaim not to be used after successful reclosing cycle.
7. Autoreclosing Reclaim Time is exceeded and Autorecloser is set to Ready state waiting for next request.

Auto-reclosing in meshed or ring networks

If the overhead line feeder has distributed power generation, which can arise even more often in the future since renewable power sources become more common, typical autoreclosing scheme cannot be applied directly. In this kind of autoreclosing schemes two end autoreclosing has to be used so that the relays in both ends of the line operate as master-follower autoreclosing in co-operation. If the reclosing is not applied so that the DG power plant is disconnected prior to the breaker close command, firstly the reclosing will fail since the DG power plant will keep the fault on during the dead time of the

autorecloser and also the closing of the breaker when the main grid has been disconnected from the DG power plant will most probably cause problems for the DG power plant due to phase shift of the DG power plant during the dead time.

Figure 3.104 Autoreclosing with distributed generation in the line.



For this operation there needs to be communication link in between of the substation master relay and 20 kV collector station incomer follower relay. When autoreclosing is initiated the collector station breaker is opened until the autoreclosing cycle is completed. If the autoreclosing is not successful from the 20 kV substation towards the collector station there is no point to allow the closing of the collector station breaker either. In case the autoreclosing cycle is successful after reclaim time the close permission for the collector station can be given and the breaker should be closed with synchroswitch function.

After the collector station is disconnected the basic principles of autoreclosing can be applied for the overhead line as described previously. This same principle should apply for any ring or meshed network where in the same line power can be fed from more than one direction. For typical consumer radial network this problem does not exist.

Arcing time and Discrimination time

After the Dead time has elapsed and the breaker is closed by autorecloser, behavior of the autorecloser can be set in various ways. Generally after breaker is closed Reclaim time starts running and if during this Reclaim time new reclosing request occurs Autorecloser shall continue to next state whether it would be next shot or in case all shots have been used to Final Trip.

The entering to next state can be controlled by Arcing time and Discrimination time settings. These settings are either or type which means that if Arcing time is selected Discrimination time cannot be selected for same request and same shot simultaneously.

Arcing time can be used for controlling the autoreclosing in cases protection function Start signal is making the requests. In case if the request (start) activates during the Reclaim time the Arcing time calculation starts and if fault persists autorecloser shall continue to next stage. If Arcing time calculation starts but stops before the set time have been used then Reclaim time calculation continues normally and when it is elapsed autorecloser shall return to either General Reclaim time or into Ready mode and the shot is considered as successful. Arcing time counter is not resetting from the request drop off during the Reclaim time and every time the request is activated (e.g. protection function starts) the arcing time counter is deducted by the time request is on. This means that the time set to Arcing time parameter means cumulative time of start allowed in Reclaim time before decision is made that the shot is failed or succeeded.

In case the autoreclosing is used in the time coordinated network protected by IDMT time characteristics and the relays are old mechanical types which have also current dependent release time the operation of the protection selectivity has to be guaranteed by allowing all of the relays timing devices reset completely during the dead time so that the correct time discrimination is maintained after reclosing to the fault. Time required for mechanical IDMT relay to reset may be even 10 s in some cases. When short dead times are required the relays should reset almost instantaneously so that the current dependent time grading operates as expected. For these cases in the autorecloser is possible to set certain discrimination time instead of arcing time, which starts simultaneously with reclaim time and if during this discrimination time any new

reclosing requests are made the recloser will halt and let the protection devices operate based on their settings and does not interfere on the operation of the protection functions or the breaker. This means also that further reclosing are not made before the autorecloser is reset manually and the breaker shall remain open until it is manually closed.

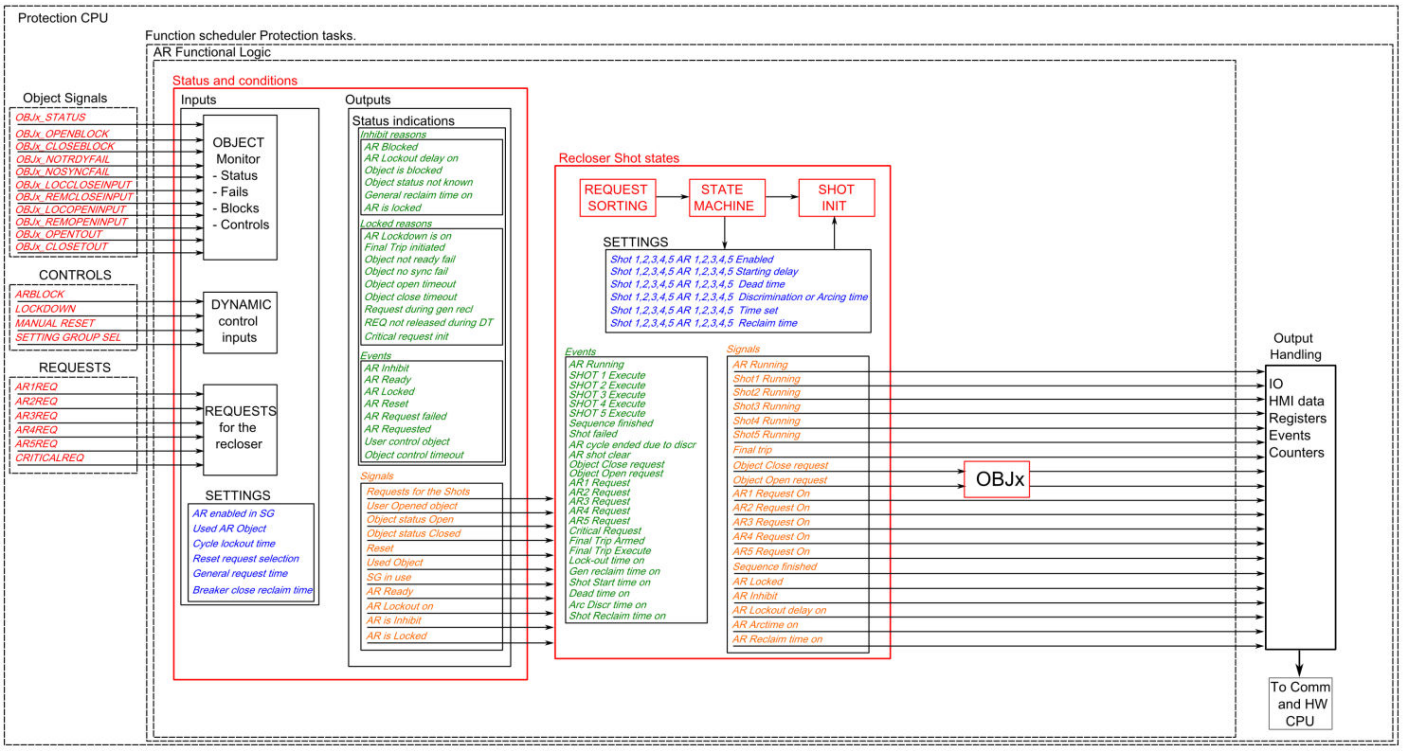
Auto-recloser IO

Main outputs of the autorecloser function are Object open and Object close control signals. In addition to these output controls the function will report the recloser status information to be used in the logics or LED indications as well as applied operations. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function.

Inputs for the function are binary recloser request signals, blockings and controlling signals, controlled object monitoring and status signals. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the two output signal as well as several operational event signals. Time stamp resolution is 1ms. Function provides also cumulative counters for each applied reclosing events and requests.

Autorecloser function can be divided into starter, shot selector state machine, sorter and shot blocks which operate dynamically during the reclosing cycles based on the given settings and input signals monitoring. Autorecloser behavior can be changed dynamically even during the cycle based on programmed reclosing scheme and active requests.

Figure 3.105 Simplified function block diagram of the AR function.



As can be seen in the function block diagram the autorecloser is tightly dependent of the object function block status information and configuration. Therefore in order to use autoreclosing the controlled object has to be configured before the autoreclosing can be used. In the MVR-2xx platform the object control block takes all control of the breaker operations which means that for example synchrocheck, breaker status monitoring etc. breaker related functionality is not taken separately in to account in the autorecloser function. Should any of these fail in the circuit breaker opening or closing object control function will report the event to autorecloser function which will do corresponding action.

In addition to the previously mentioned also manual control of the breaker whether open or close during the autoreclosing cycle will always cause reset of autorecloser. For example if the breaker is closed manually during the Dead Time autorecloser will enter to general reclaim mode and if the breaker is closed towards fault it will cause lock-out of autorecloser function.

Autorecloser gives through information about its operations and statuses by on-line indications, events, registered data and also output signals which can be configured to any output or logical input in the device.

If network configuration is changed during the autoreclosing sequence the operation of the autorecloser can be modified also correspondingly by switching setting group which matches for the changed network situation.

Input signals for autorecloser control

For the function is used available hardware and software digital signal statuses and command signals. The signals can be divided into Request, Command and Control signals based on how they are dealt in the function. These input signals are also setting parameters for the function. The amount of needed setting parameters depends of the required autoreclosing scheme.

Table 3.124 AR input signals.

Signal	Range	Description
AR spontaneous blocking	Any binary signal in the IED	Input for dynamically block the autoreclosing. When input is activated the recloser will halt its operation and refuses any further requests. When signal is released recloser will continue its operation as were before receiving this signal.
AR On/Off	Any binary signal in the IED	Input for enabling or disabling the autorecloser by user selected input. Parameter Use AR On/Off signals defines if this input signal is in use or not.
AR manual reset	Any binary signal in the IED	Input for resetting the recloser manually in case it is locked due to final trip or any other possible cause for locking.
AR Locking	Any binary signal in the IED	Locking of the autorecloser so that it needs manual reset before its operation is allowed to be set ready.
AR1 Request	Any binary signal in the IED	Reclosing request 1, highest priority request which overrules all lower priority requests for autoreclosing. When this request signal is activated and other conditions for reclosing are met a shot will be applied.
AR2 Request	Any binary signal in the IED	Reclosing request 2, second highest priority request which overrules all lower priority requests for autoreclosing. When this request signal is activated and other conditions for reclosing are met a shot will be applied.
AR3 Request	Any binary signal in the IED	Reclosing request 3, third highest priority request which overrules all lower priority requests for autoreclosing. When this request signal is activated and other conditions for reclosing are met a shot will be applied.
AR4 Request	Any binary signal in the IED	Reclosing request 4, fourth highest priority request which overrules all lower priority requests for autoreclosing. When this request signal is activated and other conditions for reclosing are met a shot will be applied.
AR5 Request	Any binary signal in the IED	Reclosing request 5, lowest priority request which overrules all lower priority requests for autoreclosing. When this request signal is activated and other conditions for reclosing are met a shot will be applied.
Critical Request	Any binary signal in the IED	Critical request for autoreclosing, if this signal is activated the autorecloser shall go directly to locked state and trip the breaker directly in the moment the request was received.

Status change of the input signals will always cause recorded event also in the object registers and object continuous status indications. Events can be enabled or disabled according to the application requirements.

Output signals of auto-recloser

Output functions of the autorecloser in this mean are indication signals only. The breaker open and close commands are controlled by object function.

Table 3.125 AR output signals.

Signal	Description
AR On	When the autorecloser is enabled. This signal can be OFF if parameter Use AR On/Off signals is set to Yes and the input AR On/Off is inactive.
AR In Progress	When autorecloser has opened the breaker and is calculating time towards closing the breaker this signal is activated.
AR Dead time on	When autorecloser has opened the breaker and is calculating time towards closing the breaker this signal is activated.
AR Running	When autorecloser is in running mode this signal is activated. Signal can be connected to any relay IO as well as into communication protocols.
AR1 Request On	When autorecloser is executing shot requested by AR1 priority this signal is activated. Signal can be connected to any relay IO as well as into communication protocols.
AR2 Request On	When autorecloser is executing shot requested by AR2 priority this signal is activated. Signal can be connected to any relay IO as well as into communication protocols.
AR3 Request On	When autorecloser is executing shot requested by AR3 priority this signal is activated. Signal can be connected to any relay IO as well as into communication protocols.
AR4 Request On	When autorecloser is executing shot requested by AR4 priority this signal is activated. Signal can be connected to any relay IO as well as into communication protocols.
AR5 Request On	When autorecloser is executing shot requested by AR5 priority this signal is activated. Signal can be connected to any relay IO as well as into communication protocols.
AR Shot1 Running	When autorecloser is executing Shot1 this signal is activated. Signal can be connected to any relay IO as well as into communication protocols.
AR Shot2 Running	When autorecloser is executing Shot2 this signal is activated. Signal can be connected to any relay IO as well as into communication protocols.
AR Shot3 Running	When autorecloser is executing Shot3 this signal is activated. Signal can be connected to any relay IO as well as into communication protocols.
AR Shot4 Running	When autorecloser is executing Shot4 this signal is activated. Signal can be connected to any relay IO as well as into communication protocols.
AR Shot5 Running	When autorecloser is executing Shot5 this signal is activated. Signal can be connected to any relay IO as well as into communication protocols.
AR Sequence finished	When autorecloser has closed the breaker after last shot and is waiting for the final trip to occur or the reclaim time to run out this signal is activated.
Final Trip	When autorecloser has executed Final Trip command this signal is activated. Signal can be connected to any relay IO as well as into communication protocols.
AR Locked	When autorecloser is in Locked mode this signal is activated. Signal can be connected to any relay IO as well as into communication protocols.
AR Operation inhibit	When autorecloser is in Inhibit mode this signal is activated. Signal can be connected to any relay IO as well as into communication protocols.
AR Lockout delay On	When autorecloser is calculating Lockout delay this signal is activated. Signal can be connected to any relay IO as well as into communication protocols.
AR Arcing time On	When autorecloser is calculating Arcing time this signal is activated. Signal can be connected to any relay IO as well as into communication protocols.
AR Reclaim time On	When autorecloser is calculating Reclaim time this signal is activated. Signal can be connected to any relay IO as well as into communication protocols.
AR Ready	When autorecloser is ready to execute the reclosing sequence in case a fault is detected this signal is active.
AR Lockout after successful sequence	When autorecloser sequence has been successful but new fault was detected before lockout time has been depleted no new sequence will be started and this signal will be activated. Instead AR will go into locked mode.

Setting parameters

Autorecloser function has freely configurable settings for all areas of the function in order to control the operation of the autoreclosing application to suit different kind of needs. Operation of the autorecloser can be static or dynamic based on if setting groups are used. In autorecloser are found basic settings and shot related settings. Basic settings control the desired Object selection as well as general behavior of the autorecloser in different operating schemes.

Table 3.126 Autorecloser basic settings.

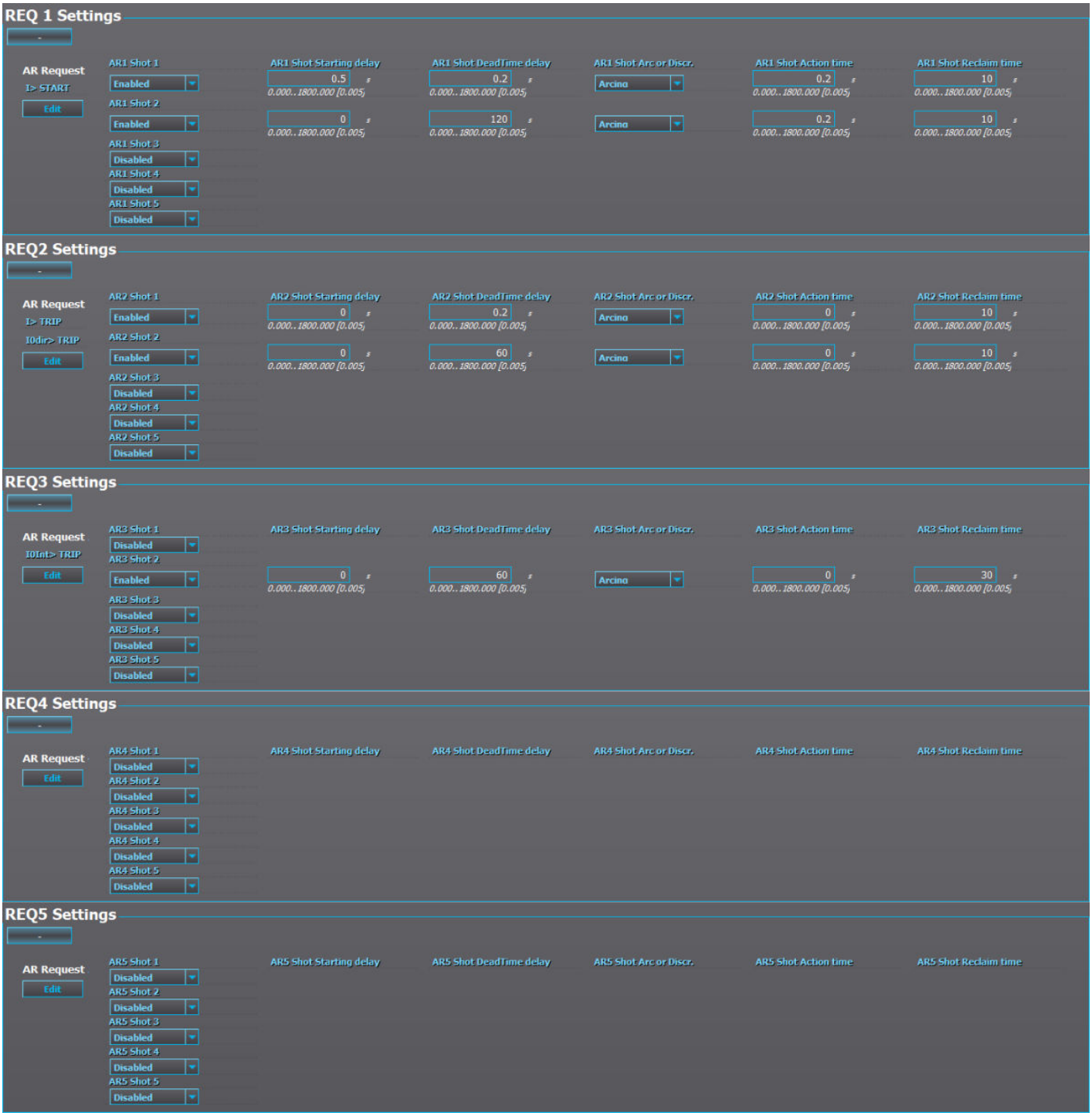
Setting	Range	SG	Description
AR Mode	0:Disabled 1:Enabled	No	Selection of the Autorecloser Enabled / Disabled in the configuration. Default value is Disabled.
AR Object	0:Object 1 1:Object 2 2:Object 3 3:Object 4 4:Object 5	8	Selection of the monitored / controlled breaker object. This selection defines the Object the autorecloser monitoring and control signals are issued. This selection can be changed dynamically by setting group selection in real time in the IED. Default setting is Object 1.
AR Enabled in SG	0:Disabled 1:Enabled	8	Selection of the autoreclosing activation in current setting group. It is possible to disable / enable autoreclosing in each setting group independently. This selection can be changed dynamically by setting group selection in real time in the IED. Default setting is Disabled.
Manual resetting	0:Required 1:Obj Close resets	8	Selection of the autorecloser resetting after locking (final trip, error condition), can be set so that only manual reset to resetting input of the function resets autorecloser or general breaker close command from any source resets the autorecloser. This selection can be changed dynamically by setting group selection in real time in the IED. Default setting is Manual reset required.
General reclaim	0:Only shot reclaim 1:Shot reclaim and general reclaim	8	Selections if autorecloser runs after successful reclose (including shot reclaim time) the general reclaim (object close reclaim time) in which if request for autoreclosing is applied will direct the autorecloser to locked state. If enabled this selection will define the minimum time allowed in between of autoreclosing cycles without changing the shot specific reclaim times. This selection can be changed dynamically by setting group selection in real time in the IED. Default setting is Only shot reclaim.
Object close reclaim	0.000...1800.000s by step of 0.005s	8	Setting for general/object close reclaim time. This time starts when the object is manually closed or if general reclaim time is selected after successful autoreclosing. If during this time autoreclosing request is applied autorecloser will enter to locked state preventing further reclosing attempts. This selection can be changed dynamically by setting group selection in real time in the IED. Default setting is 10.000s.
Lockout time	0.000...1800.000s by step of 0.005s	8	Setting of autorecloser lock-out after successful reclosing. When set to 0.000 recloser enters directly to ready state after successful reclosing. If this time is running and new reclosing request is applied autorecloser will enter to locked state preventing further reclose attempts. This selection can be changed dynamically by setting group selection in real time in the IED. Default setting is 0.000s (disabled)

Table 3.127 Autorecloser shot settings.

Setting	Range	SG	Description
AR1,2,3,4,5 Shot 1,2,3,4,5	0:Disabled 1:Enabled	8	Shotx selection enabled / disabled for request ARx. If disabled ARx request will skip Shot 1 and seek for next enabled shot. If enabled ARx request will

Setting	Range	SG	Description
			execute shot according to Shot1 settings. This selection can be changed dynamically by setting group selection in real time in the IED.
AR1,2,3,4,5 Shot 1,2,3,4,5 Starting delay	0.000...1800.000s by step of 0.005s	8	Shotx Starting Delay. This setting defines the minimum time ARx request has to be active before entering to Dead time delay counting. This setting is used only when the ARx request is made from function Start signal. If set with function Trip request to other than 0.000s value will prevent autoreclosing from starting. When the shot is not first one in all cases this setting should be set to 0.000s. This selection can be changed dynamically by setting group selection in real time in the IED. Default setting 0.000s.
AR1,2,3,4,5 Shot 1,2,3,4,5 DeadTime delay	0.000...1800.000s by step of 0.005s	8	Shotx Dead Time delay. This setting defines the breaker open time before autorecloser closes the breaker. Time calculation starts from breaker open signal. This selection can be changed dynamically by setting group selection in real time in the IED. Default setting 0.000s.
AR1,2,3,4,5 Shot 1,2,3,4,5 Arc or Discr.	0:Arcing 1:Discrimination	8	Shotx selection for the action after Dead Time in case fault persists when the breaker is closed. Selection of Arcing or Discrimination behavior depends of the application. When arcing time is selected autorecloser shall keep the breaker closed until Action time is spent and with Discrimination time if during Action time new request is activated recloser shall lock-out during the Reclaim time. This selection can be changed dynamically by setting group selection in real time in the IED. Default setting is Arcing time.
AR1,2,3,4,5 Shot 1,2,3,4,5 Action time	0.000...1800.000s by step of 0.005s	8	Shotx Action time setting after Dead Time and breaker is closed. This setting defines maximum arcing time or discrimination time when Reclaim time is running. When set to 0.000s Arcing or Discrimination time is disabled in the autoreclosing scheme. This selection can be changed dynamically by setting group selection in real time in the IED. Default setting 0.000s.

Figure 3.106 Autorecloser shot setting parameters.



Autorecloser shot settings are grouped into corresponding rows where setting of each shot is straightforward. From the settings can be seen how the reclosing cycle is executed by each request row by row and which functions initiate requests and which shots and requests are in use.

This setting example presents two shot autoreclosing. For example of the reading of the settings AR1 request is started by I> Start signal and AR2 is started by I0Dir> Trip signal. Timings for AR1 is 500ms starting time followed by 200ms Dead time which after 200ms Arcing time and 10s Reclaim time for Shot 1. If Shot 1 fails follows 120s dead time, 200ms Arcing time and 10s Reclaim time. If Shot 2 fails recloser shall init Final Trip. For AR2 request the reading of the settings is exactly the same, the values can be read from 2nd row. 3rd request has just one shot with 60 second dead time. If AR4 or 5 requests are activated, from the corresponding rows from left to right and from up to down can be seen the autoreclosing schemes for each request.

Inhibit and Locked states of auto-recloser function

Autorecloser can have several reasons to go into *locked* and *inhibit* states where reclosing for some given reason cannot be allowed. When autorecloser function enters the *not ready* state it will give indication of the reason it cannot be in ready state in order to quickly rectify what is causing the problem of the functions operation. Reason is indicated in the autorecloser registers-menu.

Inhibit reasons for autorecloser are following:

- AR is blocked (from Blocking input)
- AR is not enabled
- AR is calculating lock-out delay
- Object open or close is blocked
- Object status is not known
- General reclaim time is running
- AR is locked

When AR is in inhibit state it will recover to ready state when the reason for the inhibition is removed.

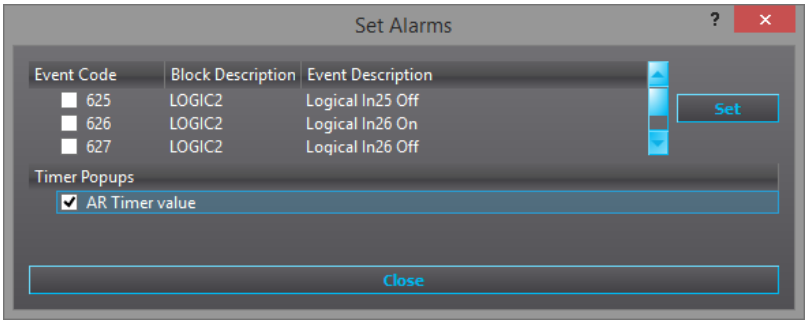
Lock-out reasons for autorecloser are following:

- Lock down signal is init (from Lockdown input)
- Final Trip signal is given
- Object not ready failed in given time (from Object)
- Object no sync failed in given time (from Object)
- Object open timeout (from Object)
- Object close timeout (from Object)
- AR request init during General reclaim time
- AR request was not released during Dead Time
- Critical request init in any state of autoreclosing cycle

When AR is in Locked state it can be recovered only by user input either from manual reset input or by closing the breaker manually. This depends on if the parameter *Require manual resetting* is set to *OBJ close resets* or *Required*.

Displaying auto recloser timers in mimic view

It is possible to enable timers to display in mimic view. The timer will display the reclaim time and dead time delay. To do this load the aqs file of the relay and enable AR timer value in *Tools → Events and logs → Alarm events*. After this click Set-button.



Events and registers

The AR function generates events and registers from the status changes of monitored signals as well as control command fails and operations. To main event buffer it is possible to select status “On” or “Off” messages.

12 last registers are available in the function where the triggering event of the function is recorded with time stamp and process data values.

Table 3.128 Event codes of the AR function.

Event Number	Event channel	Event block name	Event Code	Description
4032	63	AR1	0	AR Ready On
4033	63	AR1	1	AR Ready Off
4034	63	AR1	2	AR Locked Reset
4035	63	AR1	3	AR Reclosing request rejected On
4036	63	AR1	4	AR Reclosing request rejected Off
4037	63	AR1	5	AR Reclosing request On
4038	63	AR1	6	AR Reclosing request Off
4039	63	AR1	7	User Operated Obj AR halted and reset
4040	63	AR1	8	Object failure, AR locked
4041	63	AR1	9	Shot Failed
4042	63	AR1	10	AR cycle end due to Discr request
4043	63	AR1	11	AR Shot Clear
4044	63	AR1	12	Object Close Request
4045	63	AR1	13	Object Open Request
4046	63	AR1	14	Inhibit condition On
4047	63	AR1	15	Inhibit condition Off
4048	63	AR1	16	Locking condition On
4049	63	AR1	17	Locking condition Off
4050	63	AR1	18	Reserved
4051	63	AR1	19	AR1 Request On
4052	63	AR1	20	AR1 Request Off
4053	63	AR1	21	AR2 Request On
4054	63	AR1	22	AR2 Request Off
4055	63	AR1	23	AR3 Request On
4056	63	AR1	24	AR3 Request Off
4057	63	AR1	25	AR4 Request On
4058	63	AR1	26	AR4 Request Off
4059	63	AR1	27	AR5 Request On
4060	63	AR1	28	AR5 Request Off
4061	63	AR1	29	Critical Request On
4062	63	AR1	30	Critical Request Off
4063	63	AR1	31	AR Running On
4064	63	AR1	32	AR Running Off
4065	63	AR1	33	Shot 1 Execute On
4066	63	AR1	34	Shot 1 Execute Off
4067	63	AR1	35	Shot 2 Execute On
4068	63	AR1	36	Shot 2 Execute Off
4069	63	AR1	37	Shot 3 Execute On
4070	63	AR1	38	Shot 3 Execute Off

Event Number	Event channel	Event block name	Event Code	Description
4071	63	AR1	39	Shot 4 Execute On
4072	63	AR1	40	Shot 4 Execute Off
4073	63	AR1	41	Shot 5 Execute On
4074	63	AR1	42	Shot 5 Execute Off
4075	63	AR1	43	Seq Finished Final Trip Armed
4076	63	AR1	44	Final Trip Executed
4077	63	AR1	45	Lock Out Time On
4078	63	AR1	46	Lock Out Time Off
4079	63	AR1	47	General Reclaim time On
4080	63	AR1	48	General Reclaim time Off
4081	63	AR1	49	Shot Start Time On
4082	63	AR1	50	Shot Start Time Off
4083	63	AR1	51	Dead Time On
4084	63	AR1	52	Dead Time Off
4085	63	AR1	53	Arc Discr Time On
4086	63	AR1	54	Arc Discr Time Off
4087	63	AR1	55	Shot Reclaim Time On
4088	63	AR1	56	Shot Reclaim Time Off
4089	63	AR1	57	Seq. finished Off
4090	63	AR1	58	Final Trip Executed Off
4091	63	AR1	59	Object Close Request Off
4092	63	AR1	60	AR On
4093	63	AR1	61	AR Off
4094	63	AR1	62	AR Running (DT) On
4095	63	AR1	63	AR Running (DT) Off

In the register of the OBJ function is recorded statuses, commands etc. “On” event process data. In the table below is presented the structure of AR function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 3.129 Register content.

Date & Time	Event code	Timer value	Used SG	Inhibit reason on	Inhibit reason off	Locked reason on	Locked reason off	Status code	Timer on

AR registers are treated different from other registers seen in the IED. Following example is part from autoreclosing sequence:

dd.mm.yyyy hh:mm:ss.mss	AR Status:, AR is ready, AR is not running, AR2 Requested, Executing Shot1 AR Timers: No timers running 0.000 s

dd.mm.yyyy hh:mm:ss.mss	AR Status:, AR is ready, AR is not running, Start time counting, AR2 Requested, Executing Shot1 AR Timers: Start Delay 0.000 s
dd.mm.yyyy hh:mm:ss.mss	AR Status:, AR is ready, AR is running, Start time counting, AR2 Requested, Executing Shot1 AR Timers: Start Delay 0.000 s
dd.mm.yyyy hh:mm:ss.mss	AR Status: AR is ready, AR is running, Dead time counting, AR2 Requested, Executing Shot1 AR Timers: Dead Time 0.195 s
dd.mm.yyyy hh:mm:ss.mss	AR Status:, AR is ready, AR is running, Dead time counting, Reclaim time counting, AR2 Requested, Executing Shot1 AR Timers: Dead Time -0.270 s

Corresponding event list is as below (including also Object and protection events):

dd.mm.yyyy hh:mm:ss.mss	1664	NEF1 Start ON
dd.mm.yyyy hh:mm:ss.mss	1666	NEF1 Trip ON
dd.mm.yyyy hh:mm:ss.mss	4065	AR1 Shot 1 Execute On
dd.mm.yyyy hh:mm:ss.mss	4037	AR1 AR Reclosing request On
dd.mm.yyyy hh:mm:ss.mss	4053	AR1 AR2 Request On
dd.mm.yyyy hh:mm:ss.mss	4081	AR1 Shot Start Time On
dd.mm.yyyy hh:mm:ss.mss	4045	AR1 Object Open Request
dd.mm.yyyy hh:mm:ss.mss	2944	OBJ1 Object Intermediate
dd.mm.yyyy hh:mm:ss.mss	2952	OBJ1 Open Request On

dd.mm.yyyy hh:mm:ss.mss	2955	OBJ1 Open Command On
dd.mm.yyyy hh:mm:ss.mss	4063	AR1 AR Running On
dd.mm.yyyy hh:mm:ss.mss	2954	OBJ1 Open Request Off
dd.mm.yyyy hh:mm:ss.mss	1665	NEF1 Start OFF
dd.mm.yyyy hh:mm:ss.mss	1667	NEF1 Trip OFF
dd.mm.yyyy hh:mm:ss.mss	4038	AR1 AR Reclosing request Off
dd.mm.yyyy hh:mm:ss.mss	2945	OBJ1 Object Open
dd.mm.yyyy hh:mm:ss.mss	2956	OBJ1 Open Command Off
dd.mm.yyyy hh:mm:ss.mss	4082	AR1 Shot Start Time Off
dd.mm.yyyy hh:mm:ss.mss	4083	AR1 Dead Time On
dd.mm.yyyy hh:mm:ss.mss	2963	OBJ1 Status Change Off
dd.mm.yyyy hh:mm:ss.mss	4044	AR1 Object Close Request
dd.mm.yyyy hh:mm:ss.mss	2957	OBJ1 Close Request On
dd.mm.yyyy hh:mm:ss.mss	2958	OBJ1 Close Fail
dd.mm.yyyy hh:mm:ss.mss	2959	OBJ1 Close Request Off
dd.mm.yyyy hh:mm:ss.mss	2960	OBJ1 Close Command On
dd.mm.yyyy hh:mm:ss.mss	2962	OBJ1 Status Change On

dd.mm.yyyy hh:mm:ss.mss	2944	OBJ1 Object Intermediate
dd.mm.yyyy hh:mm:ss.mss	2946	OBJ1 Object Close
dd.mm.yyyy hh:mm:ss.mss	2961	OBJ1 Close Command Off
dd.mm.yyyy hh:mm:ss.mss	4087	AR1 Shot Reclaim Time On

As can be seen the registers complement the event list information in cases when the control has some unexpected behaviour. In this example can be seen that the Object has had issues on closing command execution which has caused the Dead Time to be 270 ms longer than it has been set. Reason for this behaviour can be verified from the Object registers.

dd.mm.yyyy hh:mm:ss.mss	ObjectOpen,WDIn,Open Allowed,Close Allowed,ObjectReady,Sync Ok,Obj opentime:0.025s
dd.mm.yyyy hh:mm:ss.mss	ObjectOpen,WDIn,Object not ready for Close request,Open Allowed, Close Allowed,Object Not Ready,Sync Ok
dd.mm.yyyy hh:mm:ss.mss	ObjectOpen,WDIn,Close request from Autorecloser,Close pending due to: Close wait for Ready,Open Allowed,Close Allowed,Object Not Ready,Sync Ok
dd.mm.yyyy hh:mm:ss.mss	ObjectOpen,WDIn,Open Allowed,Close Allowed,ObjectReady,Sync Ok
dd.mm.yyyy hh:mm:ss.mss	ObjectClosed,WDIn,Open Allowed,Close Allowed,ObjectReady,Sync Ok ,Obj closetime:0.030s

In this case the Object was not ready when it received the closing request from autorecloser and had the request pending until the Object was ready to execute the close command.

Auto-recloser operation counters

Auto-recloser function keeps statistical track of the operated auto-reclosing cycles and successful and failed shots.

Function records the following counters:

- Shot 1...5 started
- Shot 1...5 requested by AR1...5
- Shots failed
- Final Trips
- Shots cleared
- AR started

The counters are cumulative and update automatically according to the operations of the auto-recloser function. Statistics are collected in Registers-menu.

3.6.4 Fault locator (21FL) X → km

Fault locator is used for recording an estimated distance to the point where fault has occurred. It is mostly used in directional overcurrent protection or distance protection applications but can be also triggered by other protections as well. Function can be used if three phase current and three phase voltage have been connected to the relay. In the configuration the triggering signals, triggering current and reactance per km must be set.

Inputs for the function are the operating mode selections, setting parameters and measured and pre-processed voltage and current magnitudes and binary input signals. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the three output signal. Time stamp resolution is 1ms. Function provides also cumulative counter for fault locator triggering events.

Measured input values

Function block uses analog current and voltage measurements and calculated phase-to-phase loop impedances.

Table 3.130 Measurement magnitudes used by the FLX function

Signals	Description	Time base
VT1 U1,U2,U3	L-N or L-L voltages of first voltage transformer	5 ms
CT1 IL1,IL2,IL3	Measurement of phase L1/A, L2/B & L3/B current	5 ms

Fault locator triggering

Trig fault locator input defines which signal triggers the fault locator. This can be any binary signal generated by the unit. Generally using trip signal of protection functions or open status of the breaker is used.

For the fault locator to trig and record distance there are there are several conditions that have to be met. The first thing when receiving a triggering signal function checks if the calculation is blocked. Calculation blocking signals are determined by user set Block calculation matrix. Then the function checks if phase to earth voltages are available. If phase-to-earth voltages are not available fault locator can record only phase-to-phase impedance loops. If phase-to-earth voltages are available phase-to-neutral impedance loops can be recorded as well. Depending on measured phase currents at the moment of receiving a triggering signal the recorded impedance loop is chosen from the available options. See the tables below.

Table 3.131 Pick-up characteristics setting

Name	Description	Range	Step	Default
Trigger current>	Affects to the decision which impedance loop is recorded or if anything is recorded at all. See table below.	0.0xIn	0.1xIn	1xIn
Reactance per km	Used to calculate the distance to fault	0.000... 5.000ohm/km	0.001ohm/km	0.125ohm/km

Table 3.132 Current conditions needed to trig impedance recording.

Currents over limit	P-E voltages available	P-E Voltage not available
Recorded impedance	Recorded impedance	
IL1,IL2,IL3	XL12	XL12
IL1,IL2	XL12	XL12
IL2,IL3	XL23	XL23
IL1,IL3	XL31	XL31
IL1	XL1	No trig

Currents over limit	P-E voltages available	P-E Voltage not available
IL2	XL2	No trig
IL3	XL3	No trig

If none of the current measurement requirements are fulfilled when the function receives a triggering signal it will not record impedance.

Function blocking

In the blocking element the block signal is checked at the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If blocking signal is active when pick-up element activates the function shall not process the situation further.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup voltage values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Events

The FLX function generates events and registers from the status changes of triggering and calculation statuses. To main event buffer it's possible to select status "On" or "Off" messages.

12 latest registers where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values are available in the function.

Table 3.133 Event codes of FLX function.

Event Number	Event channel	Event block name	Event Code	Description
2752	43	FLX1	0	Flocator triggered On
2753	43	FLX1	1	Flocator triggered Off
2754	43	FLX1	2	Flocator Calculation On
2755	43	FLX1	3	Flocator Calculation Off

In the table below is presented the structure of FLX function register content. This information is available in 12 last recorded events.

Table 3.134 Register content.

Date & Time	Event code	Fault type	Fault direction	Fault reactance	Fault Current	Fault Current	Fault distance	Setting group in use
dd.mm.yyyy hh:mm:ss.mss	2752-2755 Descr.	L1-L2; L2-L3; L3-L1; L1-N; L2-N; L3-N; L1-L2-L3	Not detected; Forward; Reverse	In Ohms	In per unit value	In primary value	In km	SG 1-8

3.7 Machine protections

3.7.1 Power factor protection PF< (55)

Power factor is the ratio of active power to apparent power (cos φ = P / S). In fully resistive load power factor is 1. In partially inductive loads power factor is under 1. Power factor protection can detect too low power factor value.

Outputs of the function are Start Trip and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. Power factor protection function utilizes total of eight separate setting groups which can be selected from one common source.

The operational logic consists of input magnitude processing, input magnitude selection, saturation check, threshold comparator, block signal check, time delay characteristics and output processing.

Inputs for the function are the operating mode selections, setting parameters and measured and pre-processed current magnitudes and binary input signals. Function generates output signals ALARM START, ALARM, START, TRIP and BLOCKED which can be used for direct IO controlling or for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the five output signals. In instant operating mode the function outputs START and TRIP events simultaneously with equivalent time stamp. Time stamp resolution is 1ms. Function provides also cumulative counters for ALARM START, ALARM, START, TRIP and BLOCKED events.

Measured input values

Function uses power factor value. -20ms averaged value of the selected magnitude is used for pre-fault data registering.

Table 3.135 Analogic magnitudes used by the UPF function.

Signal	Description	Time base
3PH cos φ	Three phase cos phi (power factor)	5 ms

Pick-up characteristics

Pick-up of the UPF function is controlled by *Pick-up setting PF< (lead or lag) Trip* and *Pick-up setting PF< (lead or lag) Alarm* setting parameters, which define the minimum allowed power factor before action from the function. The function constantly calculates the ratio in between of the pick-up settings and measured magnitude (power factor). Reset ratio of 103 % is inbuilt in the function and is always related to the pick-up setting value.

Table 3.136 Pick-up characteristics setting

Name	Description	Range	Step	Default
Pick-up setting PF< (lead or lag) Trip	Pick-up setting for tripping	0.05...0.99	0.01	0.8
Pick-up setting PF< (lead or lag) Alarm	Pick-up setting for alarming	0.05...0.99	0.01	0.9

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Function blocking

In the blocking element the block signal is checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup current values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Operating time characteristics for trip and reset

This function supports definite time delay (DT) and inverse definite minimum time (IDMT) delay types. For detailed information on these delay types refer to chapter General properties of a protection function.

Events and registers

The UPF function generates events and registers from the status changes of ALARM START, ALARM, START, TRIP and BLOCKED. To main event buffer is possible to select status “On” or “Off” messages. The UPF function offers four independent instances which events are segregated for each instance operation.

12 last registers are available in the function where the triggering event of the function (ALARM START, ALARM, START, TRIP and BLOCKED) is recorded with time stamp and process data values.

Table 3.137 Event codes of UPF-function.

Event Number	Event channel	Event block name	Event Code	Description
8256	129	UPF1	0	Block On
8257	129	UPF1	1	Block Off
8258	129	UPF1	2	Start On
8259	129	UPF1	3	Start Off
8260	129	UPF1	4	Trip On
8261	129	UPF1	5	Trip Off
8262	129	UPF1	6	Alarm Start On
8263	129	UPF1	7	Alarm Start Off
8264	129	UPF1	8	Alarm On
8265	129	UPF1	9	Alarm Off

In the register of the UPF function is recorded start, trip or blocked “On” event process data. In the table below is presented the structure of UPF function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 3.138 Register content.

Date & Time	Event code	Trigger PF	Fault PF	Prefault PF	Trip time remaining	Used SG
dd.mm.yyyy hh:mm:ss.mss	8256-8265 Descr.	Start average current	Trip -20 ms averages	Start -200 ms averages	0ms -1800s	1 - 8

3.7.2 Machine thermal overload protection Tm> (49M)

Thermal overload function for machines (TOLM) is used for electric machines like synchronous and asynchronous motors and generators thermal capacity monitoring and protection. This function can also be used for any single or multiple time constant applications like inductor chokes, certain types of transformers and any other static units which don’t have active cooling in addition to the cables and overhead lines.

TOLM function constantly monitors phase TRMS currents (including harmonics up to 31st) instant values and calculates the set thermal replica status in 5ms cycles. TOLM function includes total memory function of the load-current conditions according to IEC 60255-8

TOLM function is based into thermal replica, which represents the protected object thermal loading in relation to the effective current in the object. Thermal replica includes the calculated thermal capacity used in the “memory” since it is integral function which tells apart this function from normal overcurrent function operating principle for the overload protection applications.

In heating/cooling situation the thermal image for TOLM function is calculated according to equations described below:

Long time constant thermal image calculation:

$$\theta_{tL} = \left(\left(\theta_{t-1} - \left(\frac{I_{EM}}{I_N \times k_{SF} \times k_{AMB}} \right)^2 \times e^{-\frac{t}{\tau_{1h/\tau_{1c0/\tau_{1cr}}}}} \right) + \left(\frac{I_{EM}}{I_N \times k_{SF} \times k_{AMB}} \right)^2 \right) \times (1 - W_f)$$

Short time constant thermal image calculation:

$$\theta_{tS} = \left(\left(\theta_{t-1} - \left(\frac{I_{EM}}{I_N \times k_{SF} \times k_{AMB}} \right)^2 \times e^{-\frac{t}{\tau_{2h/\tau_{2c}}}} \right) + \left(\frac{I_{EM}}{I_N \times k_{SF} \times k_{AMB}} \right)^2 \right) \times W_f$$

Where

$$I_{EM} = \sqrt{\left(\left(1 + \left(\left(\frac{I_2}{I_1} \right)^2 \times k_{NPS} \right) \right) \times {I_{MAX}}^2 \right)}$$

Whis is the effective current of the protected object including true RMS measurement maximum phase current and possible phase current unbalance condition.

- θ_{t-1} = Thermal image status in previous calculation cycle (the memory of the function)
- I_{MAX} = Measured maximum of the three TRMS phase currents
- I_N = Current for the 100 % thermal capacity to be used (pick-up current in p.u., with this current t_{max} will be achieved in time t)
- k_{SF} = Loading factor (service factor) coefficient, maximum allowed load current in per unit value depend of the protected object
- k_{AMB} = Temperature correction factor either from linear approximation or settable 10 point thermal capacity curve.
- τ_{1h} = Long thermal heating time constant of the protected object (in minutes)
- τ_{2h} = Short thermal heating time constant of the protected object (in minutes)
- τ_{1c0} = Long thermal cooling time constant (motor stopped) of the protected object (in minutes)
- τ_{1cr} = Long thermal cooling time constant (motor running) of the protected object (in minutes)
- τ_{2c} = Short thermal cooling time constant of the protected object (in minutes)
- W_f = Weighting factor in between of the t_1 and t_2
- I_1 = Measured positive sequence current of the fundamental frequency component

- I_2 = Measured negative sequence current of the fundamental frequency component
- k_{NPS} = Weighting factor of the NPS current biasing to the equivalent current calculation
- e = Euler's number
- t = Calculation time step in seconds (0.005s)

The result of the heating situation calculation is combined long and short time constant thermal image calculation:

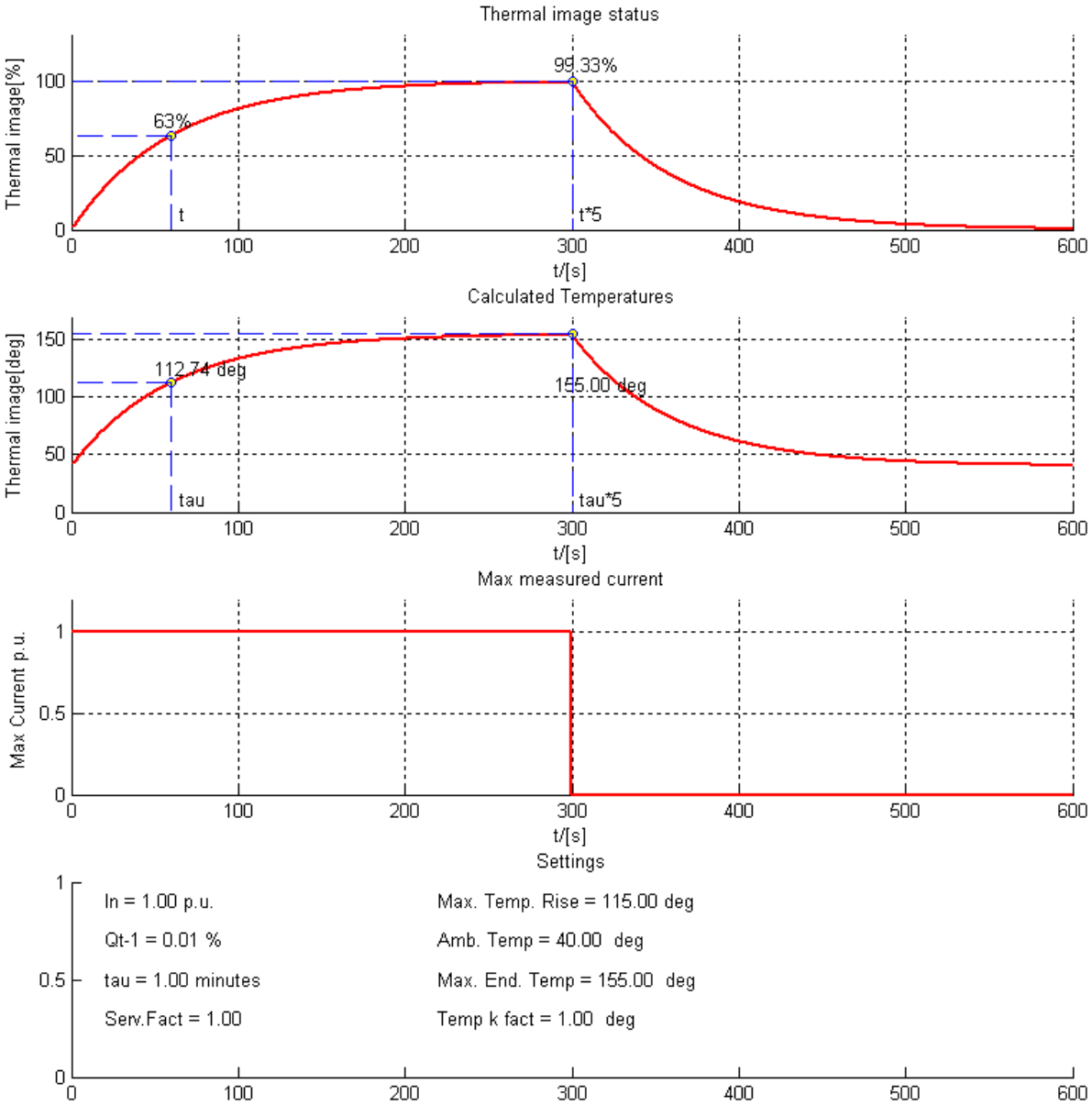
$$\theta_{t\%} = (\theta_{tL} + \theta_{tS}) \times 100\%$$

, where

- $\theta_{t\%}$ = Thermal image status in percent of the maximum thermal capacity used.

The basic operating principle of the thermal replica is based into that the nominal temperature rise is achieved when the protected object is loaded with nominal load in nominal ambient temperature. When the object is loaded with nominal load for time equal its heating constant tau (t), 63% of the nominal thermal capacity is used. When the loading continues until five times this given constant the used thermal capacity indefinitely approaches to 100% but never exceeds it. With a single time constant model cooling of the object follows this same behavior reversible to the heating when the current feeding is completely zero.

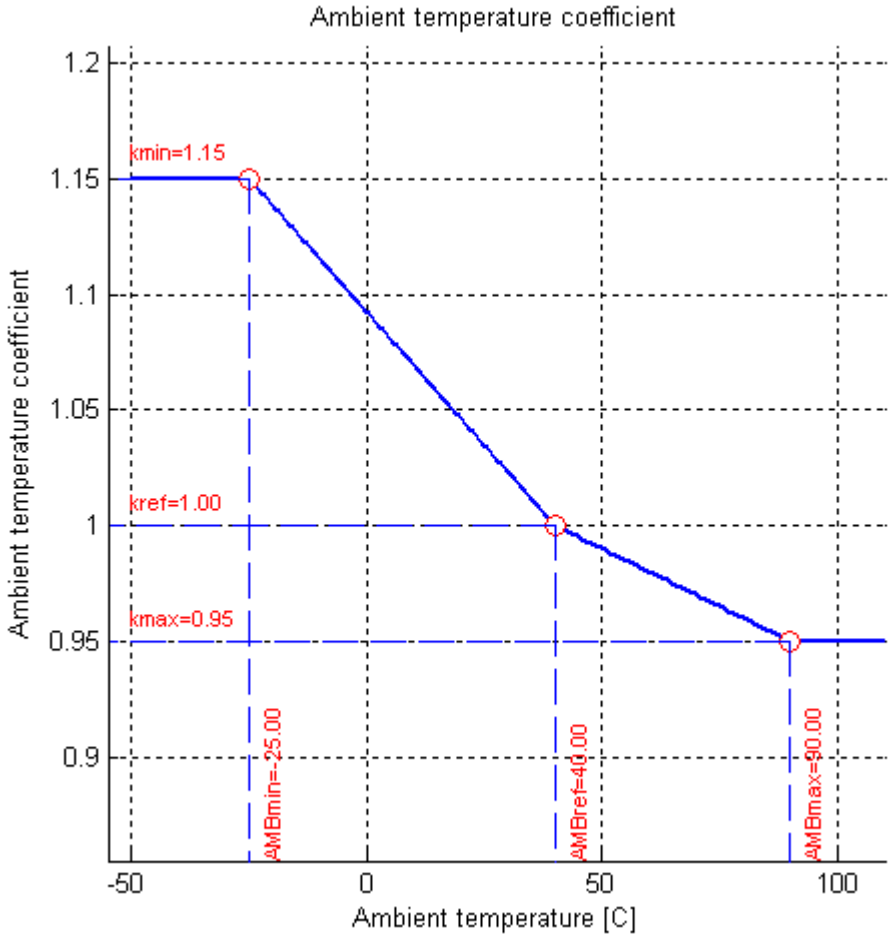
Figure 3.107 Thermal image calculation with nominal conditions, example single time constant thermal replica.



This described behavior is based into that assumption that the monitored object has a homogenous body which is generating and dissipating heat with a rate which is proportional to temperature rise caused by current squared. Installation conditions considering the prevailing conditions in the thermal replica are compensated with ambient temperature coefficient which is constantly calculated and changing when using RTD sensor for the measurement. When the ambient temperature of the protected object is stable it can be set manually.

Ambient temperature compensation takes into account the set minimum and maximum temperature and load capacity of the protected object and measured or set ambient temperature. The calculated coefficient is linear correction factor to the maximum allowed current which is presented with following formulas:

Figure 3.108 Ambient temperature coefficient calculation examples when reference temperature is +40 C with 3 point linear approximation and settable correction curve.



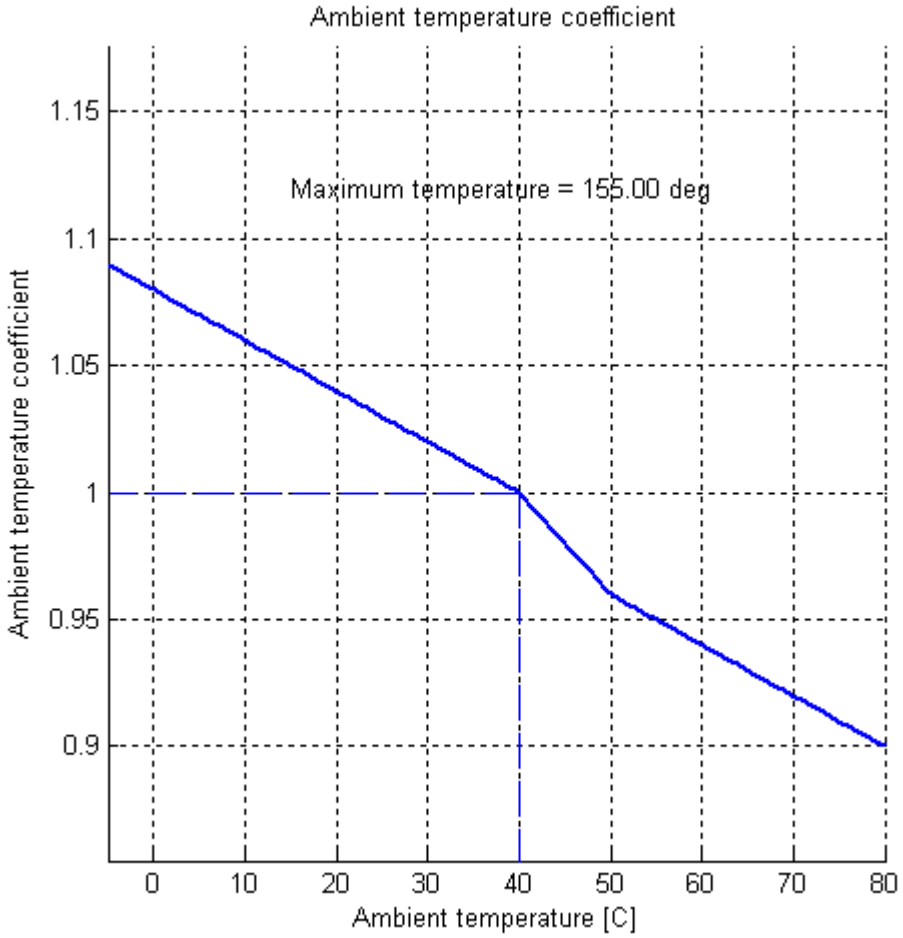
This mentioned ambient temperature coefficient relates to nominal temperature reference. +40 C is used by default (standard ambient temperature rating for machines) which gives coefficient value of 1.00 for the thermal replica.

Settable thermal capacity curve uses linear interpolation for ambient temperature correction with maximum 10 pairs of temperature – correction factor pairs.

Temperature and coefficient pairs are set to the TOLM function settable curve.

Figure 3.109 The correction coefficient curve for ambient temperature is shown in the figure.The reference temperature for electric machines usually is 40˚C which gives a correction coefficient of 1.00 which can referred as nominal temperature in this case.The curve does not need to be set with as many points as there is available.

Minimum setting is two pairs and the result will be straight line (if this is the case then better choice would be the linear approximation).

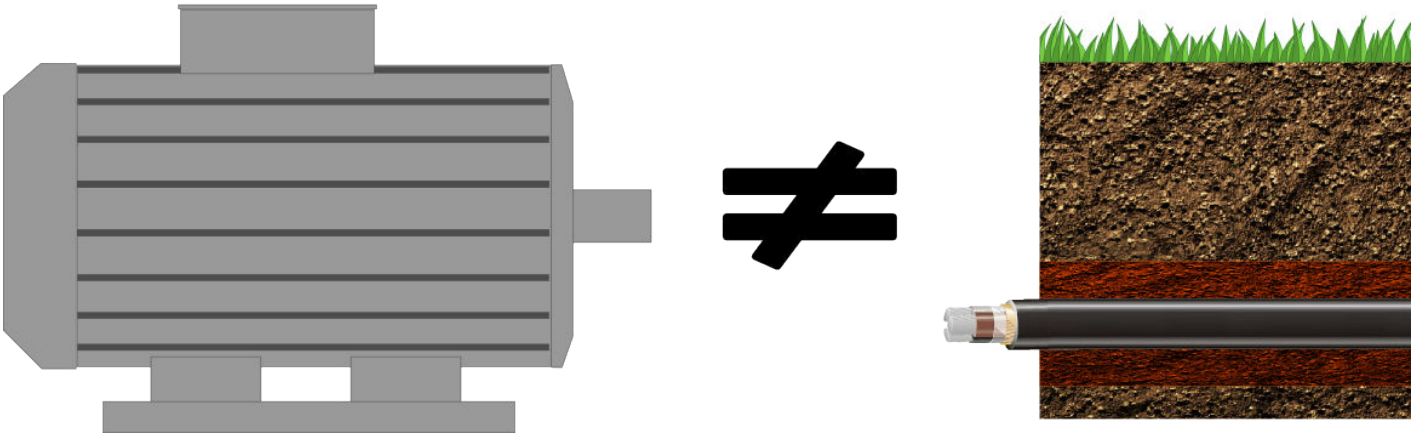


In the introduction of this chapter was presented the thermal image behavior of the single time constant model. When considering electric machines this is not the optimal solution especially when the motor drive is not start and stable loading (S1) but the motor is stopped and started frequently. In following the main reasons and differences of the single and multiple time constant models are explained.

By the terms of electrical machine the thermal behavior and time constants varies in between of heating and cooling as well as at certain point within heating and cooling when the loading current is decreased or increased instantly to minimum or maximum. This means in action that the thermal replica needs to have more settable time constants than one common constant for heating and cooling, which is the case with single time constant objects like cables. Minimum settable time constants are separate time constants for heating and cooling (most common practice).

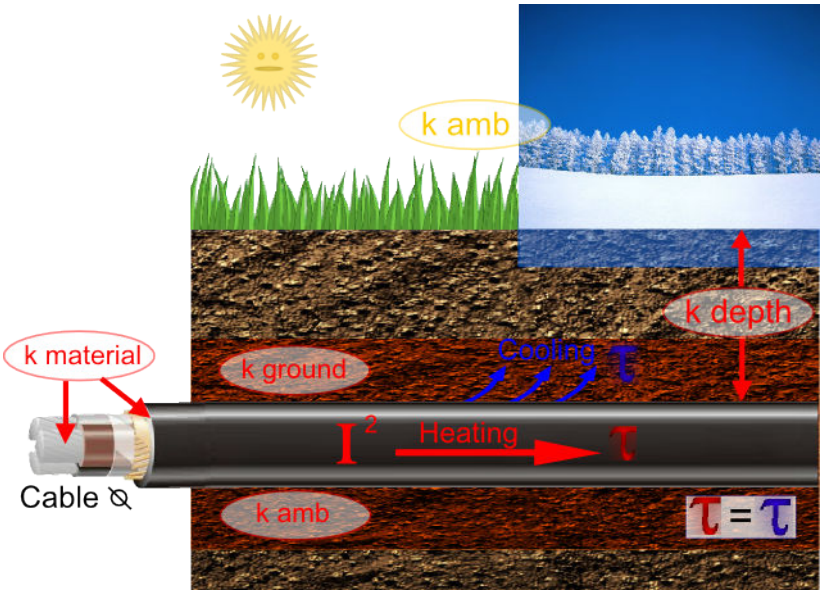
The reason for the separate heating and cooling constants is simply that the rotating machine (especially motor) usually has cooling fan in the same shaft with its drive and when the motor is running it is cooling also the surface of itself. When the motor is stopped the cooling will stop also and the time constant is longer due to heat is dissipated to surrounding air slower. If the machine has active cooling then the cooling time constant may be the same with heating constant. Anyways in this case also the starting method (DOL / Soft start / YD) etc. will tell whether there is need for another time constants for locked rotor or overloading situations in order to achieve suitable thermal image for the machine.

Figure 3.110 Motors thermal behaviour is not similar than ground dug cables.



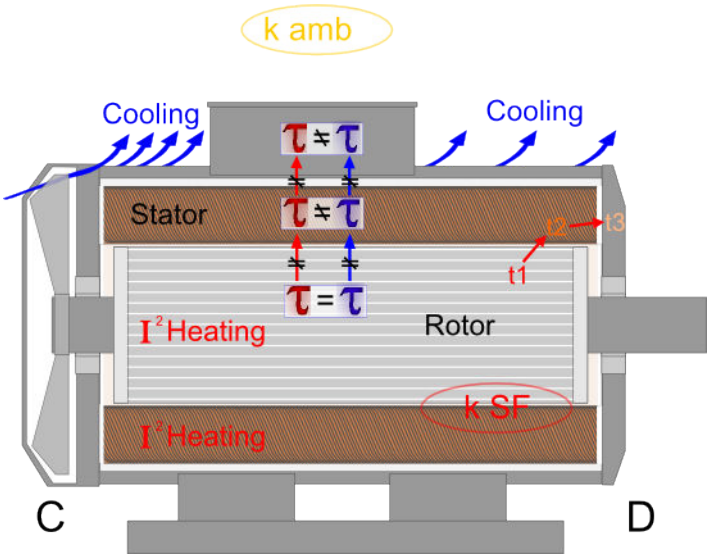
When figuring out the time constants in the motor compared to single time constant objects like cables for example can be seen following differences.

Figure 3.111 Factors effecting to cable current carrying capacity and cooling.



Cables current carrying capacity is mostly depend of the cross section of the conductor diameter as well as the conductor material. Second most important factor is the insulating material of the cable and how much it can withstand temperature. As can be seen all factors except the air temperature are quite stabile especially when the cable is dug deep enough so that it lies below the ground frost in places where the outside temperature can go under freezing point. Heat conducting from the cable into the surrounding ground is directly equal no matter if the cable is heating or cooling and it is defined by the ground composition how well the ground conducts the heat. However these matters are loading factors which effect only to the maximum current carrying capacity of the cable and they are not the time constants of the cable. When considering the time constants the only constant is the heating time constant and cooling time constant which in the case of ground dug cable is the same.

Figure 3.112 Simplified motor construction and time constants.

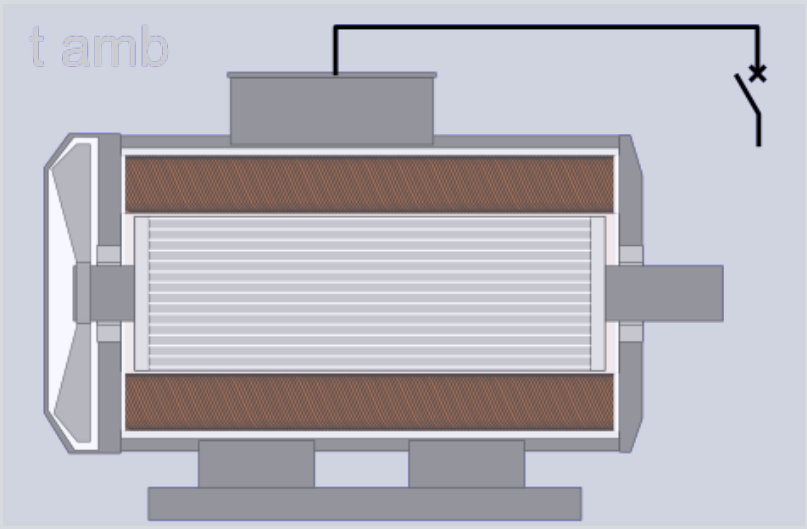


When looking at normal induction machine like electric motor the following major components can be found: Rotor, which as the name suggests is rotating and its shaft is used for power outlet from the motor (drive end), Stator generates the electromagnetic field which induces into rotor and makes it rotate (thus the name induction motor) and also the motor body which contains stator and rotor. Motors always have some cooling system. Most common is in the rotor shaft mounted fan (cooling end) and in bigger motors or slow rotating motors the cooling may be active with additional fans or with liquid cooling.

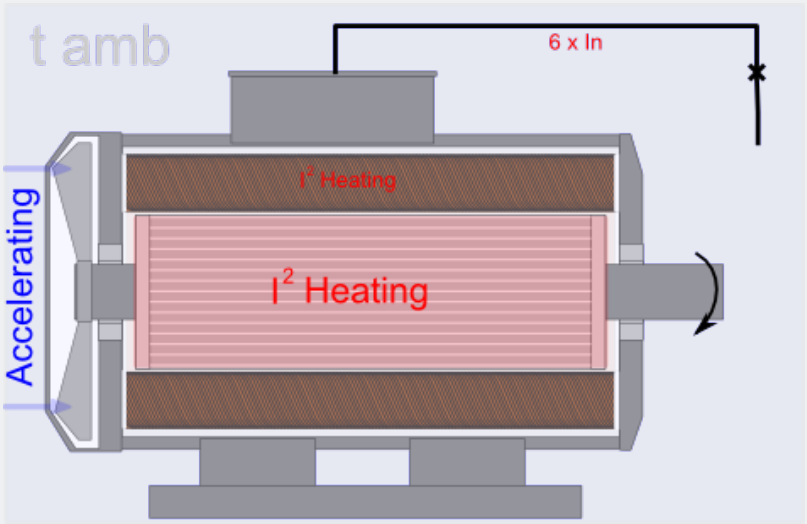
By looking at motor thermal properties can be found not just one but several very different components which all have thermal time constants of their own, rotor has own time constant which is the same for heating and cooling, stator has own time constant where the heating time constant is different from the cooling constant and also the motor body has own time constant for heating and cooling. In the terms of protecting the motor from overloading the rotor and stator are the parts which require to be taken care from overheating. Overheating in motor can cause insulator damages in the stator and melting of rotor bars. Both of these faults result to malfunction of the motor.

When considering the thermal behavior difference in between of single and multi-time constant objects like the cable and electric motor can be seen another fundamental difference. While the cable loading may as well differ during the operating conditions, high currents compared to nominal current are not in the normal profile usage but always indicate fault of some sort. With direct on line (DOL) starter motors high starting current (up to 6-7 times nominal) and the heat generation from it is very normal operation and happens every time the motor is started. Motor heating from ambient temperature to nominal temperature with direct on line (DOL) starting is described in following figures.

Table 3.139 Motor heating during DOL starting.

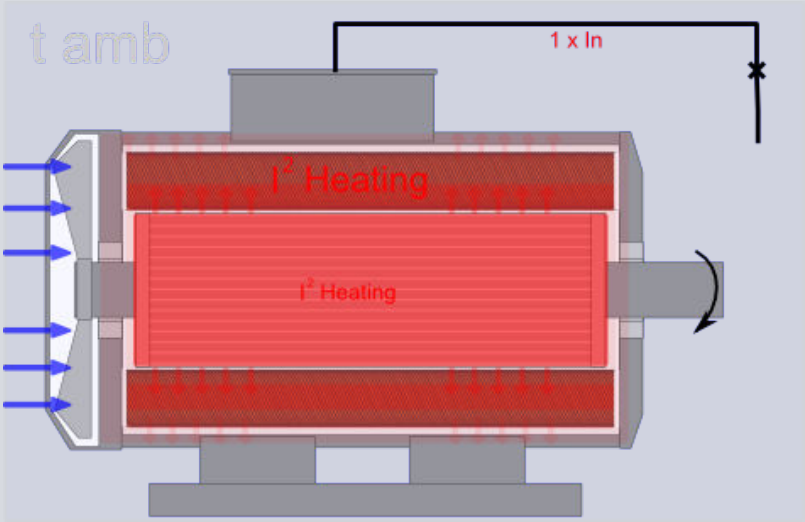


Motor is de-energized and all parts of it are in ambient temperature.



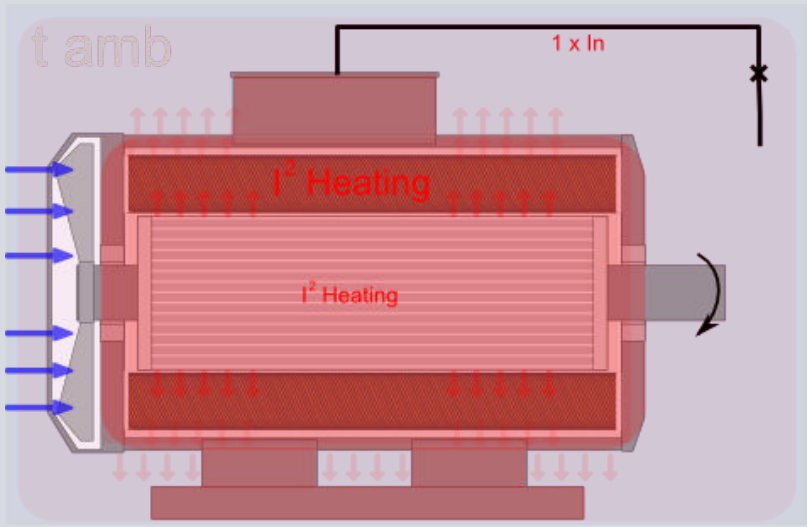
When the motor is energized the stator generates magnetic field which induces voltage to the squirrel cage rotor. Now the rotor is not yet rotating and the induced voltage and its caused current is maximum in the rotor (due to the rotating magnetic field in the stator with synchronous speed and the rotors slip now is 1 which causes that the induced voltage to the rotor is maximum and the current is maximum also) and it starts to heat up very quickly compared to stator. When the rotor is speeding up the difference in between of the stator magnetic field rotation and rotor rotation (rotor magnetic field) decreases.
The rotor speeding up leads to that the rotor current decreases which causes the rotor heating to decrease simultaneously. Also the cooling fan starts to rotate and cool the surface of the motor when the rotor speeds up. Depending of the size of the motor and the masses in the rotor and stator the starting up spent thermal capacity varies. In this term the motor start up can be rotor or stator limited which means of that which of these components limits the maximum start-up time for the motor. Most motors used are rotor

limited meaning that the rotor heats up to dangerously high temperatures before the stator.

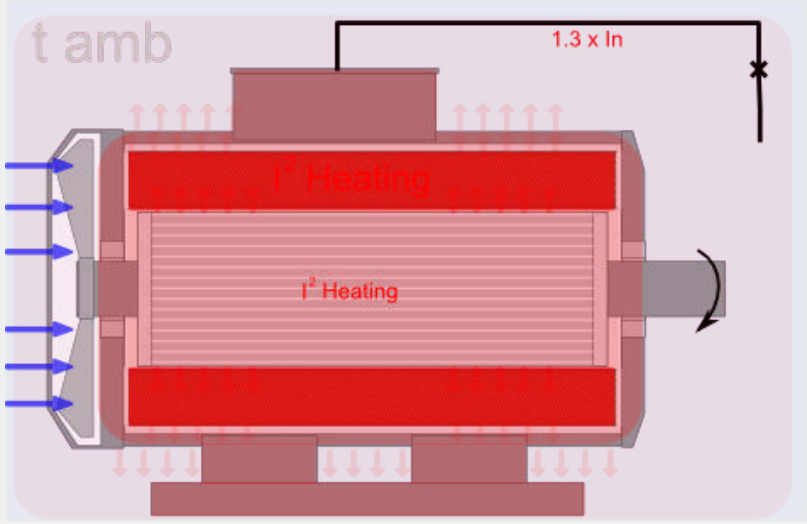


After motor is started and it is running with or without load the heat generation is switched in between of rotor and stator. When the rotor is rotating in range of nominal slip the magnetic fields of rotor and stator “cut” in nominal designed range and the voltage and its caused current in rotor is in nominal range also. Now when the motor is loaded or overloaded but it is rotating the overheating generated is for the stator only not the rotor (unless the load is so big that it stalls the motor and the situation considering the motor is back in to the starting conditions and non rotating rotor).
After the starting the cooling of the motor with a fan mounted into the rotor shaft is operational. Also the heat generated in the rotor during the starting will conduct through the stator windings into the body of the motor. This heat conduct from the rotor to stator and stator to body also is dependent of the motor masses. With a big motor the body can be slightly warm and rotor/stator completely melt already due to that the heat will not conduct so quickly from the motor inside to the body.

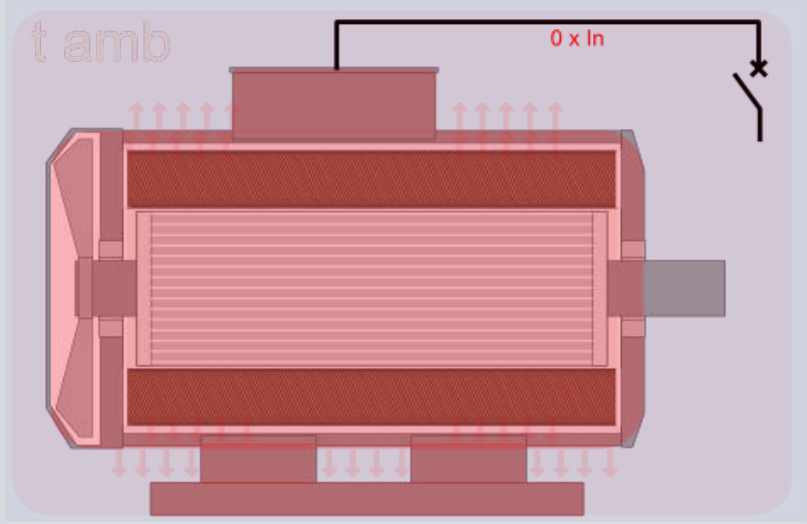
Table 3.140 Motor heating during overloading and motor cooling.



When the motor is run in nominal load for the time enough the temperatures to stabilize (5 x time constant) and the final temperatures are reached is said that the motor is running in its nominal temperature. Now the heat transfer is stabilized so that the heat generated in the motor is conducted to the surrounding air and the inside parts temperatures are not increasing anymore.



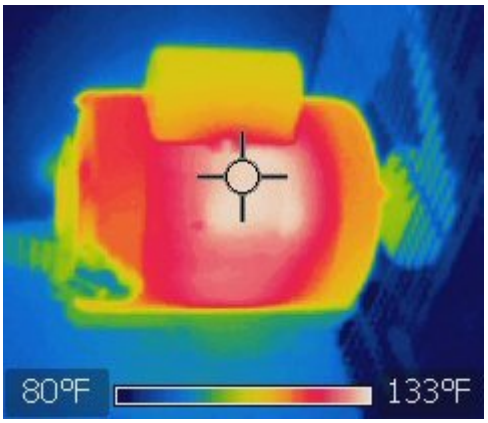
If the motor is overloaded the stator winding starts to heat up according its heating time constant and if the overload is not released in time it can lead to melting of the stator winding insulations which leads to short circuit and motor is said to be “burn”. For the rotor this situation does not differ much from its nominal conditions. When load increases also the slip increases slightly thus causing small increase to the induced voltage and current but when it is rotating the heating is not significant compared to nominal loading.



When the hot motor is de energized the temperatures inside the motor start to stabilize. Hottest part in the motor is the rotor which temperature conducts to the motor body through the stator windings and from the body to the surrounding air. When surface cooled motor is stopped this is the reason why the motor body temperature seems to keep still rising after the motor is stopped. Stopped motor cooling follows same equation than heating with difference that when the surrounding air is not moving (due to the fan is stopped) and air temperature is also increasing the cooling in the beginning is faster and slows in time since the temperature difference decreases and the heat conducts slower than in the beginning of the cooling. When the motor is run in cyclic load start and stop applications the cooling of the motor has to be modeled in thermal replica accurately in order to avoid situation where the calculated used thermal capacity “runs” from actual used thermal capacity causing the protection to be overshooting significantly.

In the previous figures were presented the motors thermal behavior in principal level. In reality the temperature of motor inside the motor windings can also be measured with RTD elements. Motor temperature is highest on the drive end due to the cooling being the weakest there as can be noted in the figure.

Figure 3.113 Running motor temperature with thermal image camera.



Rotor temperature measurement is very complicated due to its rotating nature and thus normally there are no measurements available and therefore the protection of rotor always needs to be taken care of with the calculated thermal image. Also the RTD:s installed into the motor stator windings may not be in the actual hot spot so relying fully into the measurements may not also be wise. Due to these reasons motor protection should not be designed either thermal image or RTD:s but rather in combination of these both ways of monitoring the temperature of the motor.

When considering a thermal image modeling in the protection relay there are many points which needs to be taken care of in order to get the thermal model match correctly into the motor thermal behavior. As seen in the previous chapter the motor usually has many states, which differ from each other in the terms of the heating and endangered parts of the motor. Motor thermal image sometimes needs to have a possibility to be adjusted and fine-tuned for the application so that it matches the motors actual temperature perfectly. For this reason the thermal replica needs to offer enough setting points for different situations where the motor may be running at the time and the relay needs to recognize these situations so that the thermal model can be updated correctly in the relay.

Thermal image characteristics and operating modes

To demonstrate different settings available in the thermal image, the following figure presents field test data of a motor loaded with stable load until final temperature has been reached and after that motor was de energized and let for cooling. The motor temperature was monitored with RTD installed into the driving end of the relay. Motor was loaded with its nominal current while its service factor is 1.15 and the ambient temperature was measured to be 24 degrees centigrade. In this case motor was started without load and the loading was increased directly after starting in order to concentrate stable loading heating effects.

Figure 3.114 Measured motor temperature in heating/cooling test.

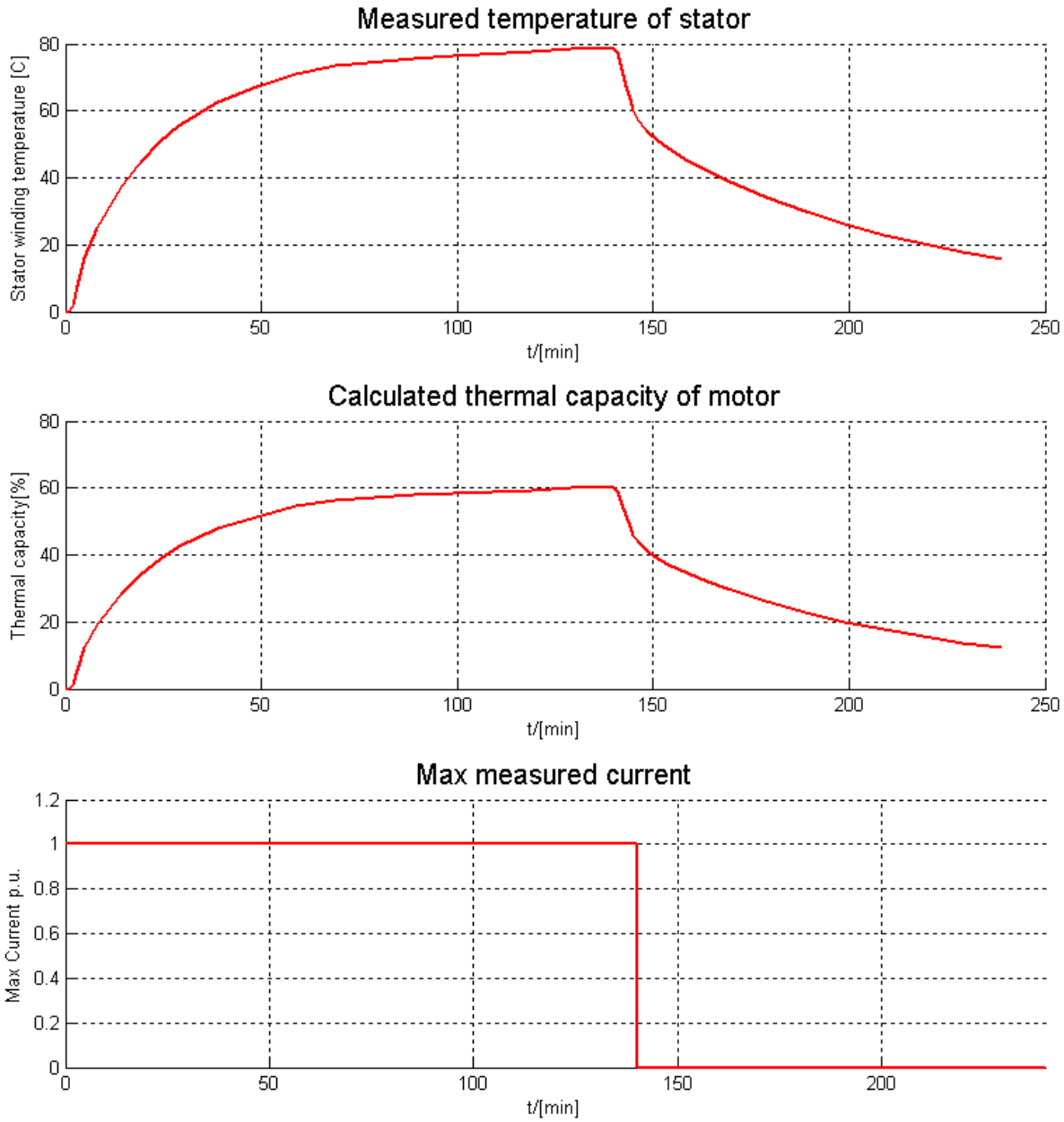
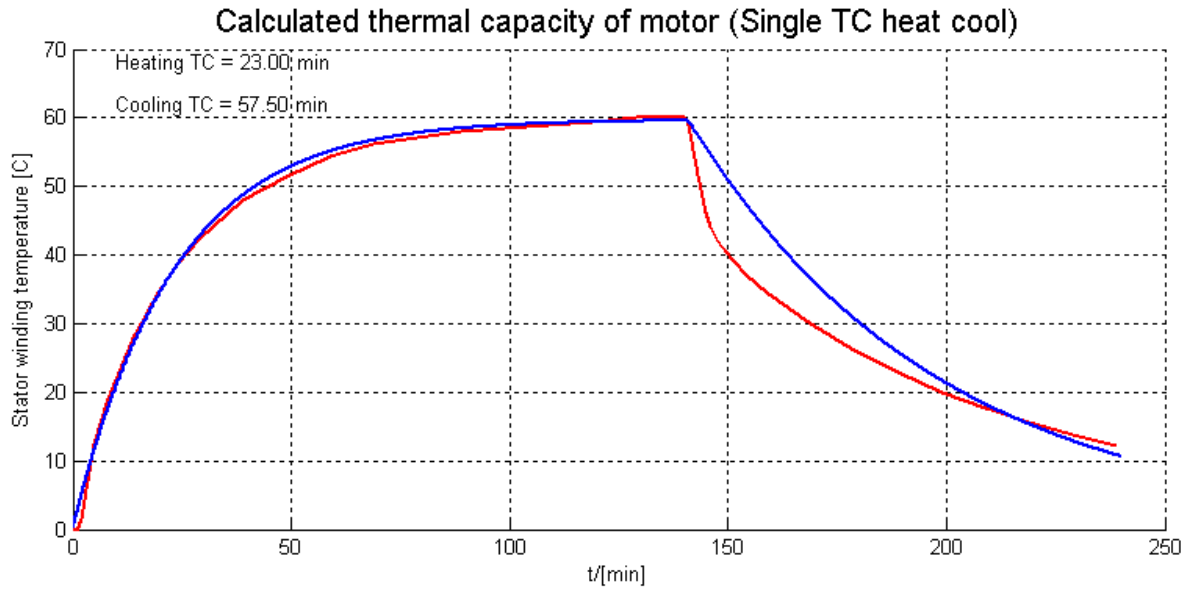
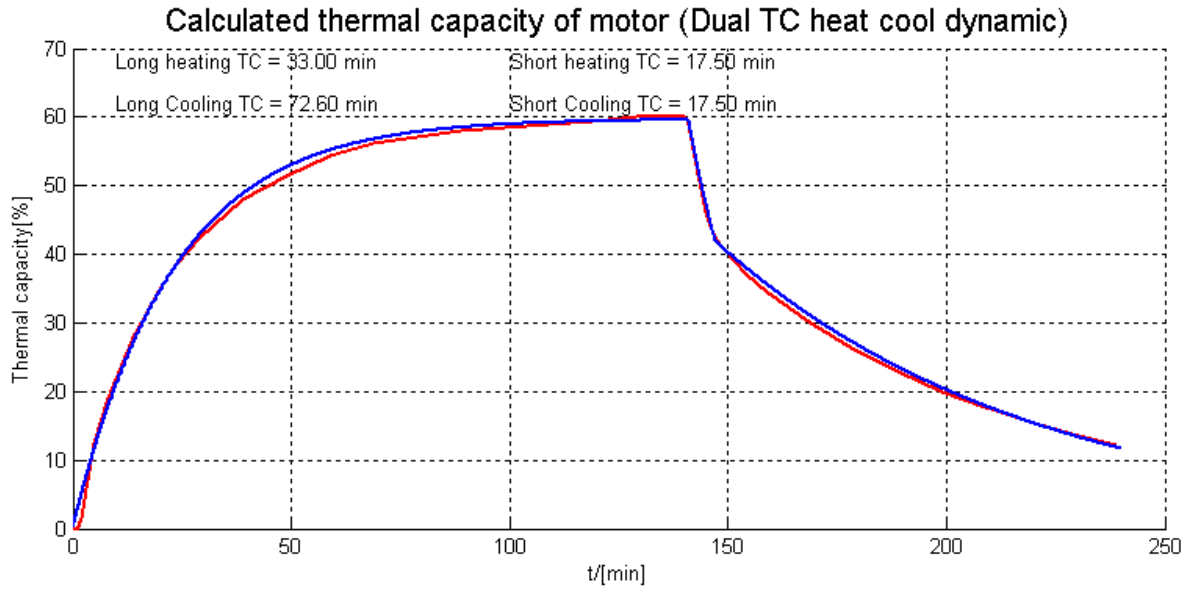


Figure 3.115 Matching of the thermal replicas to the measured thermal capacity of the motor.

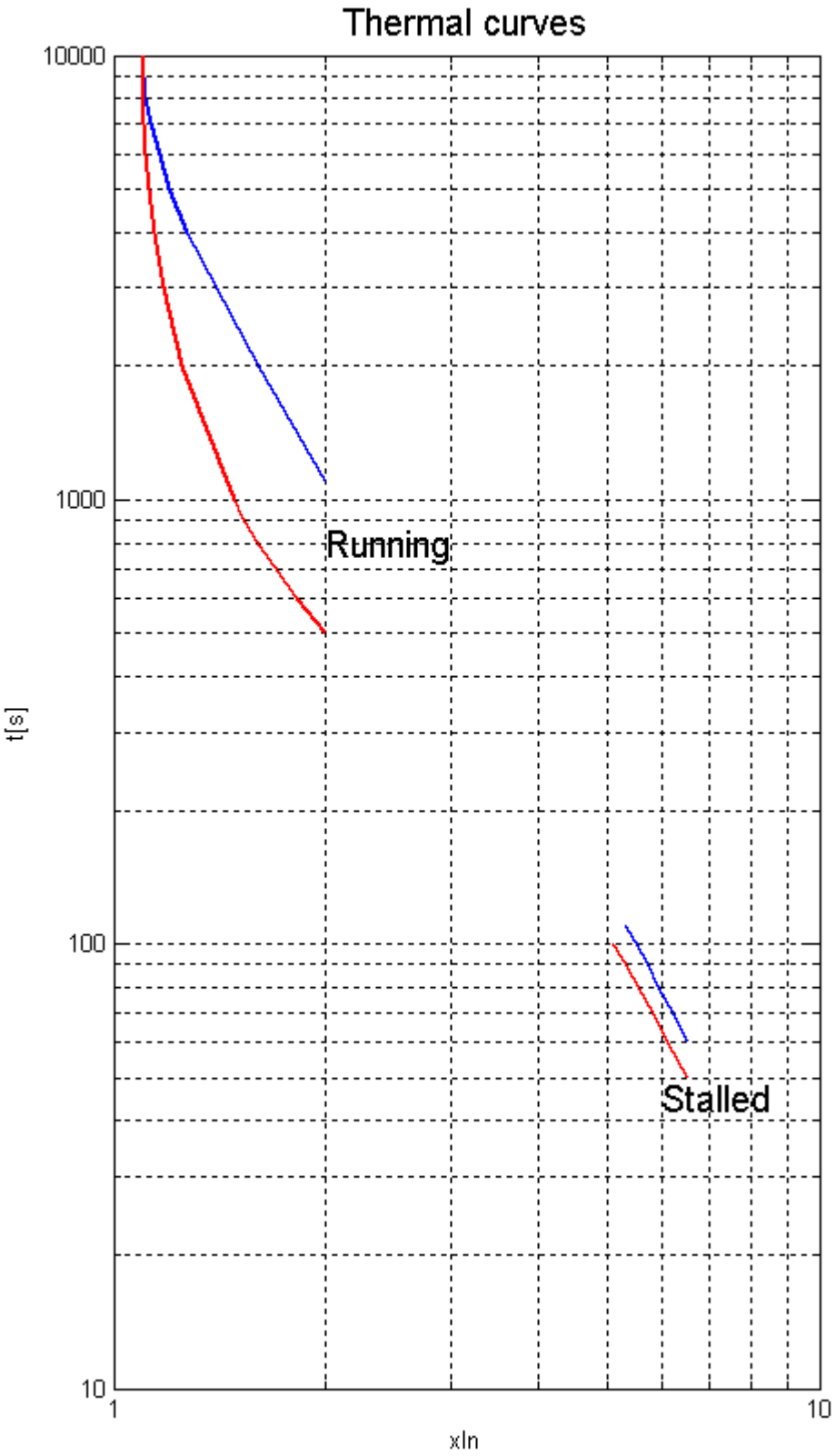




From the figure can be noted when the motor is loaded with constant current both of the replicas (single and dual time constant) follow the motor heating quite accurately. Difference in the operation comes from the cooling part. With single cooling time constant the replica does not follow the actual cooling of the motor and it can be said that the match is very poor. With dynamically controlled cooling time constants the response to measured is very accurate. If this motor would be used for cyclic loads with cooling times, most probably one time constant model would be overprotecting already in the next duty cycle, possibly causing unnecessary alarms or even trip of the motor which is still running in safe temperatures.

When studying the motor heating up in possible overload and start-up situations motor thermal curves are useful. These are usually available on request from manufacturers and the relay operation can be set according to these.

Figure 3.116 Example thermal limit curves of a motor.



If motor thermal limit curves are available from them can be seen the time constants for the overloading and also for the safe stall times for hot and cold situation. In addition to this figure the cooling time constant has to be checked from the motor datasheet or if not available the alternative option is to measure it.

The cooling time constant as presented in the previous example is very crucial in case of variable duty cycle motor applications. If the motor is constantly running with constant load then the cooling time constant is not that significant and it can be estimated to be eg. 2-3 times longer than heating time constant.

It can be estimated from the figure that the safe stall time cold is about 80 seconds and hot about 67 seconds.

When the thermal limit curves are available for the motor the operation of the thermal replica can be set very accurately for the overloading and stall conditions.

Figure 3.117 Single time constant thermal replica tripping curves compared to given motor thermal characteristics.

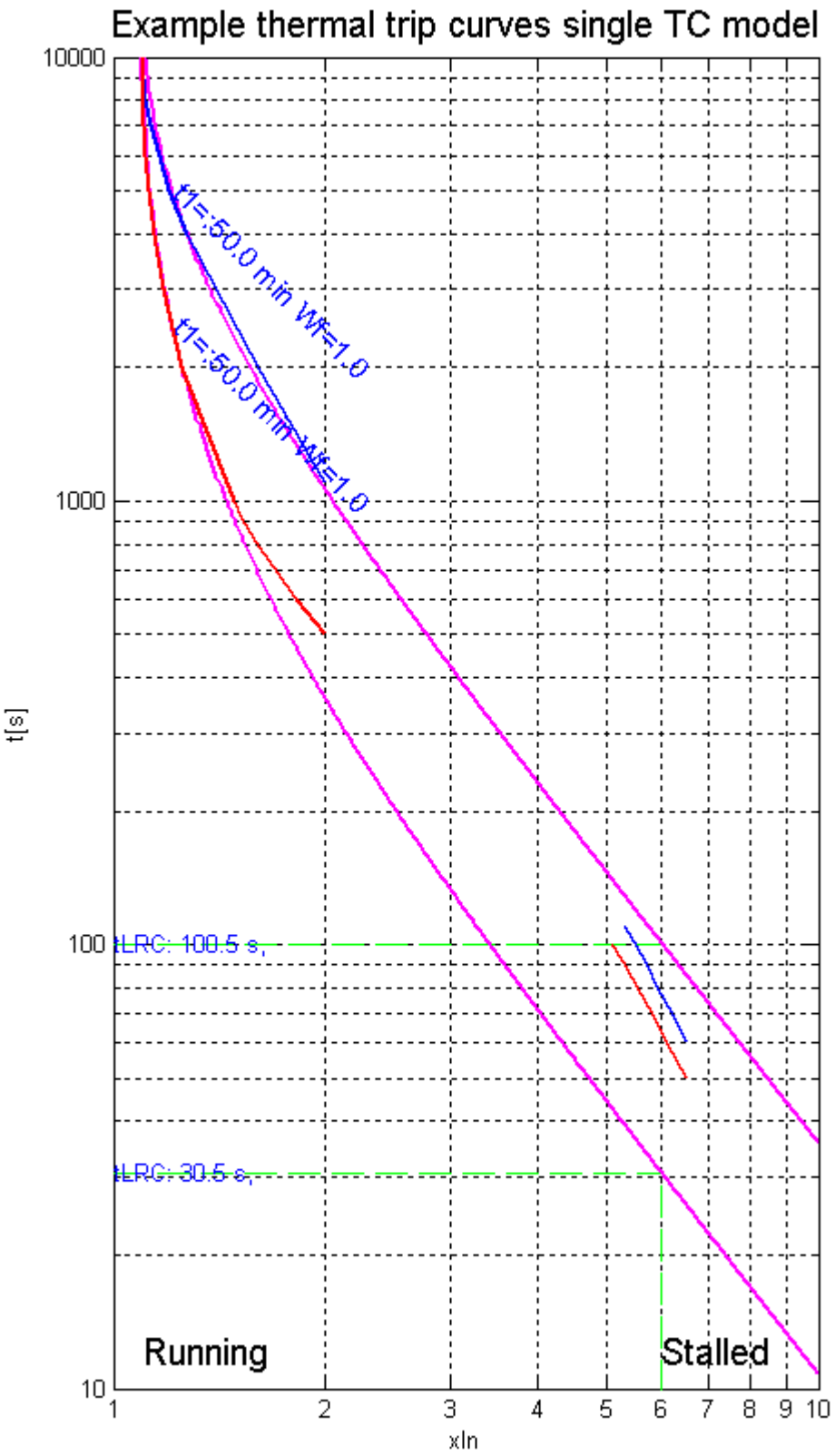
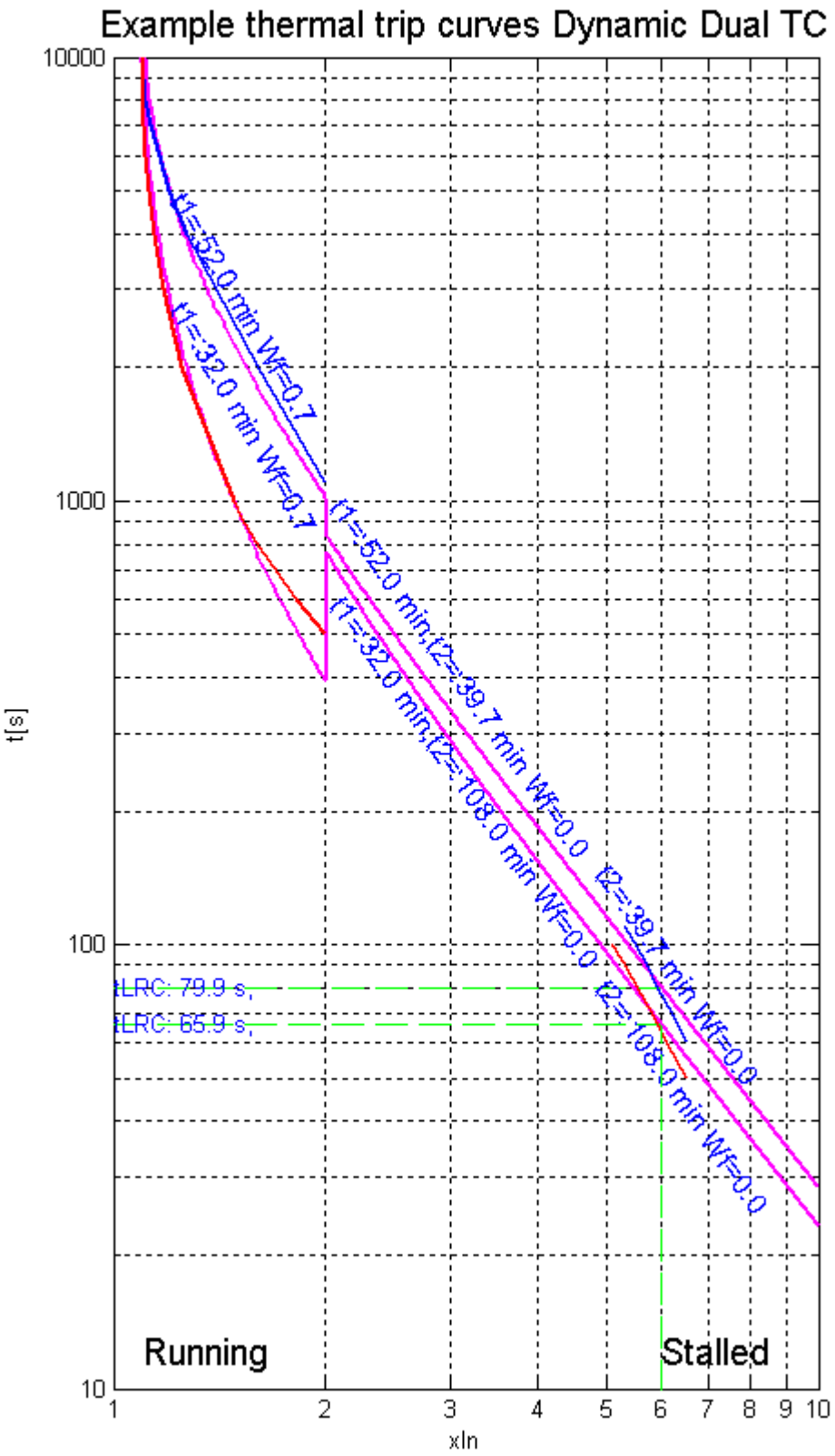


Figure 3.118 Dual time constant thermal replica tripping curves compared to given motor thermal characteristics.



From the figures can be seen that with estimated time constants from the motor thermal limit curves single time constant model is under protecting the motor in the stall condition when the motor is cold and when the motor is hot it will be heavily overprotecting allowing the motor only 30.5 second stalling time while the motor can withstand safely about 67 seconds.

When using dual time constants and dynamic time constants the relay will automatically select according to the settings correct tripping curves for the thermal replica and therefore the thermal image response will be exact in comparison to the single time constant thermal image. In overload condition both of the thermal replicas respond is acceptable even small overshoot is noticed in hot condition. In the curve simulations was hot condition defined to be when 70% of the thermal capacity was used.

Following figures present the tripping and cooling curves of the thermal replica.

Figure 3.119 Thermal tripping curves with single time constant, preload 0% (cold).

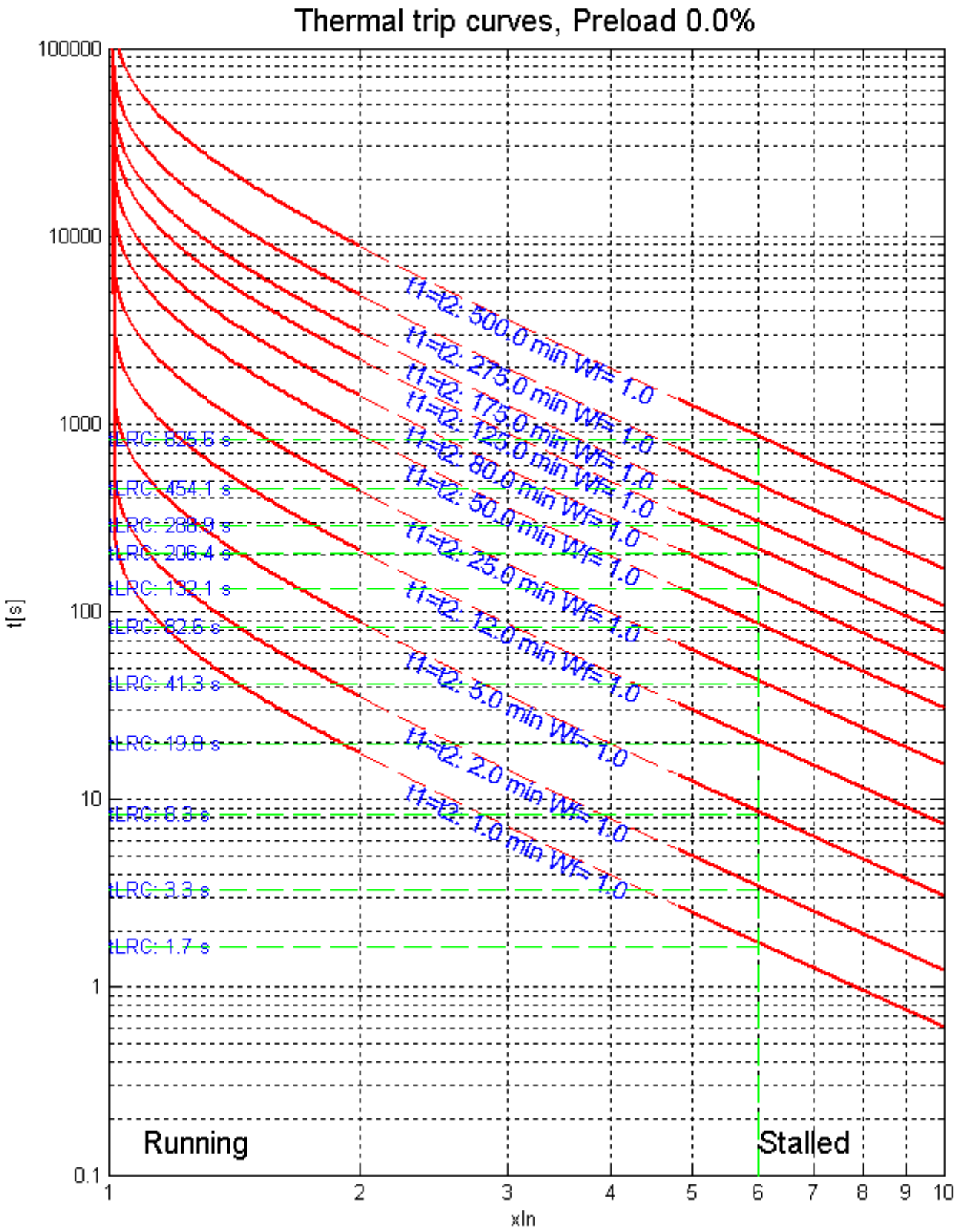


Figure 3.120 Thermal tripping curves with single time constant, preload 90% (hot).

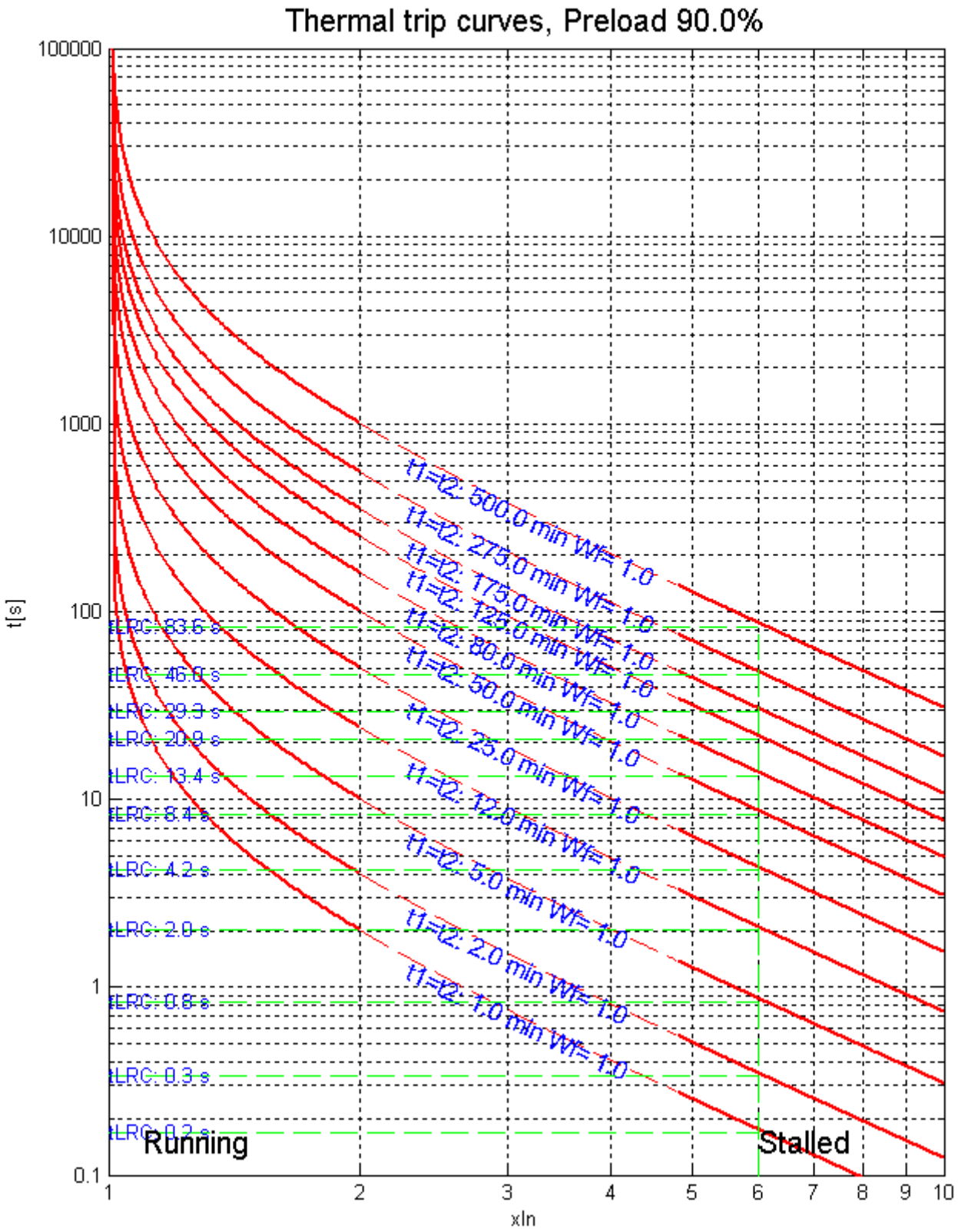


Figure 3.121 Thermal tripping curves with dual dynamic time constants and weighting factor, preload 0% (cold)

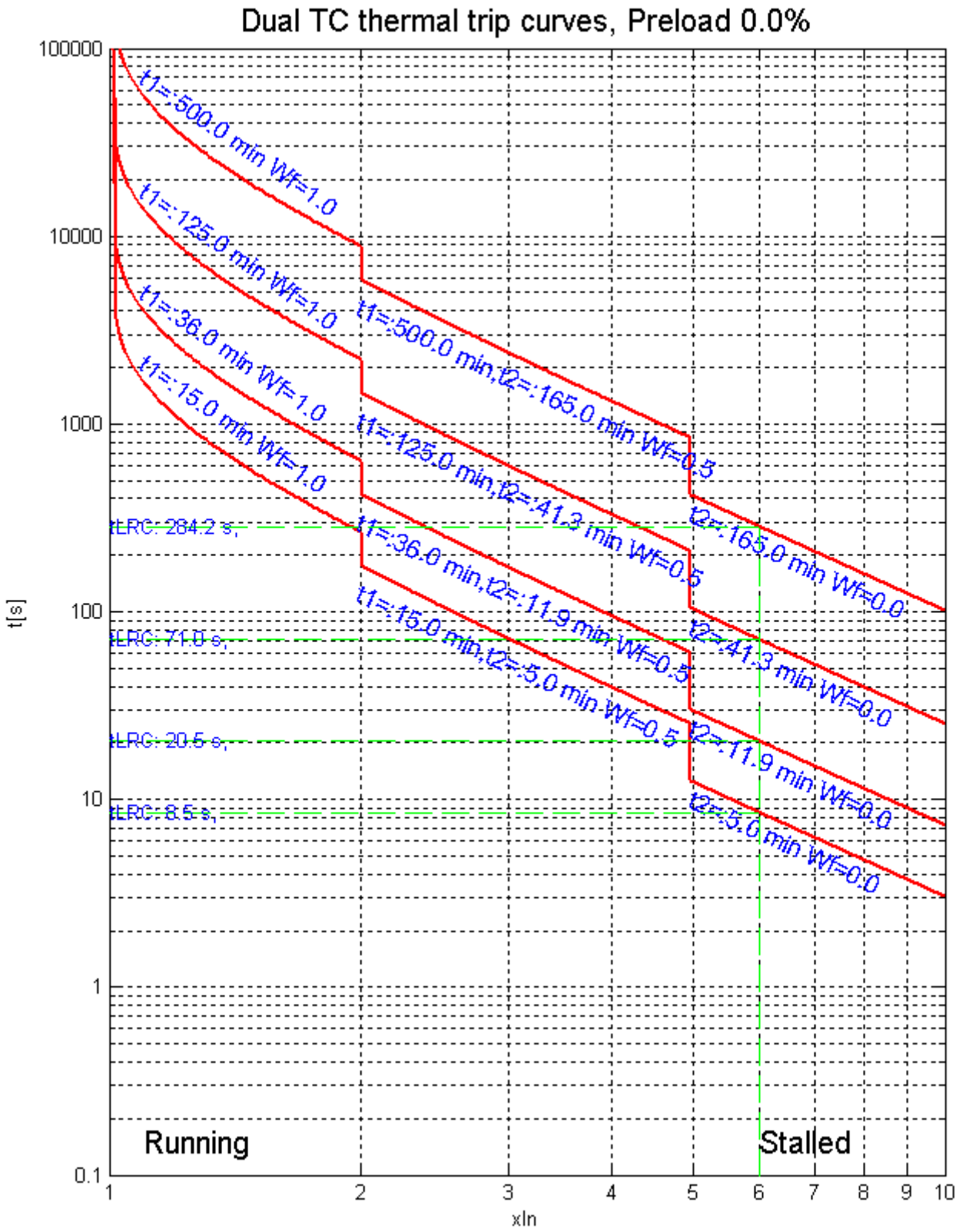


Figure 3.122 Thermal tripping curves with dual dynamic time constants and weighting factor, preload 90% (hot).

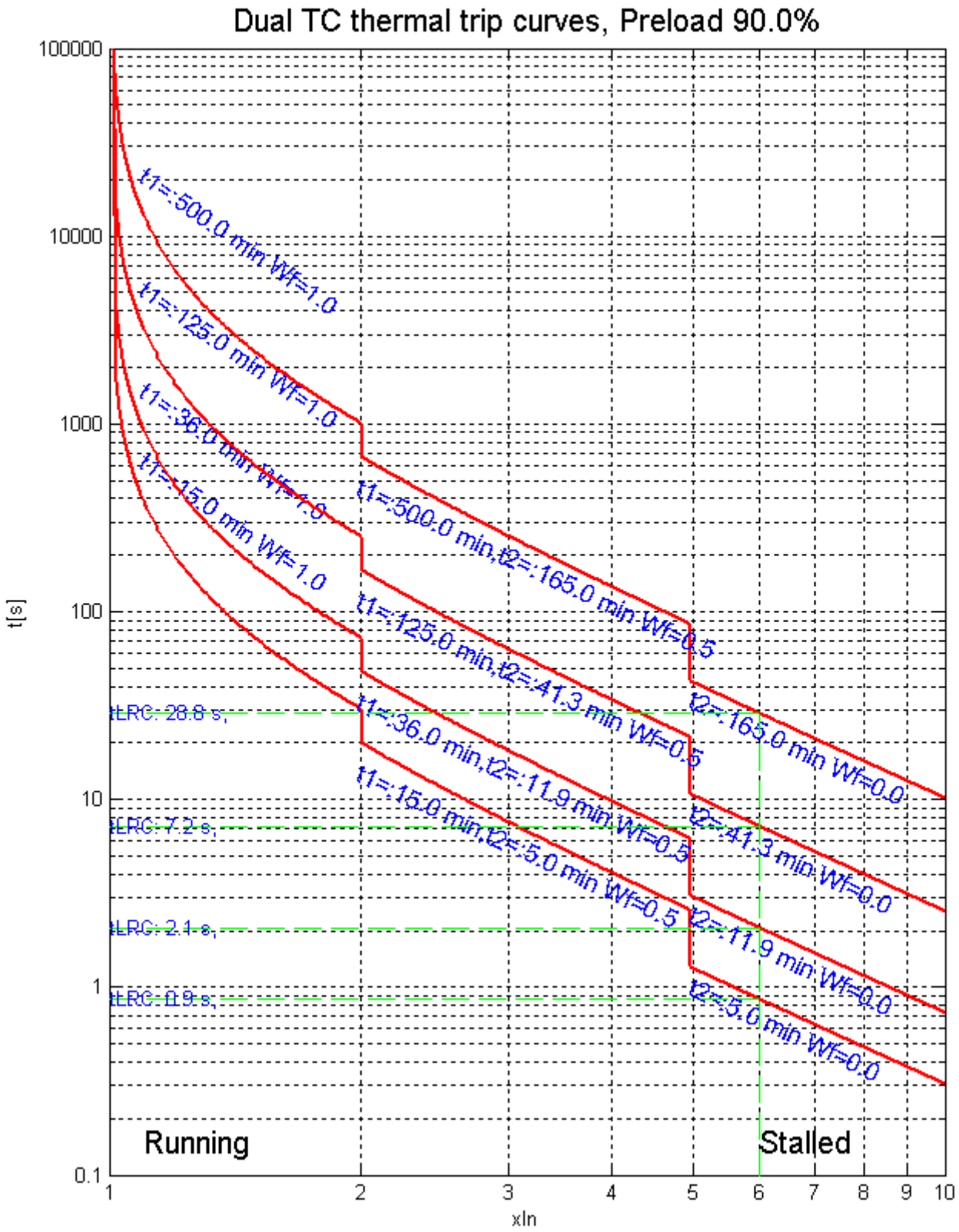


Figure 3.123 Thermal cooling curves, single cooling time constant.

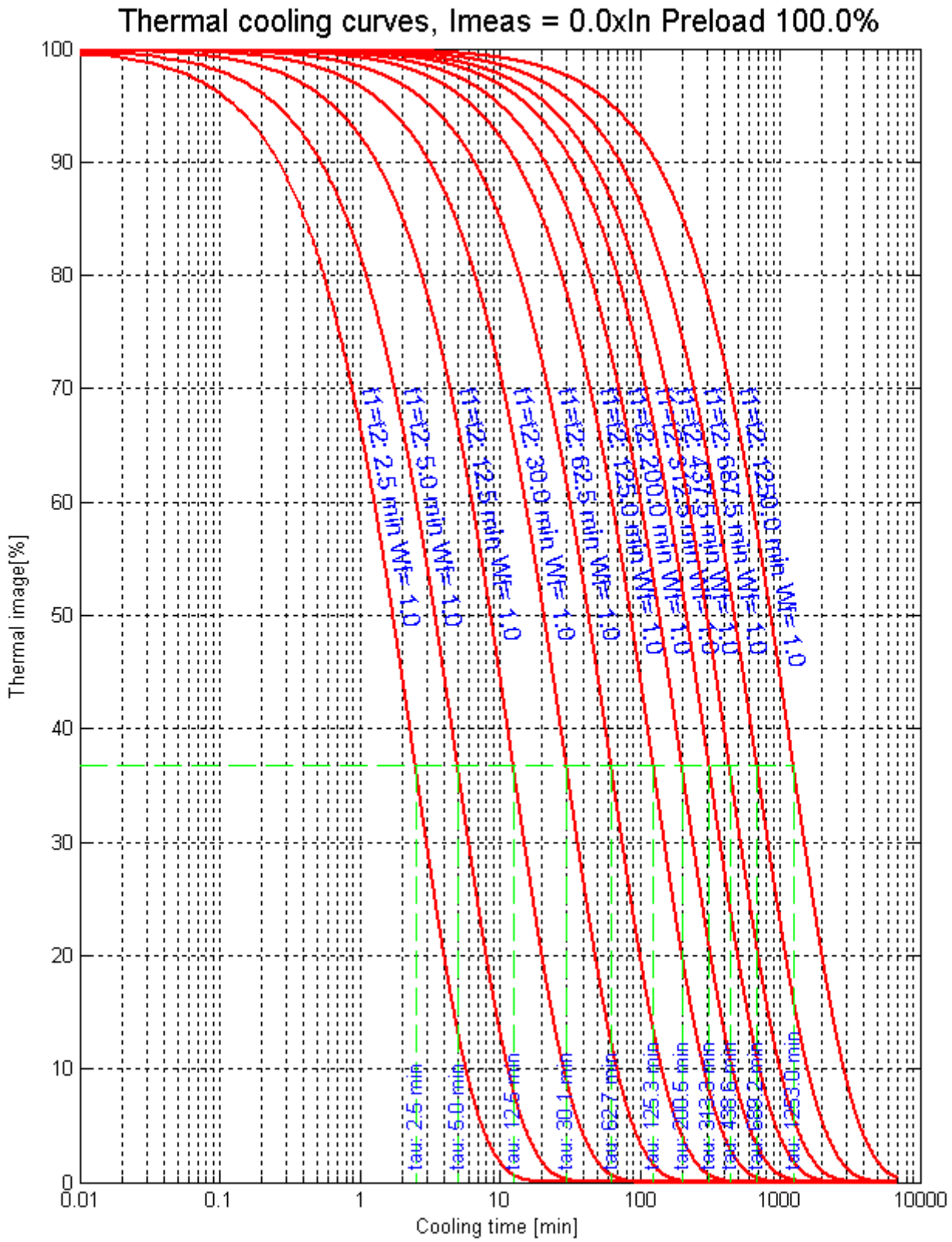


Figure 3.124 Thermal cooling curves, dynamic dual time constant.

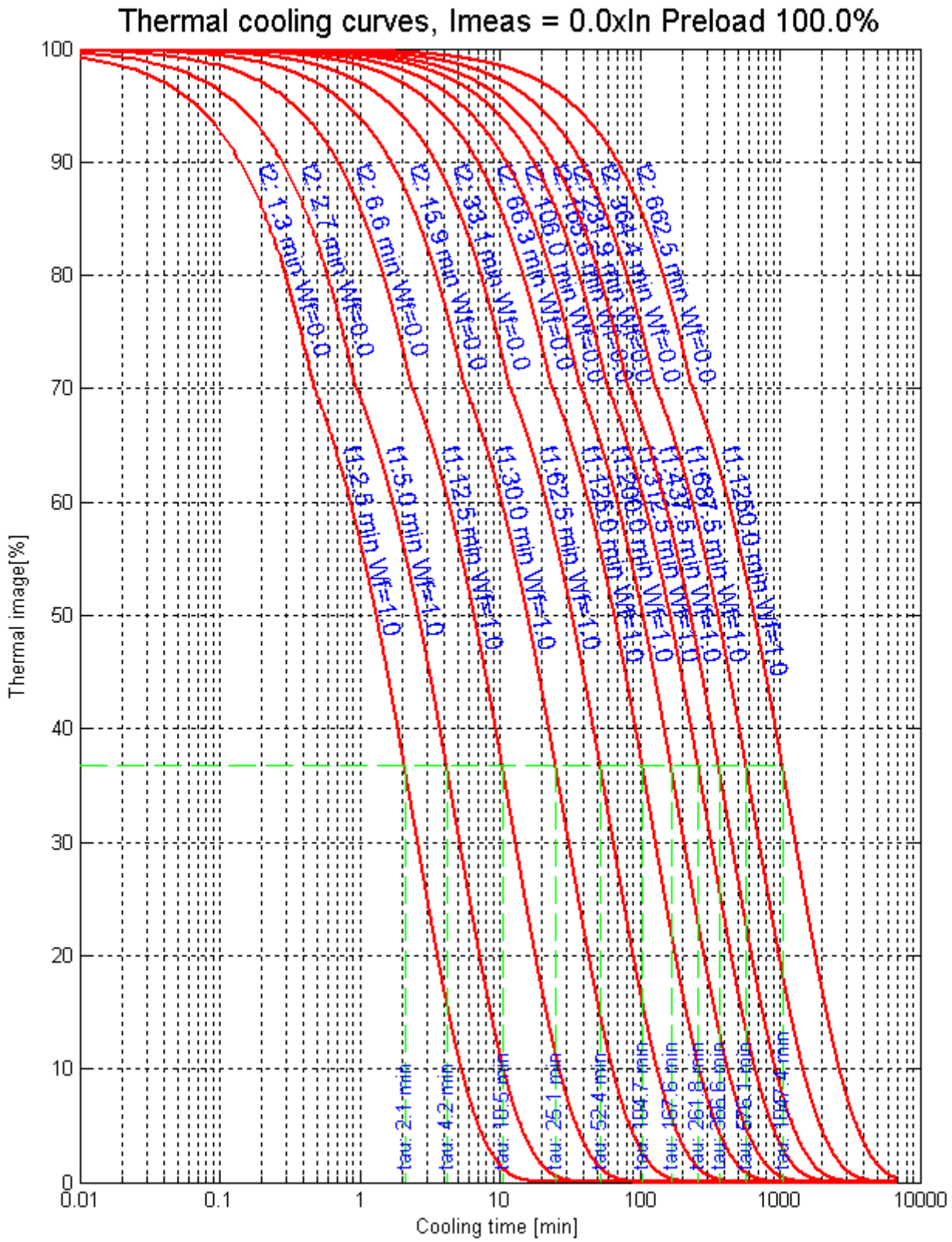


Figure 3.125 Thermal cooling curves, dynamic triple time constant (motor is running without load in the first part with dedicated time constant).

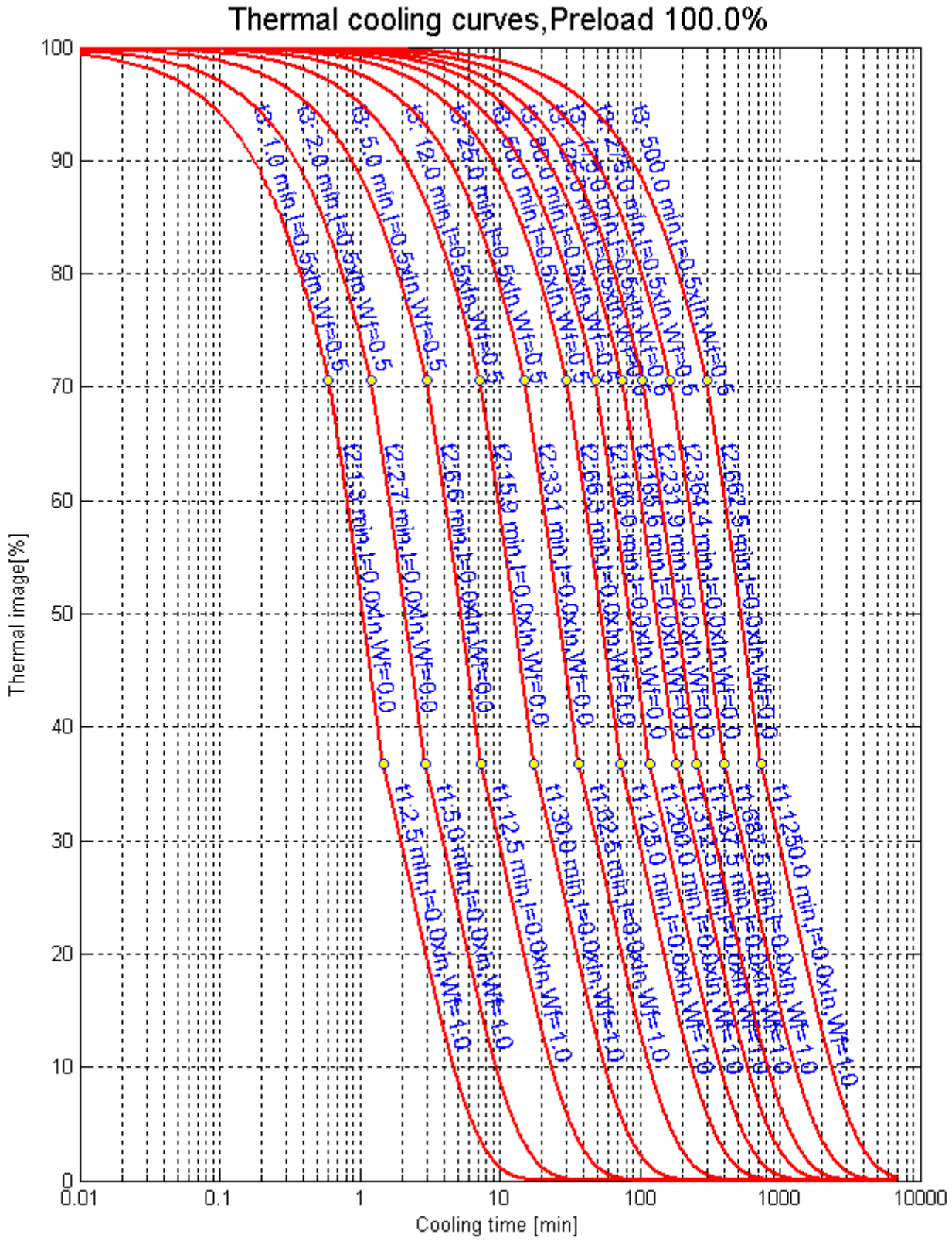


Figure 3.126 NPS biased thermal trip curves with kNPS value 1

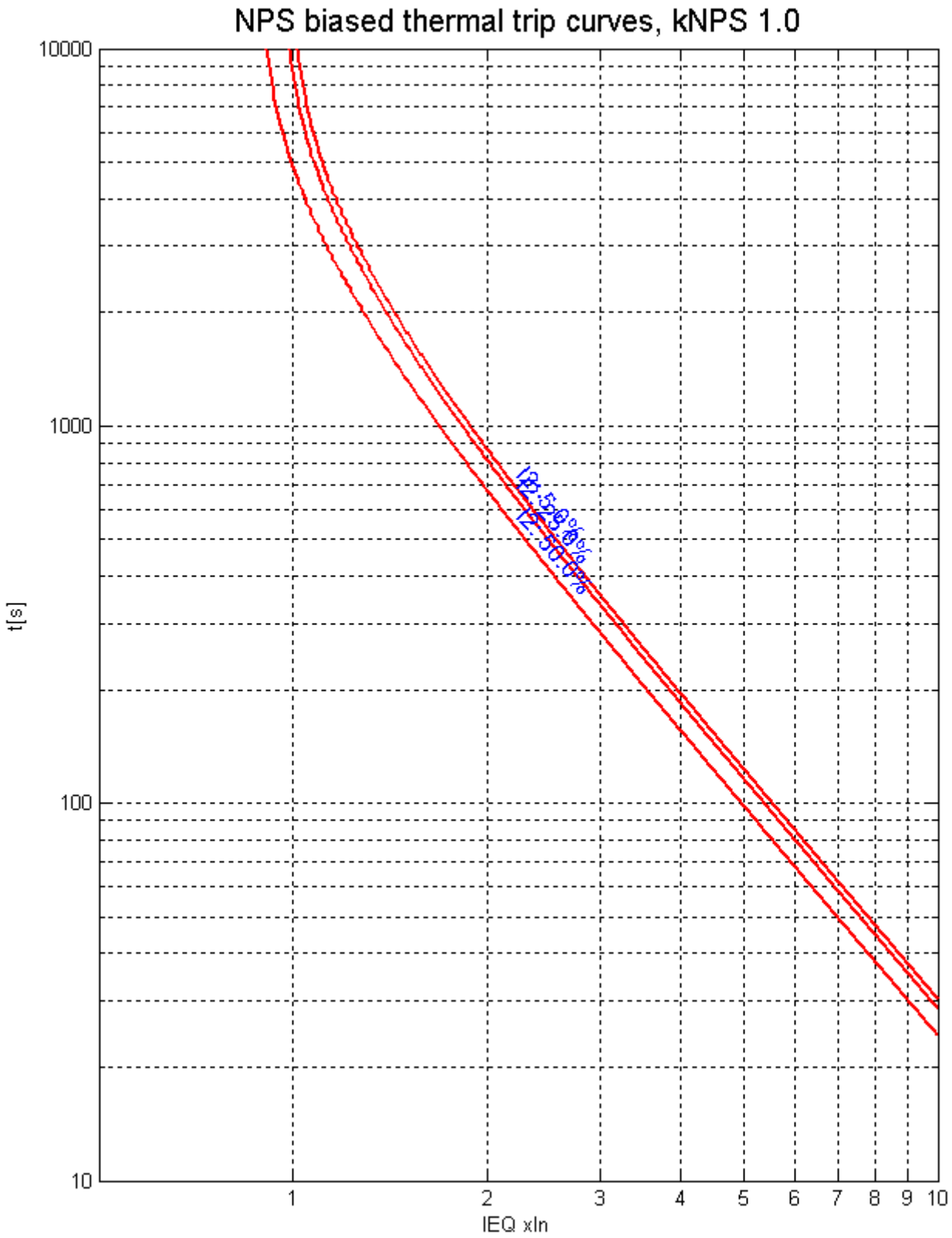


Figure 3.127 NPS biased thermal trip curves with kNPS value 3

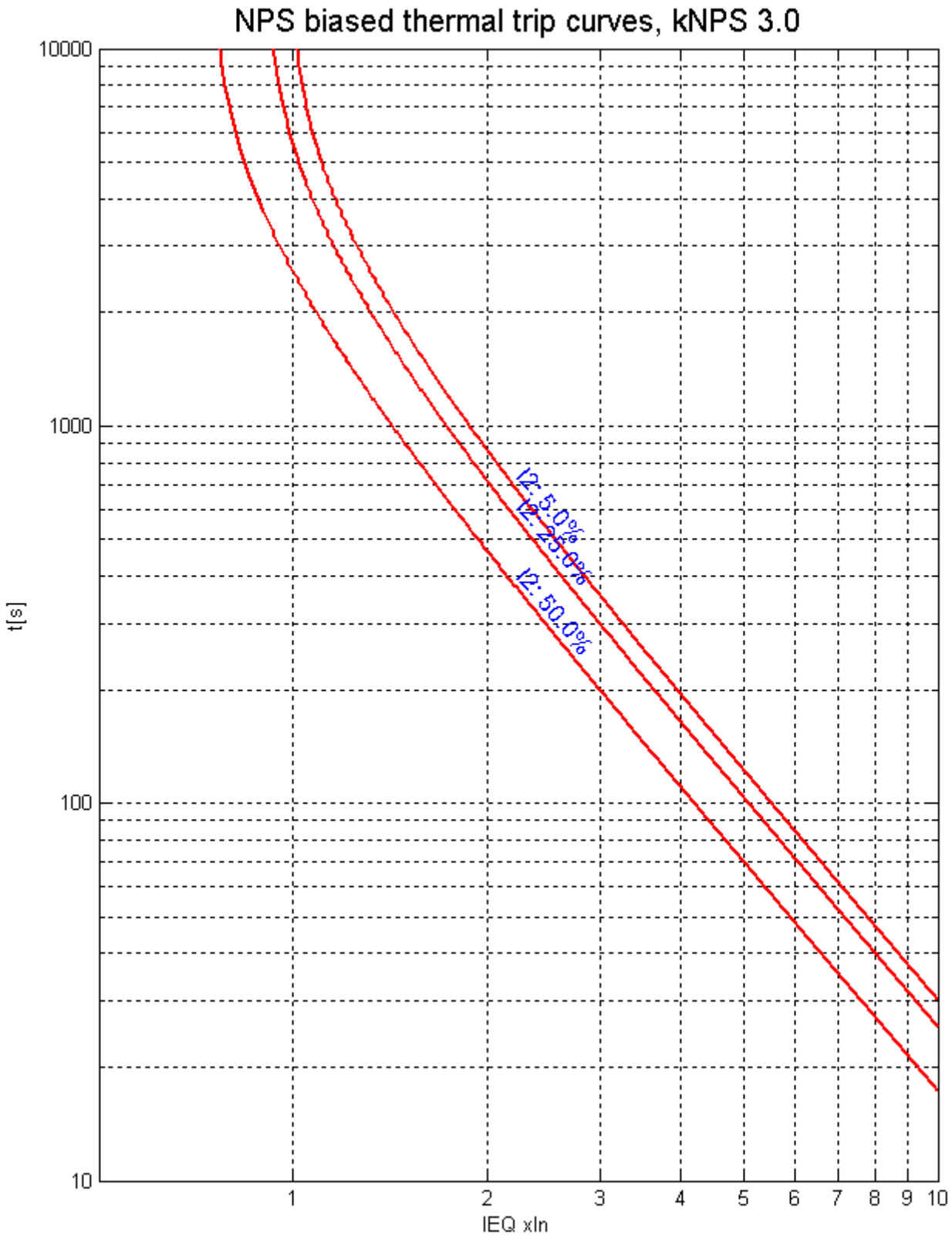


Figure 3.128 NPS biased thermal trip curves with kNPS value 7

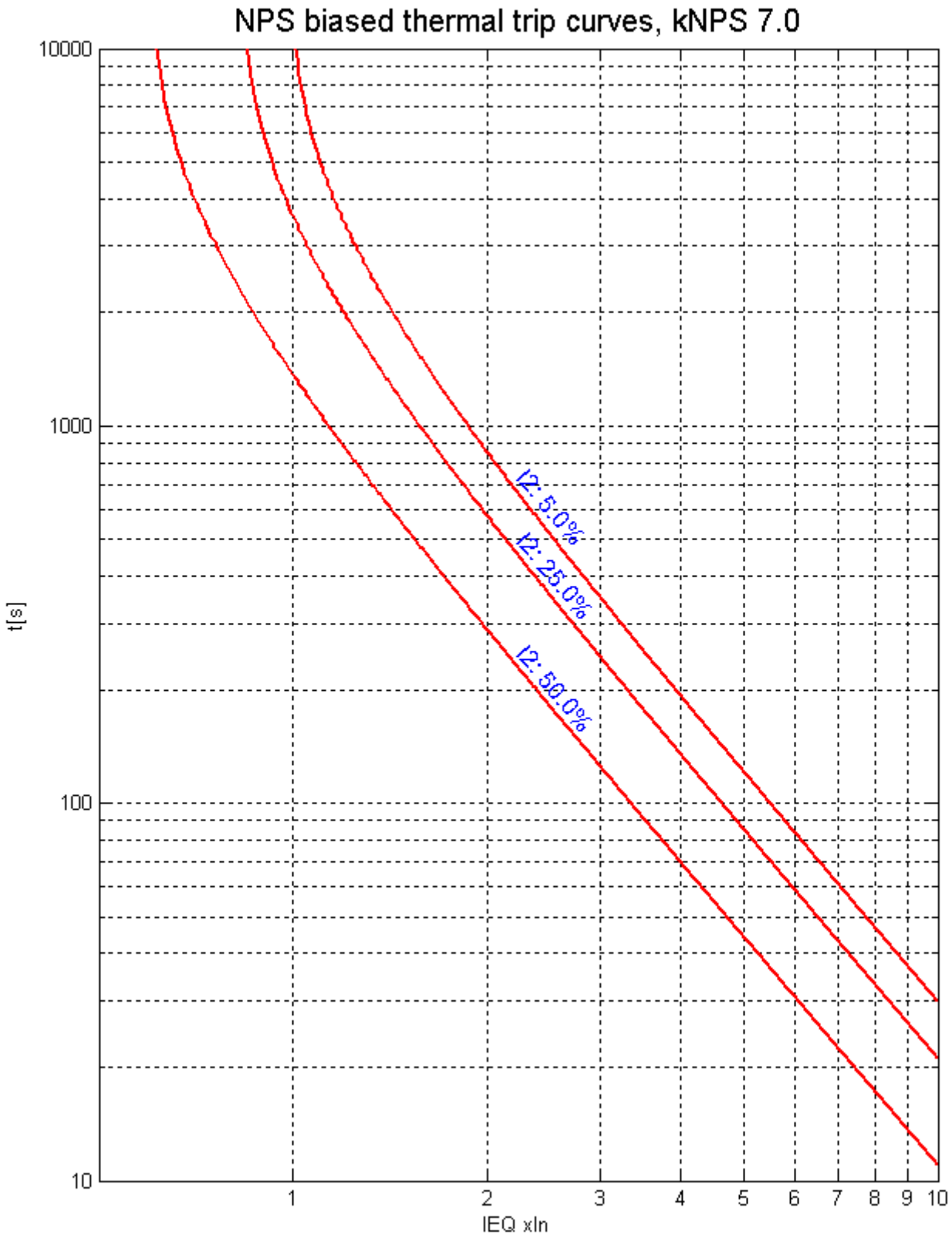
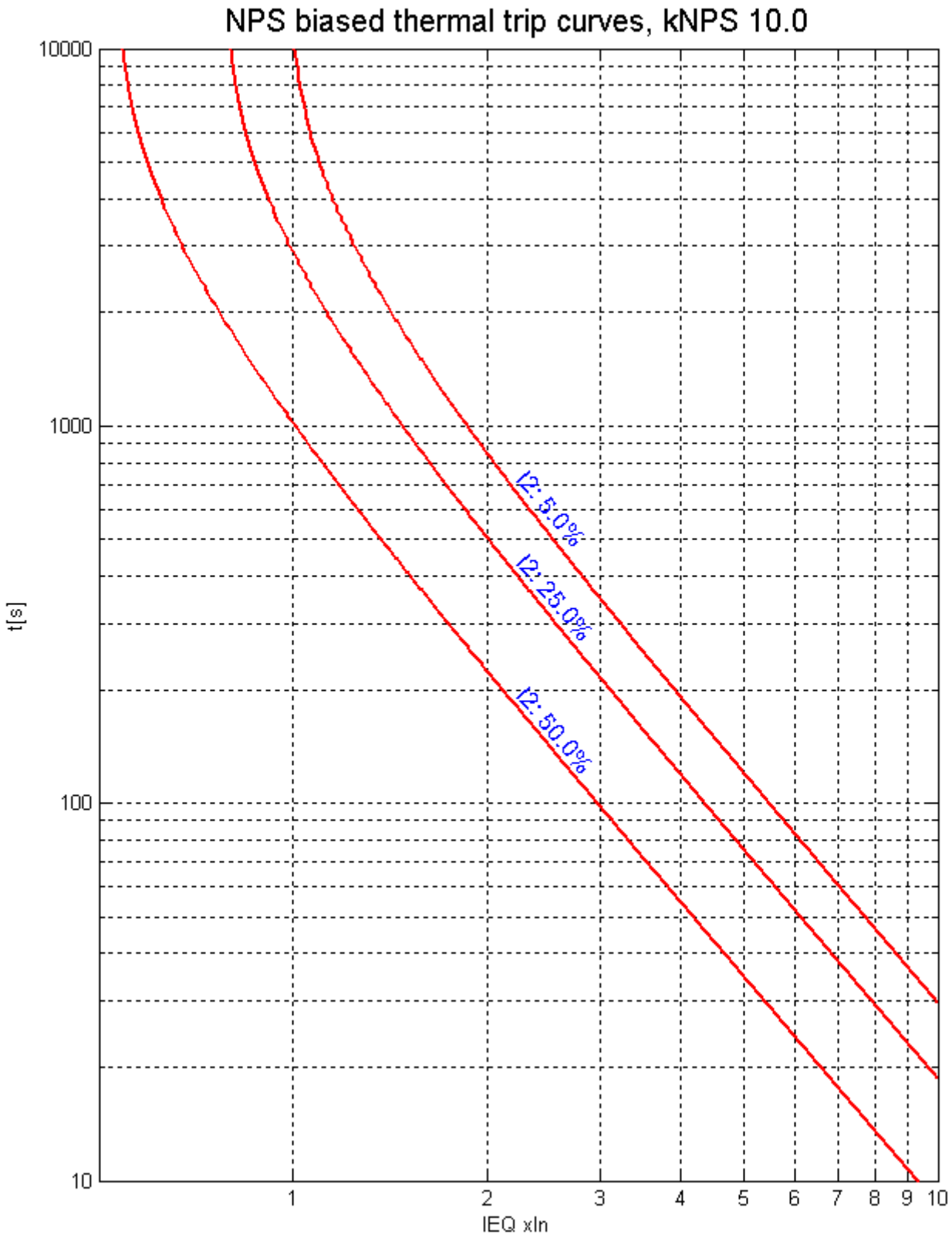


Figure 3.129 NPS biased thermal trip curves with kNPS value 10



Thermal overload function IO

Blocking signal and setting group selection controls the operating characteristics of the function during normal operation.

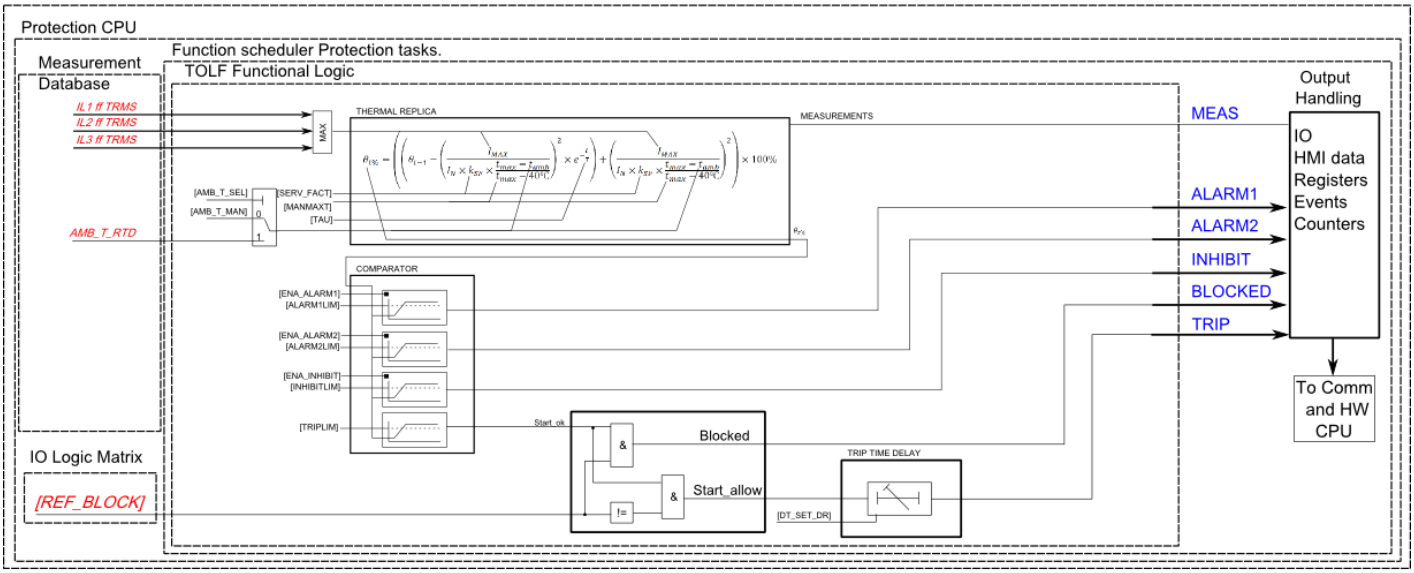
Outputs of the function are TOLM Trip and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. TOLM function utilizes total of eight separate setting groups which can be selected from one common source. Also the operating mode of the TOLM can be changed by setting group selection.

The operational logic consists of input magnitude processing, thermal replica, comparator, block signal check and output processing.

Inputs for the function are setting parameters and measured and pre-processed current magnitudes. Function output signals can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the two output signal. Time stamp resolution is 1ms. Function provides also cumulative counters for TOLM Trip, Alarm 1, Alarm 2, Inhibit and BLOCKED events.

In the following figure is presented the simplified function block diagram of the TOLM function.

Figure 3.130 Simplified function block diagram of the TOLM function.



Measured input values

Function block uses analog current measurements. Function uses the fundamental frequency magnitude of the current measurement inputs and calculated residual current with residual current measurement. For residual current measurement I01 or I02 channels can be selected.

Table 3.141 Analogic magnitudes used by TOLM function.

Signal	Description	Time base
IL1RMS	Fundamental TRMS measurement of phase L1/A current	5 ms
IL2RMS	Fundamental TRMS measurement of phase L2/B current	5 ms
IL3RMS	Fundamental TRMS measurement of phase L3/C current	5 ms
I1	Positive sequence current	5 ms
I2	Negative sequence current	5 ms
RTD	Temperature measurement for the ambient correction	5 ms

Setting parameters

Table 3.142 General settings of the TOLM stage (not SG selectable)

Name	Range	Step	Default	Description
TM> mode	0:Disabled 1:Activated	-	0:Disabled	Selection of the function is activated or disabled in the configuration. Default setting 0:Disabled (Not in use).
Temp C or F deg	0:C 1:F	-	0:C	Selection whether the temperature values of the thermal image and RTD compensation are shown in Celsius or Fahrenheit degrees.

Table 3.143 Motor data settings

Name	Range	Step	Default	Prot.funcs.	Description
Motor In Scaled	0.1... 40.0xIn	0.1xIn	-	MST TM> (49M) Ist> (48) I< (37) Im> (50M)	Motor nominal current scaled to per unit. If in the CT settings “Object In” is selected this value should be 1.00. If scale to CT nominal then this value may vary.
Motor In A	0.1 ... 5000A	0.1A	-	MST TM> (49M) Ist> (48) I< (37) Im> (50M)	Motor nominal current in amperes.
Nominal starting current	0.1... 40.0xIn	0.1xIn	6.0xIn	MST TM> (49M) Ist> (48) Im> (50M)	Motors locked rotor current with nominal voltage. This setting is used for the dynamic curve selection and calculation. Also nominal starting capacity calculation is made with this value.
Nominal starting current A	0.1 ... 5000A	0.1A	-	MST TM> (49M) Ist> (48) Im> (50M)	Motors locked rotor current in amperes.
Min locked rotor current	0.1... 40.0xIn	0.1xIn	3.5xIn	MST TM> (49M) Ist> (48) Im> (50M)	Minimum locked rotor current of the motor. This setting defines the current limit when in the dynamic curve selection and control only short time constant (stall) is used if this current is exceeded.
Min locked rotor current A	0.1 ... 5000A	0.1A	-	MST TM> (49M) Ist> (48) Im> (50M)	Minimum locked rotor current of the motor. This setting defines the current limit when in the dynamic curve selection and control only short time constant (stall) is used if this current is exceeded.
Max locked rotor current	0.1... 40.0xIn	0.1xIn	7.5xIn	MST TM> (49M) Ist> (48) Im> (50M)	Maximum locked rotor current of the motor. This setting defines the current limit which is maximum current for the motor to draw in locked rotor situation (starting or stalled). If the measured current exceeds this setting limit it is considered to be overcurrent fault and corresponding measures can be applied to disconnect the feeder and motor from the supply.
Max locked rotor current A	0.1 ... 5000A	0.1A	-	MST TM> (49M) Ist> (48) Im> (50M)	Maximum locked rotor current in amperes.
Max overload current	0.1... 40.0xIn	0.1xIn	2.0xIn	MST TM> (49M) Ist> (48) Im> (50M)	Max overload current of the motor. Over this setting motor is stalled. This setting defines when the thermal replica switches to short (stall) time constant if exceeded. Under this setting value the motor should be running still even overloaded.

Name	Range	Step	Default	Prot.funcs.	Description
Max overload current A	0.1 ... 5000A	0.1A	-	MST TM> (49M) Ist> (48) Im> (50M)	Max overload current of the motor in amperes.
No load current <	0.1... 40.0xIn	0.1xIn	0.2xIn	MST TM> (49M) I< (37)	Motors no load current. This setting defines the “Stopped” condition when the current is below this setting value. Also below this value undercurrent protection stage is locked.
No load current < A	0.1 ... 5000A	0.1A	-	MST TM> (49M) I< (37)	Motors no load current in amperes.
Motor service factor	0.01... 5.00xIn	0.01xIn	1.00xIn	MST TM> (49M)	Service factor which corrects the maximum allowed loading according to installation, construction etc. conditions which vary from the presumption conditions. Frequently motors are stamped to service factor of 1.15 which means that they can withstand continuous 15% overloading from the rated current continuously (not necessary in all possible conditions therefore consult the motor datasheet/manual for details). If the service factor is not known leave this parameter to 1.00 xIn.
Hot condition theta limit	0.0... 100.0%	0.1%	70%	MST N> (48) TM> (49M) Ist> (48) Im> (50M)	Setting of the thermal limit Hot / Cold situation of the motor. When this setting value is not exceed and locked rotor situation occurs cold stall curve adjusted with actual used thermal capacity is utilized. After this setting value hot stall curve is utilized. Applies also for Starts when hot / cold selection.
Safe stall time cold	0.1...600.0s	0.1s	20.0s	MST TM> (49M) Ist> (48) Im> (50M) N> (48)	Safe stall time when motor is cold. If this value is not informed then set to same than hot stall time. This leads most probably to overprotection with cold motor stall but is best guess in such case. This setting value is used for the cold thermal stall curve selection in automatic control. Also motor start-up and number of starts calculations use this parameter.
Safe stall time hot	0.1...600.0s	0.1s	15.0s	MST TM> (49M) Ist> (48) Im> (50M) N> (48)	Safe stall time when motor is hot. This setting value is used for the hot thermal stall curve selection in automatic control. Also motor start-up and number of starts calculations use this parameter.

Table 3.144 Motor thermal image settings

Name	Range	Step	Default	Description
Pick-up current (xIn)	0.10...40.00xIn	0.01xIn	1.00xIn	Current for the 100 % thermal capacity to be used (pick-up current in p.u., with this current t_{max} will be achieved in time t x 5). Default setting is 1.00 xIn.
NPS Biasing in use	0: No NPS biasing 1:NPS biasing in use	-	0:No NPS biasing in use	Selection whether thermal replica reference current is biased with NPS current.
NPS bias factor	0.1...10.0	0.1	3.0	Negative sequence current biasing factor. This factor depends on the motor construction and is the relation of the positive/negative sequence rotor resistances. Typical value for this is the default setting 3.0.
Time constants	0: Single 1:Multiple	-	0:Single	Selection whether single heating and cooling time constants or multiple time constants are used for thermal replica. If “Single” is selected only Long heating (cold) and Long cool Stop time

Name	Range	Step	Default	Description
				constants are shown. With “Multiple” selected all time constants available are shown. Default setting is “Single”.
Estimate Short TC and timings	0:Set manually 1:Estimate (on-line)	-	0:Set manually	Selection whether the relay estimates short heating and cooling time constants and the timing for short and long time constants when motor is stopped. These values can be set also manually. Default setting is “Set manually”.
Long heat T const (cold)	0...500.0min	1.0min	10.0min	Long heating time constant setting. This setting is for “Cold” motor condition and is used when the calculated thermal capacity is under setting “Hot condition theta limit” set value.
Long heat T const (hot)	0...500.0min	1.0min	10.0min	Long heating time constant setting. This setting is for “Hot” motor condition and is used when the calculated thermal capacity is over setting “Hot condition theta limit” set value. If the motor thermal characteristics vary in between of the “hot” and “cold” situation this setting can be modified for that purpose. Otherwise if the characteristics do not change set this setting to same with Long heat T const (cold) setting value. (This setting is visible when “multiple” time constants is selected)
Long Cool T const Run	0...3000.0min	1.0min	10.0min	Long cooling time constant for “Run” condition of the motor. When the motor is cooling while running its time constant is not the same with stopped cooling constant but typically lot shorter (since motor cooling fan is active). This setting may need testing of the motor cooling characteristics. If not known set it to same with Long Cool T const Stop for conservative setting or Long heat T const for faster cooling setting. (This setting is visible when “multiple” time constants is selected)
Long Cool T const Stop	0...3000.0min	1.0min	10.0min	Setting for stopped motor cooling time constant. When motor is stopped the thermal replica calculates the cooling according to this setting value. Typically this time constant is about 2.5 – 3.5 times heating time constant.
Short heat T const (cold)	0...500.0min	1.0min	10.0min	Setting for short heating time constant for “cold” motor status. This time constant defines the locked rotor and stalled tripping curve selection. This setting is not the safe stall time directly, it defines the used tripping curve for locked rotor condition. (This setting is visible when “multiple” time constants is selected and also “Set manual” is selected for the “Estimate short TC and timings”).
Short heat T const (cold)est	0...500.0min	1.0min	10.0min	Estimated setting for short heating time constant for “cold” motor status. This time constant defines the locked rotor and stalled tripping curve selection. This setting value is calculated based on information given for LRC and cold safe stall time. (This setting value is visible when “multiple” time constants is selected and also “Estimate” is selected for the “Estimate short TC and timings”).
Short heat T const (hot)	0...500.0min	1.0min	10.0min	Setting for short heating time constant for “hot” motor status. This time constant defines the locked rotor and stalled tripping curve selection. This setting is not the safe stall time directly, it defines the used tripping curve for locked rotor condition. (This setting is visible when “multiple” time constants is selected and also “Set manual” is selected for the “Estimate short TC and timings”).
Short heat T const (hot)est	0...500.0min	1.0min	10.0min	Estimated setting for short heating time constant for “hot” motor status. This time constant defines the locked rotor and stalled tripping curve selection. This setting value is calculated based on information given for LRC and hot safe stall time. (This setting value is visible when “multiple” time constants is selected and also “Estimate” is selected for the “Estimate short TC and timings”).

Name	Range	Step	Default	Description
Short Cool T const	0...3000.0 min	1.0 min	10.0 min	Short cooling time constant. This value is the same for running and stopped condition and typically it is the same in between heating and cooling. (This setting is visible when “multiple” time constants is selected and also “Set manual” is selected for the “Estimate short TC and timings”).
Wf factor for L/S T const	0.0...1.0	0.1	0.5	Weighting factor in between of the currently used long and short time constants. With this setting the heating/cooling calculation can be fine tuned. Setting value 0.5 means that 50% of the heating or cooling is calculated based into long time constant and 50% based into short time constant. 0.0 means 100% short time constant and 1.0 means 100% long time constant. (This setting value is visible when “multiple” time constants is selected).
T const dyn. balancing	0:Fixed 1:Dynamic	-	0:Fixed	Selection whether the thermal replica balances and switches the time constants dynamically based into the detected motor status. Switching is based into the settings given for maximum overload current and minimum locked rotor current. With selection “Dynamic” the thermal replica switches the timeconstants and with setting “Fixed” no time constants are switched. (This setting value is visible when “multiple” time constants is selected).
Short Cool T used when stop	0.0...3000min	0.1min	30.0min	Setting for how long time the short cooling time constant is used when the motor is stopped. When motor is just stopped the cooling typically is faster in the beginning. May be need to be adjusted according to application for perfect match. (This setting value is visible when “multiple” time constants is selected).
Short Cool T used when stop (est)	0.0...3000min	0.1min	30.0min	Estimated setting for how long time the short cooling time constant is used when the motor is stopped. When motor is just stopped the cooling typically is faster in the beginning. (This setting value is visible when “multiple” time constants is selected).
Cold Reset theta default	0.0...150.0%	0.1%	60.0%	Default theta when function is restarted. Also, possible to fully reset thermal element. This parameter can be used when testing the function to manually set the current thermal cap to any value.

Table 3.145 Environmental settings

Name	Range	Step	Default	Description
Dev.Temp (tmax)	0:A 1:B 2:F 3:H 4:Manual set	-	2:F	Maximum allowed temperature for the protected object. Default setting is “F” which is +155 degrees centigrade.
Obj.Max.temp(tmax=100%)	0...500deg	1deg	125deg	Visible when the Dev.Temp.(tmax) is set to “4:Manual set”.
Ambient temp sel	0:Manual set 1:RTD	-	0:Manual set	Selection whether fixed or measured ambient temperature should be used for the thermal image biasing.
Man.Amb.Temp.Set	0...500deg	1deg	40deg	Manual fixed ambient temperature setting for the thermal image biasing. For underground cables commonly is used 15 degrees Celsius. Setting is visible if Ambient temp sel is set to “Manual set”.
RTD Amb.Temp.Read	0...500 deg	1 deg	40 deg	RTD ambient temperature reading for the thermal image biasing. Setting is visible if Ambient temp sel is set to “RTD”.

Name	Range	Step	Default	Description
Ambient lin. or curve	0:Linear est. 1:Set curve	-	0:Linear est	Selection of ambient temperature correction either by internally calculated compensation based into end temperatures or user settable curve. Default setting is 0:Linear corr, which means internally calculated correction for ambient temperature.
Temp.reference (tref) k_{amb}=1.0	-60...500deg	1deg	15deg	Temperature reference setting. In this temperature manufacturer presumptions apply and the thermal correction factor is 1.00 (rated temperature). For ground dug cables this is usually 15˚C and in air 25 ˚C. Setting is visible if Ambient lin. or curve is set to "Linear est."
Max ambient temp	0...500deg	1deg	45deg	Maximum ambient temperature setting. If measured temperature is more than maximum set temperature the set correction factor for maximum temperature shall be used. Setting is visible if Ambient lin. or curve is set to "Linear est."
k at max amb temp	0.01...5.00xIn	0.01xIn	1.00xIn	Temperature correction factor for maximum ambient temperature setting. Setting is visible if Ambient lin. or curve is set to "Linear est."
Min ambient temp	-60...500deg	1deg	0deg	Minimum ambient temperature setting. If measured temperature is less than minimum set temperature the set correction factor for minimum temperature shall be used. Setting is visible if Ambient lin. or curve is set to "Linear est."
k at min amb temp	0.01...5.00xIn	0.01xIn	1.00xIn	Temperature correction factor for minimum ambient temperature setting. Setting is visible if Ambient lin. or curve is set to "Linear est."
Amb.Temp.ref1...10	-50.0... 500.0deg	0.1deg	15deg	Temperature reference points for the user settable ambient temperature coefficient curve. Setting is visible if Ambient lin. or curve is set to "Set curve".
Amb.Temp.k1...k10	0.01...5.00	1.00	0.01	Coefficient value for the temperature reference point. Coefficient and temperature reference points must be set as pairs. Setting is visible if Ambient lin. or curve is set to "Set curve".
Add curvepoint 3...10	0:Not used 1:Used	-	0:Not used	Selection whether the curve temperature / coefficient pair is in use. Minimum amount is two pairs to be set for the temperature / coefficient curve and maximum is ten pairs. If measured temperature is less than set minimum temperature reference or more than maximum set temperature reference the used temperature coefficient shall be the first or last value in the set curve. Setting is visible if Ambient lin. or curve is set to "Set curve".

Operating characteristics

The operating characteristic of the TOLM function is completely controlled by the thermal image. From the thermal image calculated thermal capacity used value can be set IO controls with Alarm 1, Alarm 2, Inhibit and Trip signals.

Table 3.146 Pick-up characteristics setting (SG selectable)

Name	Range	Step	Default	Description
Enable TM> Alarm 1	0: Disabled	-	0:Disabled	Enabling / Disabling of the Alarm 1 signal and IO

Name	Range	Step	Default	Description
	1:Enabled			
TM> Alarm 1 level	0.0...150.0%	0.1%	40%	Alarm 1 activation threshold. Default setting is 40%.
Enable TM> Alarm 2	0: Disabled 1:Enabled	-	0:Disabled	Enabling / Disabling of the Alarm 2 signal and IO
TM> Alarm 2 level	0.0...150.0%	0.1%	40%	Alarm 2 activation threshold. Default setting is 40%.
Enable TM> Rest Inhibit	0: Disabled 1:Enabled	-	0:Disabled	Enabling / Disabling of the Inhibit signal and IO
TM> Inhibit level	0.0...150.0%	0.1%	80%	Inhibit activation threshold. Default setting is 80%.
TM> Trip level	0.0...150.0%	0.1%	100%	Inhibit activation threshold. Default setting is 80%.
TM> Trip delay	0.000...3600.000s	0.005s	0.000s	Trip signal additional delay. This delay will prolong the trip signal generation for the set time. Default setting is 0.000s which will not give added time delay for the trip signal.

The pick-up activation of the IO is direct for all other signals except TRIP signal which has also blocking check before the trip signal is generated.

Function blocking

In the blocking element the block signal is checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a Trip signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If Trip function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup current values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Measurements and indications of the function

TOLM function outputs measured process data from following magnitudes:

Table 3.147 General status codes

Name	Range	Description
TM> Condition	0: Normal 1: Alarm1 On 2: Alarm2 On 3: Inhibit On 4: Trip On 5: Blocked	TOLM function operating condition at the moment considering binary IO signal status. When the status is “Normal” no outputs are controlled.
Thermal status	0: Stopped 1: Stalled 2:Just Stopped 3:Overloading 4:Running normal	TOLM function thermal image status. When the measured current is below 1 % of nominal status “Light / No load” will be shown, when the measured current is below trip limit status “Load normal” will be shown, when the measured current is over pick-up limit but under 2 xIn status “Overloading” will be shown and when measured current is over 2 xIn status “High overload” will be shown.

Table 3.148 Measurements

Name	Range	Description / values
Currents	0: Primary A 1: Secondary A 2: Per unit	Active phase current measurement from IL1(A), IL2(B) and IL3(C) phases in given scalings.
Thermal Image	0:Thermal image calc.	- TM> Trip expect mode: No trip expected / Trip expected - TM> time to 100% theta: Time to reach 100% thermal cap - TM> reference T curr.: Reference / pick-up value (IEQ) - TM> Active meas curr.: Measured max TRMS current at the moment - TM> T est.with act curr.: Estimate of used thermal capacity with current at the moment - TM> T at the moment: Thermal capacity used at the moment
	1: Temp estimates	- TM> Used k for amb.temp: Ambient correction factor at the moment - TM> Max.Temp.Rise All: Maximum temperature rise allowed - TM> Temp.Rise atm: Calculated temperature rise at the moment - TM> Hot Spot estimate: Estimated hot spot temperature including the ambient temperature - TM> Hot Spot Max. All: Maximum allowed temperature for the object
	2: Timing status	- TM> Trip delay remaining: Time to reach 100% theta - TM> Trip time to rel.: Time to theta to reach under trip limit when cooling - TM> Alarm 1 time to rel.: Time to theta to reach under Alarm 1 limit when cooling - TM> Alarm 2 time to rel.: Time to theta to reach under Alarm 2 limit when cooling - TM> Inhibit time to rel.: Time to theta to reach under Inhibit limit when cooling

Table 3.149 Counters

Name	Description / values
Alarm1 inits	Times the TOLM function has activated the Alarm 1 output
Alarm2 inits	Times the TOLM function has activated the Alarm 2 output
Restart inhibits	Times the TOLM function has activated the Restart inhibit output
Trips	Times the TOLM function has tripped
Trips Blocked	Times the TOLM function trips has been blocked

Events and registers

The TOLM function generates events and registers from the status changes of the Trip activated and blocked signals. To main event buffer is possible to select status “On” or “Off” messages.

In the function is available 12 last registers where the triggering event of the function (Trip activated or blocked) is recorded with time stamp and process data values.

Table 3.150 Event codes of the TOLM function instance

Event Number	Event channel	Event block name	Event Code	Description
4352	68	TOLM1	0	Alarm1 On
4353	68	TOLM1	1	Alarm1 Off
4354	68	TOLM1	2	Alarm2 On
4355	68	TOLM1	3	Alarm2 Off
4356	68	TOLM1	4	Inhibit On
4357	68	TOLM1	5	Inhibit Off
4358	68	TOLM1	6	Trip On

Event Number	Event channel	Event block name	Event Code	Description
4359	68	TOLM1	7	Trip Off
4360	68	TOLM1	8	Block On
4361	68	TOLM1	9	Block Off

In the register of the TOLM function is recorded activated, blocked etc. “On” event process data. In the table below is presented the structure of TOLM function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 3.151 Register content

Date & Time	Event code	Time to reach 100% theta	Ref. T current	Active meas current	T at the moment
dd.mm.yyyy hh:mm:ss.mss	4352- 4361 Descr.	seconds	xIn	xIn	%
Max temp rise allowed	Temp rise at the moment	Hot Spot estimate	Hot spot max all.	Trip delay rem	Used SG
deg	deg	deg	deg	s	1 - 8

3.7.3 Running hour counter

Running hour counter is capable of counting the running time of motor, generator or similar application. Counter runs whenever the user defined Activate counter input is activated. Counter value can be added to mimic view and read to SCADA. Clear Hours resets the counter.

It is possible to set the running hour counter value manually by user. The user input must be set in seconds which is then converted by the IED to hours:minutes:seconds.

Table 3.152 Event codes of RHC function.

Event Number	Event channel	Event block name	Event Code	Description
10048	157	RHC1	0	Running hour counter On
10049	157	RHC1	1	Running hour counter Off
10050	157	RHC1	2	Running hour counter cleared On
10051	157	RHC1	3	Running hour counter cleared Off

3.7.4 Resistance temperature detectors (Modbus IO) (RTD) (49T)

See **Protections, Transformer protections, Resistance temperature detectors (Modbus IO) (RTD) (49T)**.

3.7.5 Transformer thermal overload protection TT> (49TR)

See **Protections, Transformer protections, Transformer thermal overload protection TT> (49TR)**.

3.8 Motor protections

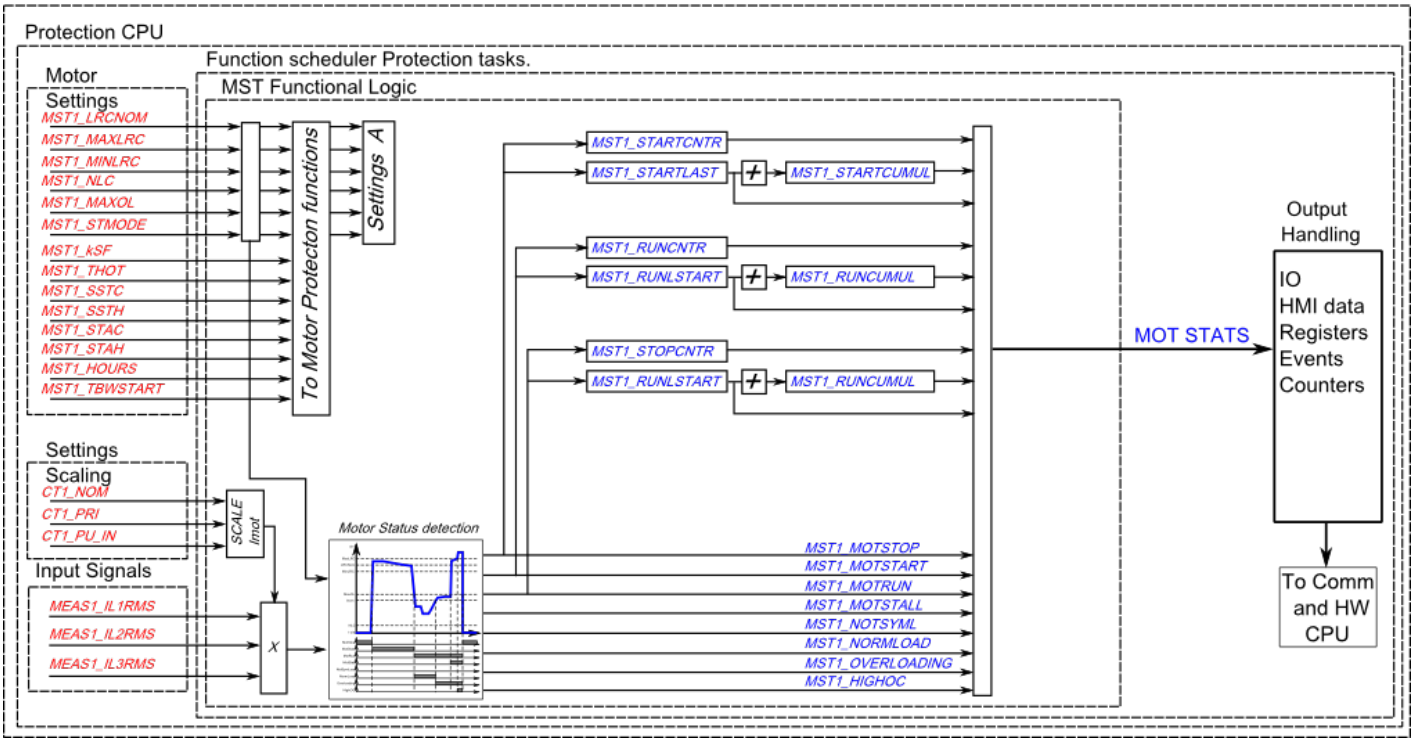
3.8.1 Motor status monitoring (MST)

Motor status monitoring function (MST) is designed to be the common place to set up all necessary motor data and to select the used motor protection functions. Settings related to the protection functions can be edited also inside of each function and after changed they will be also updated into MST function. In addition to motor data settings MST function

counts motor starts, times motor start succeeded, times motor has been stopped, running time, starting time, stopped time cumulatively and from last event separately.

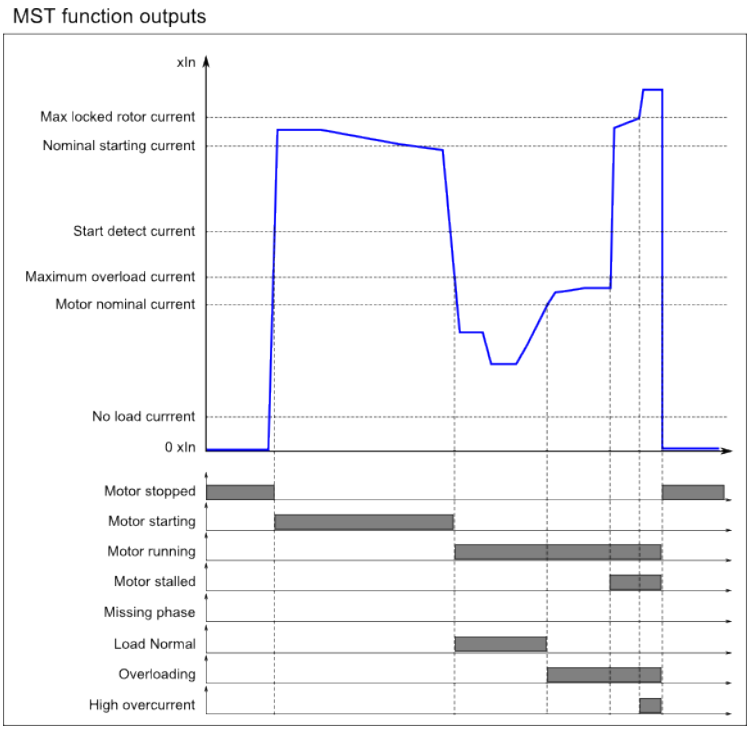
Outputs of the MST function are output motor stopped, motor starting, motor running, motor stalled, missing phase, load normal, overloading, and high overcurrent signals which can be used in indication or in application logics. From these signals MST also generates events if so wanted.

Figure 3.131 Simplified function block diagram of the MST function.



The MST function outputs are dependent on the set motor data. MST function outputs in different kind of situations are presented in the following diagram.

Figure 3.132 MST function outputs activation.



“Motor stopped” signal is activated when the current is under “No load current” limit for more than 10 ms time. When current increases from this status to over “Start detect current” setting, start of the motor is detected and “Motor starting” signal is activated. If the current stays under “Max locked rotor current” setting start-up situation continues. When the current decreases under “Maximum overload current” setting, start situation is considered to be over and motor is in running status and “Motor running” signal is activated. When the measured current is in between of “No load current” and Motor nominal current (including the service factor and ambient temperature factor) load is considered to be normal and “Load Normal” signal is activated. If from this condition current exceeds “Motor nominal current” setting and does not exceed “Maximum overload current” setting the “Overloading” signal is activated. If the current exceeds the “Maximum overload current” setting “Motor stalled” signal is activated. If “Max locked rotor current” setting value is exceed “High overcurrent” output is activated. When the measured current decreases under “No load current” setting “Motor stopped” signal is activated again. The “Missing phase” signal is activated if during starting or running one of the phases is lost and the measured current is decreased in that phase under the “No load current” setting.

These motor status signals can be used in the motor protection scheme for blocking overcurrent stages, change setting groups and also release blockings for example in case if during start-up something happens.

Application example of motor starting scheme and usage of motor status signals of MST function.

When motor is starting usually the low set stage overcurrent is either blocked or in some relays the setting value is multiplied by some given factor in order that the protection stage does not activate and prevent the motor from starting especially in cases when the low set overcurrent stage operating time is shorter than the start-up time of the protected motor. In following figure is presented the behavior of the start signals during motor start-up. Motor starting signal can be used for blocking the overcurrent stage.

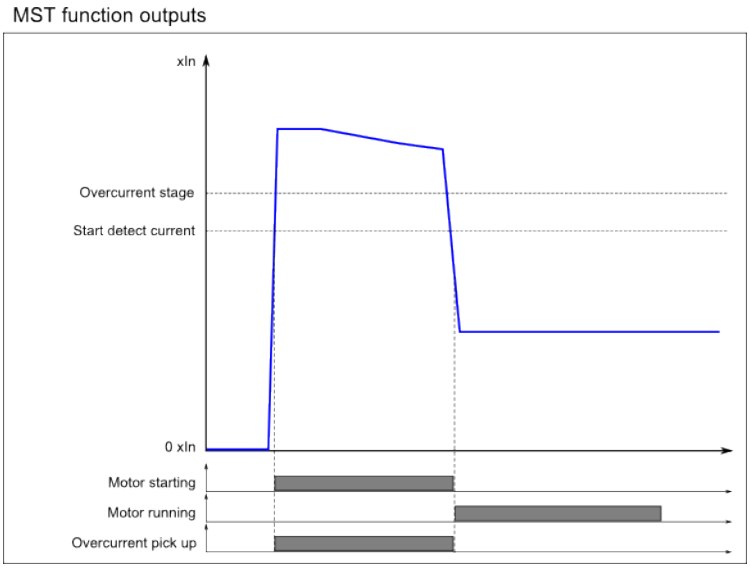
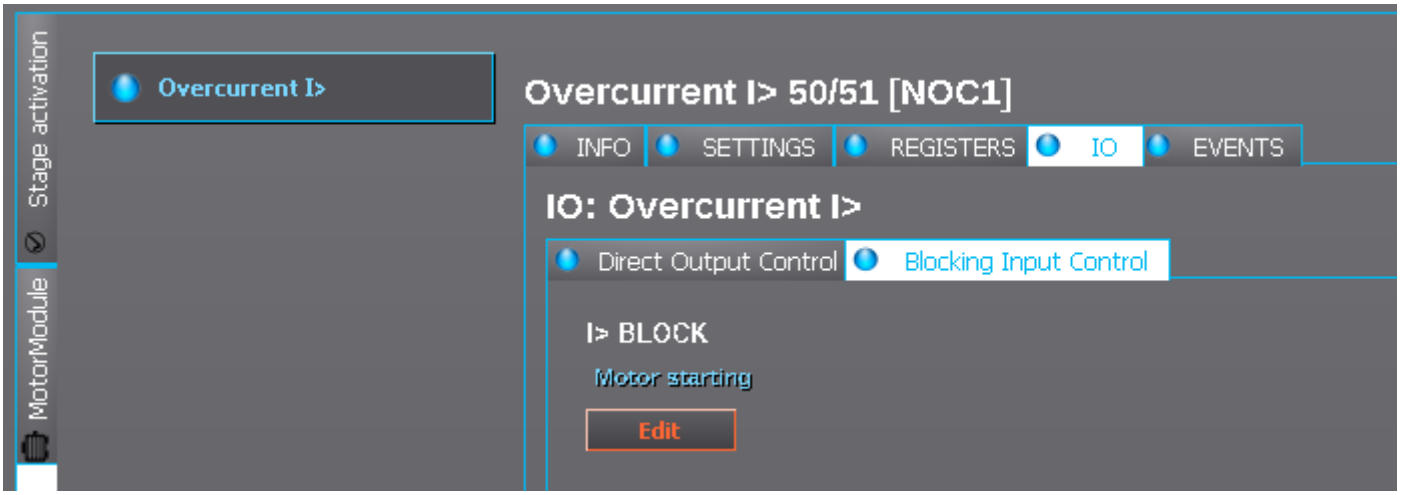
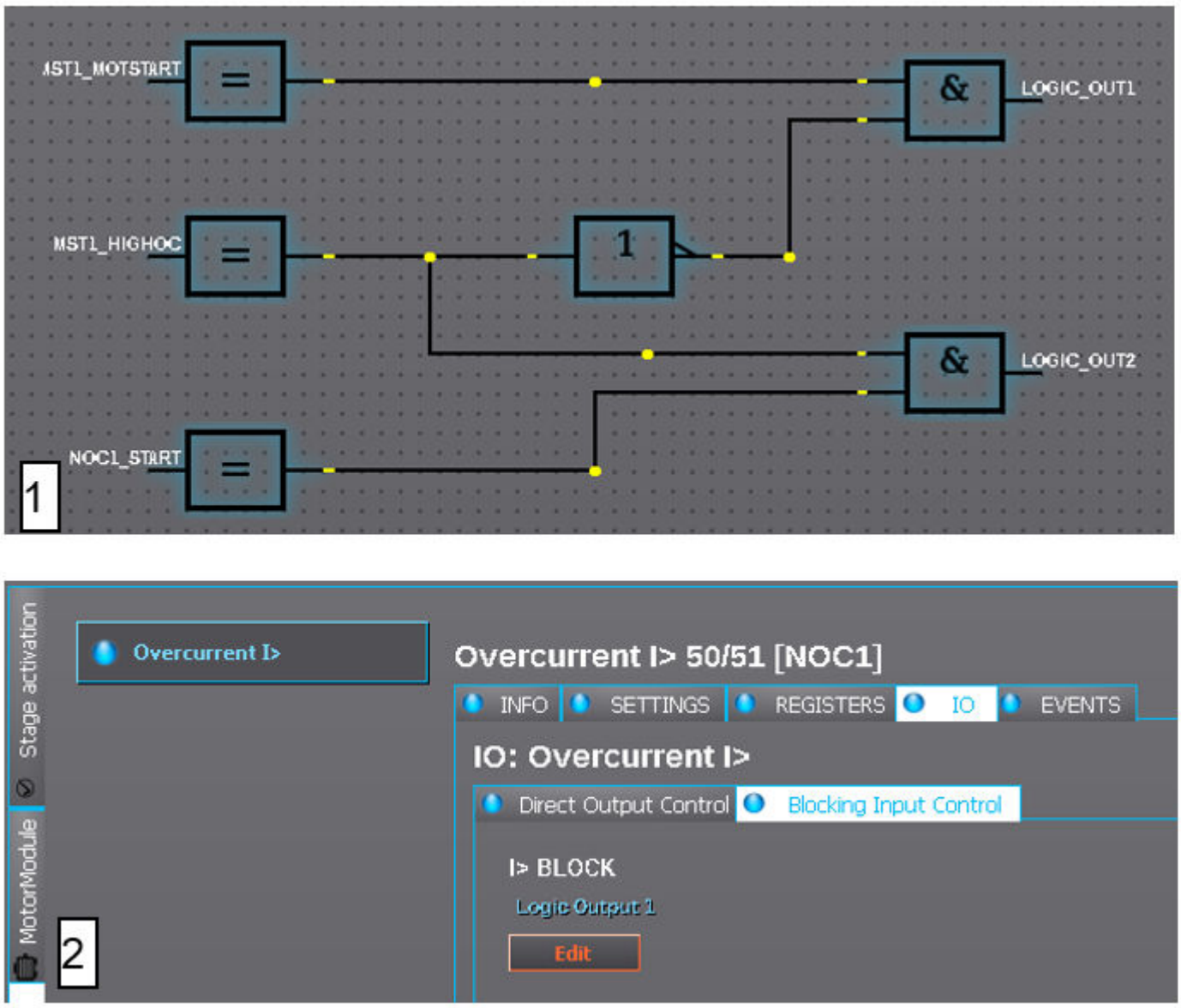


Figure 3.133 Blocking application in the relay configuration.



Problem in this example application may be that if during the start-up of the motor, short circuit fault occurs in cases when the overcurrent stage is blocked it may prolong the fault clearing time since the relay is considering this situation still as starting. For this purpose following logic can be used to prevent the prolongation of the fault clearing time during startup of the motor. Benefit of this logic is that there is no need to spend another protection stage for short circuit faults since the one stage set below the starting current of the motor can be used for short circuits and also overcurrent faults.

Figure 3.134 Motor start up overcurrent control logic.



Picture 1. In the start-up situation MST_MOTSTART signal is connected to LOGIC_OUT1 signal with “AND” gate to “NOT” high overcurrent detect in the MST function. When motor is started I> stage is blocked, if high overcurrent is detected during the startup the blocking is released. If wanted the high overcurrent detect can be combined with I> (NOC1) start signal to “AND” and use for example LOGIC_OUT2 to change the active setting group of I> function to instant operating.

Picture 2. This LOGIC_OUT1 signal is connected to I> blocking input (NOC1, first stage overcurrent) function to block the stage in motor start-ups.

Picture 3. High overcurrent detect signal can also be directly connected to output relay. With this application there is no need for extra logics for the fault clearing control and the fault clearing is very fast.

In addition to this application suggestion there is possible also to just release the tripping of I> stage when the high overcurrent is detected and let the overcurrent function to operate on its set timer settings. Requirement for this scheme to work properly is that the motor start detection current is set below of to be blocked overcurrent stage.

Settings and signals

Settings of the motor status monitor (MST) function are mostly shared with motor protection functions in the motor module of the IED. In following table are shown the functions which use these settings also.

Table 3.153 Settings of the MST function.

Name	Range	Step	Default	Prot.funcs.	Description
Motor Start	0: DOL 1: StarDelta 2: Softstart	-	0:DOL	MST Ist> (48)	Motor starting mode selection. Direct On Line, Star-Delta or soft started application will be selectable in future releases.
Motor In Scaled	0.1... 40.0xIn	0.1xIn	-	MST TM> (49M) Ist> (48) I< (37) Im> (50M)	Motor nominal current scaled to per unit. If in the CT settings “Object In” is selected this value should be 1.00. If scale to CT nominal then this value may vary.
Motor In A	0.1 ... 5000A	0.1A	-	MST TM> (49M) Ist> (48) I< (37) Im> (50M)	Motor nominal current in amperes.
Nominal starting current	0.1...40.0xIn	0.1xIn	6.0xIn	MST TM> (49M) Ist> (48) Im> (50M)	Motors locked rotor current with nominal voltage. This setting is used for the automatic curve selection and calculation. Also nominal starting capacity calculation is made with this value.
Nominal starting current A	0.1 ... 5000A	0.1A	-	MST TM> (49M) Ist> (48) Im> (50M)	Motors locked rotor current in amperes.
Start detect current	0.1...40.0xIn	0.1xIn	1.5 xIn	MST Ist> (48)	Motor starting current detection limit. When in DOL or Start delta mode this setting defines the starting situation when measured current exceeds this and no load current setting in 10 ms time.
Start detect current A	0.1 ... 5000A	0.1A	-	MST Ist> (48)	Motor starting current detection limit in amperes.
Min locked rotor current	0.1...40.0xIn	0.1xIn	3.5 xIn	MST TM> (49M) Ist> (48) Im> (50M)	Minimum locked rotor current of the motor. This setting defines the current limit when in the automatic curve selection and control only short time constant (stall) is used if this current is exceeded.
Min locked rotor current A	0.1 ... 5000A	0.1A	-	MST TM> (49M) Ist> (48) Im> (50M)	Minimum locked rotor current of the motor. This setting defines the current limit when in the automatic curve selection and control only short time constant (stall) is used if this current is exceeded.
Max locked rotor current	0.1...40.0xIn	0.1xIn	7.5 xIn	MST TM> (49M) Ist> (48) Im> (50M)	Maximum locked rotor current of the motor. This setting defines the current limit which is maximum current for the motor to draw in locked rotor situation (starting or stalled). If the measured current exceeds this setting limit it is considered to be overcurrent fault and corresponding measures can be applied to disconnect the feeder and motor from the supply.
Max locked rotor current A	0.1 ... 5000A	0.1A	-	MST TM> (49M) Ist> (48) Im> (50M)	Maximum locked rotor current in amperes.
Max overload current	0.1...40.0xIn	0.1xIn	2.0xIn	MST TM> (49M) Ist> (48) Im> (50M)	Max overload current of the motor. Over this setting motor is stalled. This setting defines when the thermal replica switches to short (stall) time constant if exceeded. Under this setting value the motor should be running still even overloaded.

Name	Range	Step	Default	Prot.funcs.	Description
Max overload current A	0.1 ... 5000A	0.1A	-	MST TM> (49M) Ist> (48) Im> (50M)	Max overload current of the motor in amperes.
No load current <	0.1...40.0xIn	0.1xIn	0.2xIn	MST TM> (49M) I< (37)	Motors no load current. This setting defines the “Stopped” condition when the current is below this setting value. Also below this value undercurrent protection stage is locked.
No load current < A	0.1 ... 5000A	0.1A	-	MST TM> (49M) I< (37)	Motors no load current in amperes.
Motor service factor	0.01...5.00xIn	0.01xIn	1.00 xIn	MST TM> (49M)	Service factor which corrects the maximum allowed loading according to installation, construction etc. conditions which vary from the presumption conditions. Frequently motors are stamped to service factor of 1.15 which means that they can withstand continuous 15% overloading from the rated current continuously (not necessary in all possible conditions therefore consult the motor datasheet/manual for details). If the service factor is not known leave this parameter to 1.00 xIn.
Hot condition theta limit	0.0...100.0%	0.1%	70%	MST N> (48) TM> (49M) Ist> (48) Im> (50M)	Setting of the thermal limit Hot / Cold situation of the motor. When this setting value is not exceed and locked rotor situation occurs cold stall curve adjusted with actual used thermal capacity is utilized. After this setting value hot stall curve is utilized. Applies also for Starts when hot / cold selection. NOTE:Usage requires that the Thermal protection TM> is activated and in use.
Safe stall time cold	0.1...600.0s	0.1s	20.0s	MST TM> (49M) Ist> (48) Im> (50M) N> (48)	Safe stall time when motor is cold. If this value is not informed then set to same than hot stall time. This leads most probably to overprotection with cold motor stall but is best guess in such case. This setting value is used for the cold thermal stall curve selection in automatic control. Also motor start-up and number of starts calculations use this parameter.
Safe stall time hot	0.1...600.0s	0.1s	15.0s	MST TM> (49M) Ist> (48) Im> (50M) N> (48)	Safe stall time when motor is hot. This setting value is used for the hot thermal stall curve selection in automatic control. Also motor start-up and number of starts calculations use this parameter.
Starts when cold	1...100st	1st	3st	MST N> (48)	Allowed starts per x hours for cold motor.
Starts when hot	1...100st	1st	2st	MST N> (48)	Allowed starts per x hours for hot motor.
Starts in hours	1...100h	1h	1h	MST N> (48)	Hours when the allowed given hot and cold starts applies.
Min time betw. starts	0.1...600.0s	0.1s	20.0s	MST N> (48)	Minimum time in between of starts or start attempts.

Table 3.154 Output signals of the MST function

Name	Range	Step	Default	Description
Motor stopped	0:Not active	-	0:Not active	Signal is active when the MST function detects current below “No load current”. This signal presents situation when the motor is not running.

Name	Range	Step	Default	Description
	1:Active			
Motor starting	0:Not active 1:Active	-	0:Not active	Motor starting signal is active when motor start up is detected. In DOL mode it is active when measured current is exceeding “Start detect current” from “Motor stopped” situation until current decreases below “Max overloading current”.
Motor running	0:Not active 1:Active	-	0:Not active	Motor running signal is active when measured current is over the set “No load current” after the “Motor starting” situation is passed first. Motor running signal is released when the measured current is below “No load current” setting.
Motor stalled	0:Not active 1:Active	-	0:Not active	Motor stalled signal is active if the measured current exceeds “Max overload current” setting from the “Motor running” situation.
Missing phase	0:Not active 1:Active	-	0:Not active	Missing phase signal is activated if one of the phases measured current is below “No load current” setting and two phases measured current is over “Min. locked rotor current” setting. This signal can be used for quick halting the start up of the motor if one phase is lost and the motor cannot start.
Load Normal	0:Not active 1:Active	-	0:Not active	Load normal signal is active when measured current is over the set “No load current” and under motor nominal current including ambient and service factor corrections.
Overloading	0:Not active 1:Active	-	0:Not active	Overloading signal is active if the measured current exceeds the motor nominal current including ambient and service factor corrections but not over the set “Max overload current” setting.
High overcurrent	0:Not active 1:Active	-	0:Not active	High overcurrent signal is active when the measured current is over the set “Max locked rotor current” and presents situation which is impossible for the motor to cause even starting or stalled. If this signal activates it indicates short circuit fault and should be used for halting start-up or stalled situations immediately.

Events and registers

MST function generates events from detected motor status. From changes of the events also data register is available.

Table 3.155 Event codes of MST function.

Event Number	Event channel	Event block name	Event Code	Description
3969	62	MST1	1	Motor Stopped Off
3970	62	MST1	2	Motor Starting On
3971	62	MST1	3	Motor Starting Off
3972	62	MST1	4	Motor Running On
3973	62	MST1	5	Motor Running Off
3974	62	MST1	6	Motor Stalled On
3975	62	MST1	7	Motor Stalled Off
3976	62	MST1	8	Load not symm On
3977	62	MST1	9	Load not symm Off
3978	62	MST1	10	Load normal On
3979	62	MST1	11	Load normal Off
3980	62	MST1	12	Overload On
3981	62	MST1	13	Overload Off

Event Number	Event channel	Event block name	Event Code	Description
3982	62	MST1	14	High Overcurrent On
3983	62	MST1	15	High Overcurrent Off

In the table below is presented the structure of MST function register content. This information is available in 12 last recorded events.

Table 3.156 Register content.

Date & Time	Event code	L1 current	L2 current	L3 current	Therm delta	Motor load
dd.mm.yyyy hh:mm:ss.mss	3968-3983 Descr.	Phase L1 current xIn	Phase L2 current xIn	Phase L3 current xIn	Detected change in thermal capacity	Motor loading when triggered

3.8.2 Load jam protection Im> (51M)

Mechanical jam protection (MJP) is used for monitoring motor loading after starting of the motor. In cases if the motor run apparatus jams during the work load the mechanical jam protection can be used to disconnect the motor from the feeding network in order to avoid further damage to the motor drive. Mechanical jam protection is active only after the motor is started and during starting MJP function is blocked. MJP function operates similarly to the LCR function (locked rotor) but is always definite time and does not work during starting. With dedicated locked rotor function/mechanical jam protection possible fault situations can be divided also in the relay events for quick definition of the fault types. Also with heavy inertia loads the LCR function set-up for during work load locked rotor situations may be complicated. With separate functions the start-up and mechanical jam situations can be clearly divided and the mechanical jam protection may be set to instant operation for example while LCR function may allow several tens of seconds starting.

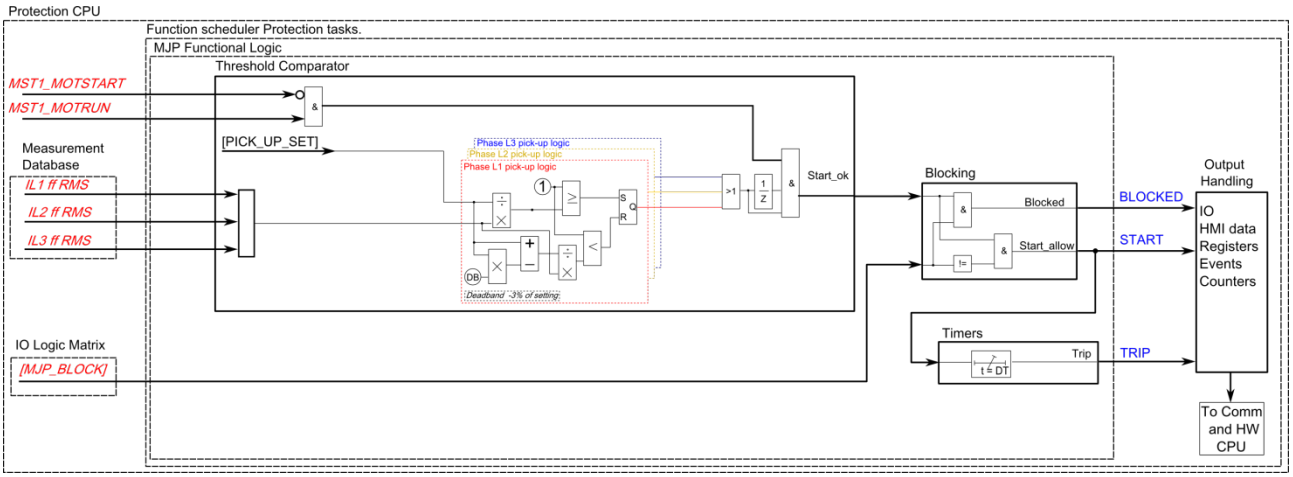
Outputs of the function are Start Trip and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. Non directional undercurrent function utilizes total of eight separate setting groups which can be selected from one common source.

The function can be operating on instant or time delayed mode. In time delayed mode the operation can be set to operate on definite set time delay.

Inputs for the function are setting parameters and measured and pre-processed current magnitudes and binary input signals. Function outputs START, TRIP and BLOCKED signals which can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the three output signal. In instant operating mode the function outputs START and TRIP events simultaneously with equivalent time stamp. Time stamp resolution is 1ms. Function provides also cumulative counters for START, TRIP and BLOCKED events.

In the following figure is presented the simplified function block diagram of the MJP function.

Figure 3.135 Simplified function block diagram of the MJP function.



Measured input values

For the function block is used analog current measurement values. Function block utilizes fundamental frequency phase current RMS measurements. For the pre-fault data registering is used -20 ms averaged value of the selected magnitude.

Table 3.157 Analogic magnitudes used by the MJP function.

Signal	Description	Time base
IL1RMS	Fundamental RMS measurement of phase L1/A current	5 ms
IL2RMS	Fundamental RMS measurement of phase L2/B current	5 ms
IL3RMS	Fundamental RMS measurement of phase L3/C current	5 ms

Selection of the used AI channel is made with a setting parameter. In all possible input channel variations pre-fault condition is presented with 20 ms averaged history value from -20 ms of Start or Trip event.

Pick-up characteristics

Pick-up of the MJP function is controlled by *Iset* setting parameter, which defines the maximum allowed measured current before action from the function. The function constantly calculates the ratio in between of the Iset and measured magnitude (Im) per all three phases. Reset ratio of 97 % is inbuilt in the function and is always related to the *Iset* value. The setting value is common for all measured phases and single-, dual- or all phases Im measured lower of the *Iset* value will cause pick-up operation of the function.

Table 3.158 Motor data settings of the MJP function

Name	Range	Step	Default	Prot.funcs.	Description
Motor In Scaled	0.1... 40.0xIn	0.1xIn	-	MST TM> (49M) Ist> (48) I< (37) Im> (50M)	Motor nominal current scaled to per unit. If in the CT settings “Object In” is selected this value should be 1.00. If scale to CT nominal then this value may vary.
Motor In A	0.1 ... 5000A	0.1A	-	MST TM> (49M) Ist> (48) I< (37) Im> (50M)	Motor nominal current in amperes.
Nominal starting current	0.1... 40.0xIn	0.1xIn	6.0xIn	MST TM> (49M) Ist> (48) Im> (50M)	Motors locked rotor current with nominal voltage. This setting is used for the automatic curve selection and calculation. Also nominal starting capacity calculation is made with this value.

Name	Range	Step	Default	Prot.funcs.	Description
Nominal starting current A	0.1 ... 5000A	0.1A	-	MST TM> (49M) Ist> (48) Im> (50M)	Motors locked rotor current in amperes.
Min locked rotor current	0.1... 40.0xIn	0.1xIn	3.5xIn	MST TM> (49M) Ist> (48) Im> (50M)	Minimum locked rotor current of the motor. This setting defines the current limit when in the automatic curve selection and control only short time constant (stall) is used if this current is exceeded.
Min locked rotor current A	0.1 ... 5000A	0.1A	-	MST TM> (49M) Ist> (48) Im> (50M)	Minimum locked rotor current of the motor. This setting defines the current limit when in the automatic curve selection and control only short time constant (stall) is used if this current is exceeded.
Max locked rotor current	0.1... 40.0xIn	0.1xIn	7.5xIn	MST TM> (49M) Ist> (48) Im> (50M)	Maximum locked rotor current of the motor. This setting defines the current limit which is maximum current for the motor to draw in locked rotor situation (starting or stalled). If the measured current exceeds this setting limit it is considered to be overcurrent fault and corresponding measures can be applied to disconnect the feeder and motor from the supply.
Max locked rotor current A	0.1 ... 5000A	0.1A	-	MST TM> (49M) Ist> (48) Im> (50M)	Maximum locked rotor current in amperes.
Max overload current	0.1... 40.0xIn	0.1xIn	2.0xIn	MST TM> (49M) Ist> (48) Im> (50M)	Max overload current of the motor. Over this setting motor is stalled. This setting defines when the thermal replica switches to short (stall) time constant if exceeded. Under this setting value the motor should be running still even overloaded.
Max overload current A	0.1 ... 5000A	0.1A	-	MST TM> (49M) Ist> (48) Im> (50M)	Max overload current of the motor in amperes.
Hot condition theta limit	0.0... 100.0%	0.1%	70%	MST N> (48) TM> (49M) Ist> (48) Im> (50M)	Setting of the thermal limit Hot / Cold situation of the motor. When this setting value is not exceed and locked rotor situation occurs cold stall curve adjusted with actual used thermal capacity is utilized. After this setting value hot stall curve is utilized. Applies also for Starts when hot / cold selection. NOTE:Usage requires that the Thermal protection TM> is activated and in use.
Safe stall time cold	0.1...600.0s	0.1s	20.0s	MST TM> (49M) Ist> (48) Im> (50M) N> (48)	Safe stall time when motor is cold. If this value is not informed then set to same than hot stall time. This leads most probably to overprotection with cold motor stall but is best guess in such case. This setting value is used for the cold thermal stall curve selection in automatic control. Also motor start-up and number of starts calculations use this parameter.
Safe stall time hot	0.1...600.0s	0.1s	15.0s	MST TM> (49M) Ist> (48) Im> (50M) N> (48)	Safe stall time when motor is hot. This setting value is used for the hot thermal stall curve selection in automatic control. Also motor start-up and number of starts calculations use this parameter.

Table 3.159 Pick-up setting

Name	Description	Range	Step	Default
Iset	Pick-up setting	0.10 ... 40.00 x In	0.01 x In	0.5 x In

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

The operating timers' behavior of the function can be set for trip signal and also for the release of the function in case the pick-up element is reset before the trip time has been reached. There are three basic operating modes available for the function. Instant operation gives the trip signal with no additional time delay simultaneously with start signal. Definite time operation (DT) will give trip signal with user given time delay regardless of the measured current as long as the current is above the Iset value and thus pick-up element is active (independent time characteristics).

In the following table are presented the setting parameters for the function time characteristics.

Table 3.160 Operating time characteristics setting parameters.

Name	Range	Step	Default	Description
Definite operating time delay	0.000... 1800.000s	0.005s	0.040s	Definite time operating delay. Setting is active and visible when Delay Type is selected to DT. When set to 0.000 s the stage operates as instant (PIOC, 50) stage without added delay. When the parameter is set to 0.005 – 1800 s the stage operates as independent delayed (PTOC, 51).

Table 3.161 Reset time characteristics setting parameters.

Name	Range	Step	Default	Description
Release Time delay	0.000... 150.000s	0.005s	0.06s	Resetting time. Time allowed in between of pick-ups if the pick-up has not lead into trip operation. During this time the start signal is held on for the timers if delayed pick-up release is active.
Delayed Pick-up release	No Yes	-	Yes	Resetting characteristics selection either time delayed or instant after pick-up element is released. If activated the start signal is reset after set release time delay.
Time calc reset after release time	No Yes	-	Yes	Operating timer resetting characteristics selection. When active the operating time counter is reset after set release time if pick-up element is not activated during this time. When disabled the operating time counter is reset directly after the pick-up element reset.
Continue time calculation during release time	No Yes	-	No	Time calculation characteristics selection. If activated the operating time counter is continuing until set release time even the pick-up element is reset.

Resetting characteristics can be set according to the application. Default setting is delayed with 60 ms and the time calculation is held during the release time.

When using the release delay option where the operating time counter is calculating the operating time during the release time, function will not trip if the input signal is not activated again during the release time counting.

Function blocking

In the blocking element the block signal is checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup current values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Events and registers

The MJP function generates events and registers from the status changes of start, trip and blocked. To main event buffer is possible to select status “On” or “Off” messages. The MJP function offers four independent instances which events are segregated for each instance operation.

In the function is available 12 last registers where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values.

Table 3.162 Event codes of the MJP function

Event Number	Event channel	Event block name	Event Code	Description
3776	59	MJP1	0	Start ON
3777	59	MJP1	1	Start OFF
3778	59	MJP1	2	Trip ON
3779	59	MJP1	3	Trip OFF
3780	59	MJP1	4	Block ON
3781	59	MJP1	5	Block OFF

In the register of the MJP function is recorded start, trip or blocked “On” event process data. In the table below is presented the structure of MJP function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 3.163 Register content.

Date & Time	Event code	Fault type	Trigger current	Fault current	Prefault current	Trip time remaining	Used SG
dd.mm.yyyy hh:mm:ss.mss	3776-3781 Descr.	L1-G ... L1-L2-L3	Start average current	Trip -20 ms averages	Start -200 ms averages	0ms -1800s	1 - 8

3.8.3 Undercurrent I< (37)

Undercurrent function (NUC) is used for monitoring motor loading especially in conveyor type of applications. If the motor load is suddenly lost it indicates problems in the actual load rather than in the motor itself. In conveyor application this may indicate broken belt and the motor should be turned off quickly in order to avoid further problems. Other reasons may be mechanical breakdowns of the motor used apparatus. In some cases this undercurrent function output may be also used for the automation system to indicate that the device has finished work load and is ready for next batch. To operate this function needs the internally connected motor status running signal. This is due that the operation is blocked when the motor is not running.

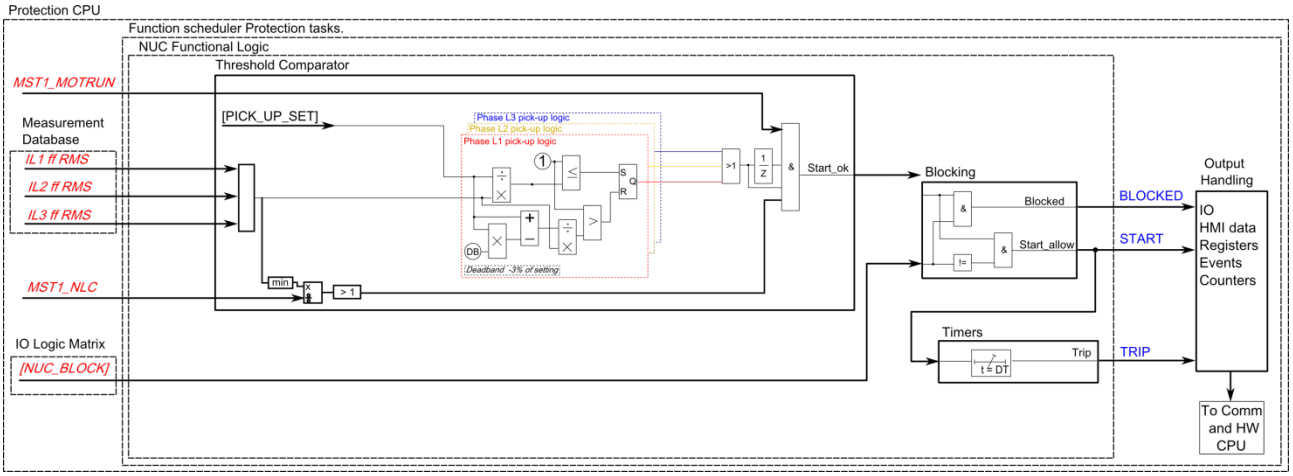
Outputs of the function are Start Trip and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. Non-directional undercurrent function utilizes total of eight separate setting groups which can be selected from one common source.

The function can be operating on instant or time delayed mode. In time delayed mode the operation can be set to operate on definite set time delay.

Inputs for the function are setting parameters and measured and pre-processed current magnitudes and binary input signals. Function outputs START, TRIP and BLOCKED signals which can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the three output signal. In instant operating mode the function outputs START and TRIP events simultaneously with equivalent time stamp. Time stamp resolution is 1ms. Function provides also cumulative counters for START, TRIP and BLOCKED events.

In the following figure is presented the simplified function block diagram of the NUC function.

Figure 3.136 Simplified function block diagram of the NUC function.



Measured input values

For the function block is used analog current measurement values. Function block utilizes fundamental frequency phase current RMS measurements. For the pre-fault data registering is used -20 ms averaged value of the selected magnitude.

Table 3.164 Analogic magnitudes used by the NUC function.

Signal	Description	Time base
IL1RMS	Fundamental RMS measurement of phase L1/A current	5 ms
IL2RMS	Fundamental RMS measurement of phase L2/B current	5 ms
IL3RMS	Fundamental RMS measurement of phase L3/C current	5 ms

Selection of the used AI channel is made with a setting parameter. In all possible input channel variations pre-fault condition is presented with 20 ms averaged history value from -20 ms of Start or Trip event.

Pick-up characteristics

Pick-up of the NUC function is controlled by Iset setting parameter, which defines the minimum allowed measured current before action from the function. The function constantly calculates the ratio in between of the Iset and measured magnitude (Im) per all three phases. Reset ratio of 97 % is inbuilt in the function and is always related to the Iset value. The setting value is common for all measured phases and single-, dual- or all phases Im measured lower of the Iset value will cause pick-up operation of the function.

Table 3.165 Motor data settings of the NUC function

Name	Range	Step	Default	Prot.funcs.	Description
Motor In Scaled	0.1... 40.0xIn	0.1xIn	-	MST TM> (49M) Ist> (48) I< (37)	Motor nominal current scaled to per unit. If in the CT settings “Object In” is selected this value should be 1.00. If scale to CT nominal then this value may vary.

Name	Range	Step	Default	Prot.funcs.	Description
				Im> (50M)	
Motor In A	0.1 ... 5000A	0.1A	-	MST TM> (49M) Ist> (48) I< (37) Im> (50M)	Motor nominal current in amperes.
No load current<	0.1...40.0xIn	0.1xIn	0.2xIn	MST TM> (49M) I< (37)	Motors no load current. This setting defines the “Stopped” condition when the current is below this setting value. Also below this value undercurrent protection stage is locked.
No load current< A	0.1 ... 5000A	0.1A	-	MST TM> (49M) I< (37)	Motors no load current in amperes.

Table 3.166 Pick-up setting

Name	Description	Range	Step	Default
Iset	Pick-up setting	0.10...40.00xIn	0.01xIn	0.5xIn

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Operating time characteristics for trip and reset

This function supports definite time delay (DT) and inverse definite minimum time (IDMT) delay types. For detailed information on these delay types refer to chapter General properties of a protection function.

Function blocking

In the blocking element the block signal is checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup current values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Events and registers

The NUC function generates events and registers from the status changes of start, trip and blocked. To main event buffer is possible to select status “On” or “Off” messages. The NUC function offers four independent instances which events are segregated for each instance operation.

In the function is available 12 last registers where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values.

Table 3.167 Event codes of the NUC function

Event Number	Event channel	Event block name	Event Code	Description
3840	60	NUC1	0	Start ON
3841	60	NUC1	1	Start OFF
3842	60	NUC1	2	Trip ON
3843	60	NUC1	3	Trip OFF
3844	60	NUC1	4	Block ON
3845	60	NUC1	5	Block OFF

In the register of the NUC function is recorded start, trip or blocked “On” event process data. In the table below is presented the structure of NUC function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 3.168 Register content.

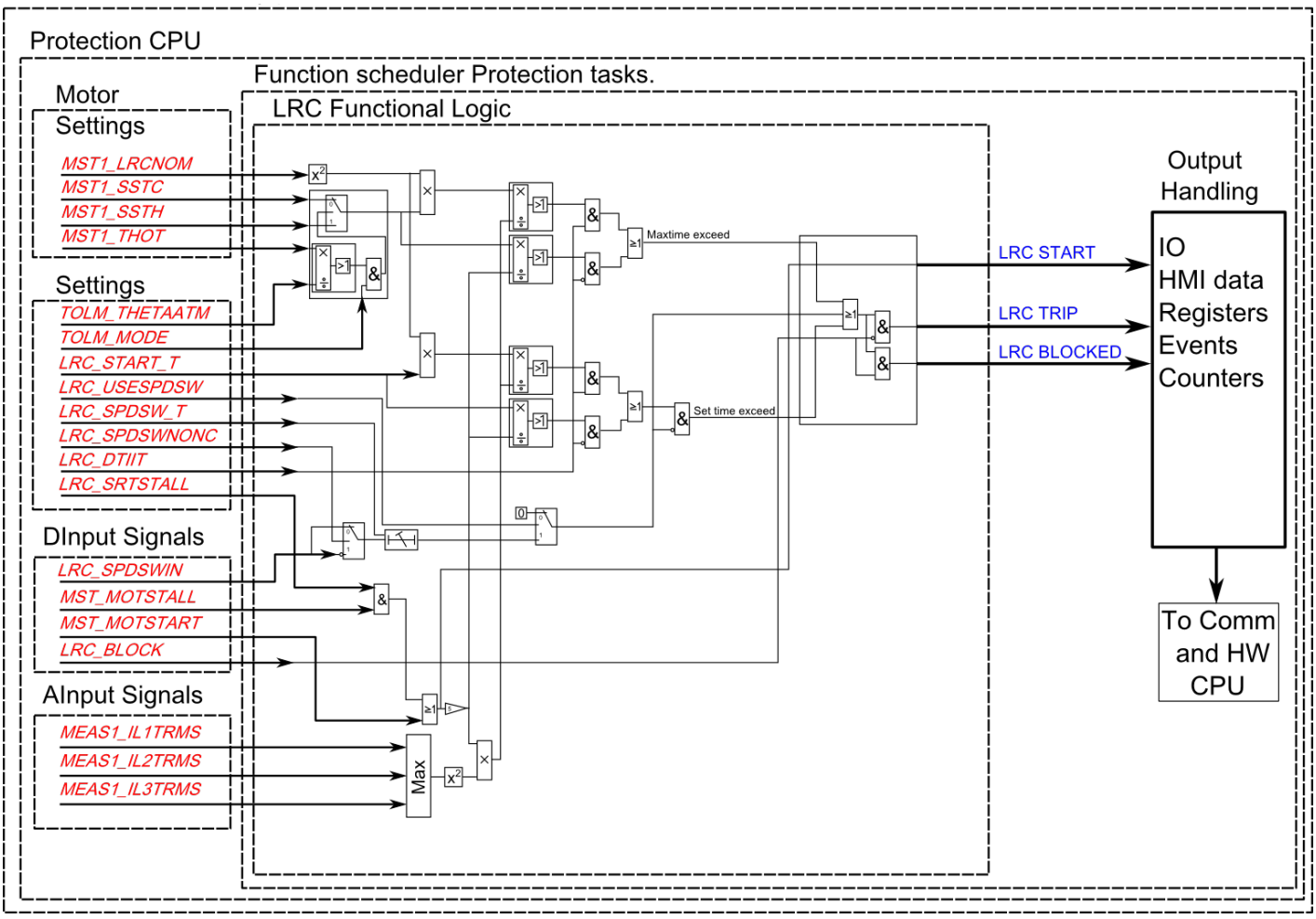
Date & Time	Event code	Fault type	Trigger current	Fault current	Prefault current	Trip time remaining	Used SG
dd.mm.yyyy hh:mm:ss.mss	3840-3845 Descr.	L1-G ... L1-L2-L3	Start average current	Trip -20 ms averages	Start -200 ms averages	0ms -1800s	1 - 8

3.8.4 Motor start / Locked rotor monitoring (LRC) IST> (48, 14)

Motor start/locked rotor monitoring function (LRC) is used for monitoring the startup duration and also the startup stress of the motor. LCR protection function can also be used after starting for locked rotor protection.

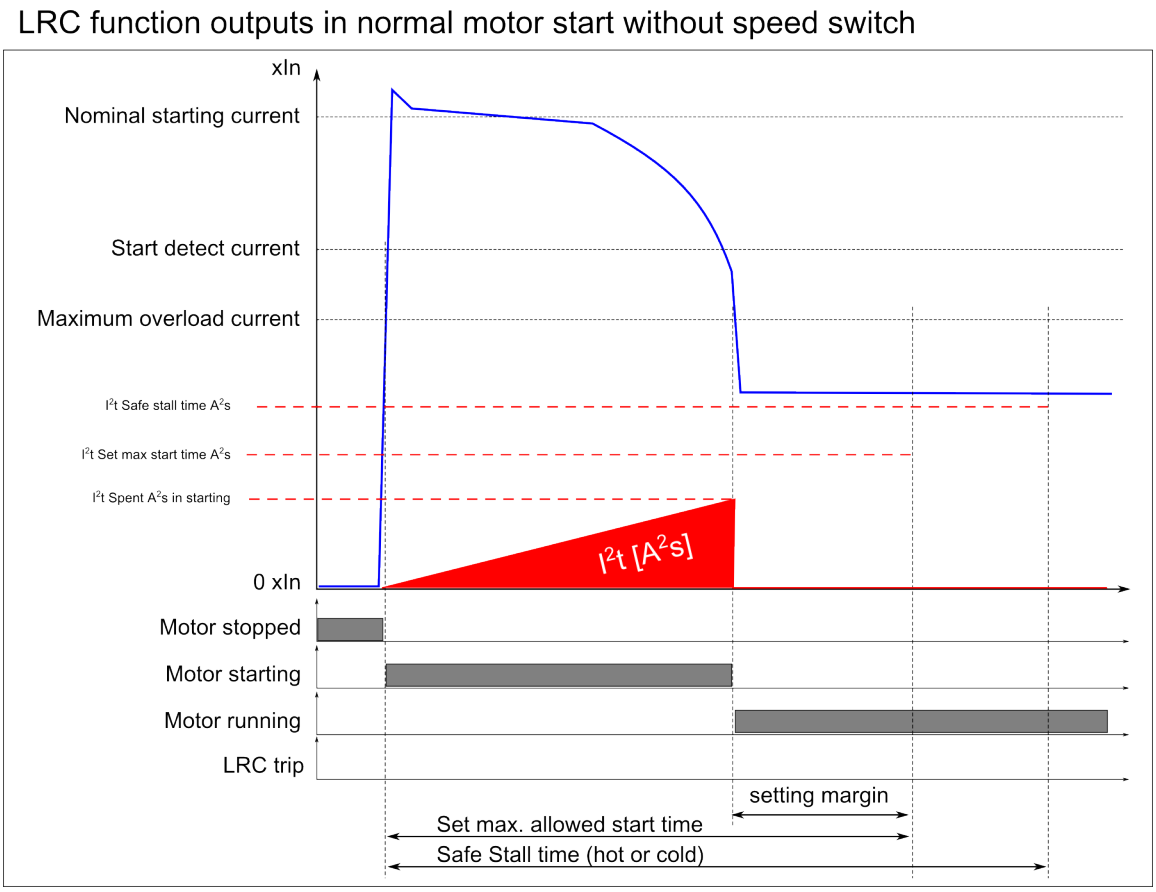
Operating principle of the LCR function is either definite maximum locked rotor time monitoring or inverse operating time based into allowed I^2t calculation. When using I^2t calculation given start up timing the maximum allowed starting time is automatically scaled according to the motor current and for example it is giving longer starting time for the motor if the network voltage is lower and thus the starting current is lower, the motor start-up will take longer time also. Maximum allowed starting time can be set manually or the function can be set to follow motor manufacturer given hot and cold safe stalling times automatically. This requires that the thermal overload (TOLM) function is activated and set up for the automatic safe stalling times to be picked and the thermal status of the motor to be known for the LCR function. In addition to the settable allowed starting time also speed switch input can be set for the function. Speed switch may be required in some high mass applications when the starting up may last long time and the starting situation should be checked that the motor is actually accelerating and not standing still with its rotor locked.

Figure 3.137 Simplified function block diagram of the LRC function.



Suggestion for the LRC setup is so that the I^2t mode is used in the starting and if the application is such that in normal use during motor running locked rotor situations may happen in some part of the duty cycle, also the locked rotor protection is applied. In following pictures the suggested application of the LRC is described in different situations. If the speed switch is available it is advised that it is also used for the motor start monitoring especially when the motor is starting high mass and the startup duration is thus very long.

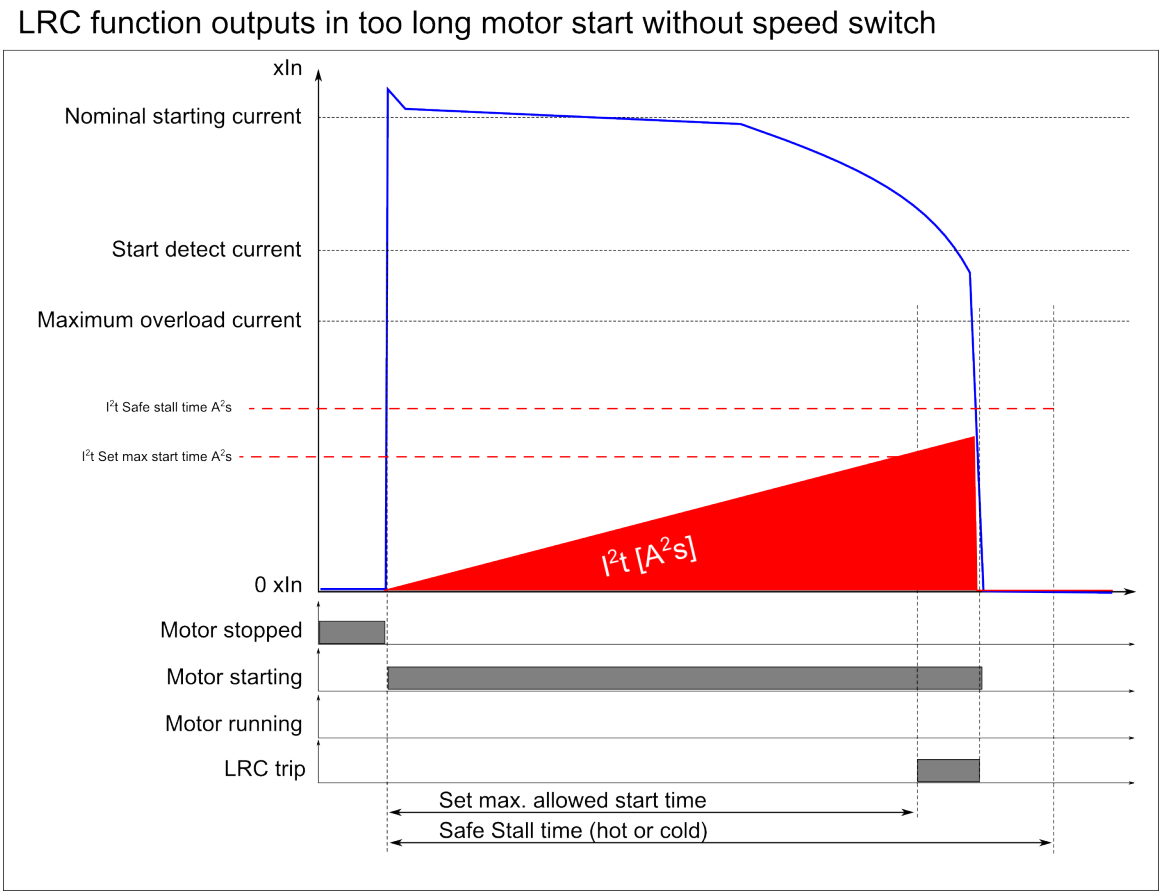
Figure 3.138 Normal start of the motor.



The LRC function should be set so that in the normal motor start the application required starting time is taken into account in the setting of the function. There should be setting margin in the expected starting time and the setting of the LRC function. If the motor starting is dependent of the process status e.g. the motor drive may be in full load or in no load when started, this may affect to the starting time of the motor and the setting should be according to the longest possible starting time. If the startup situation should always be the same then this expected starting time + 10% margin should be sufficient setting for the LRC starting monitor. During the start up the LRC function monitors the accumulated I^2t value and when it is below the calculated set I^2t value, the function lets the starting situation continue.

If the starting of the motor takes longer time than the set value is the function shall trip the breaker and halt the starting since there is something wrong in the application if the motor cannot start normally.

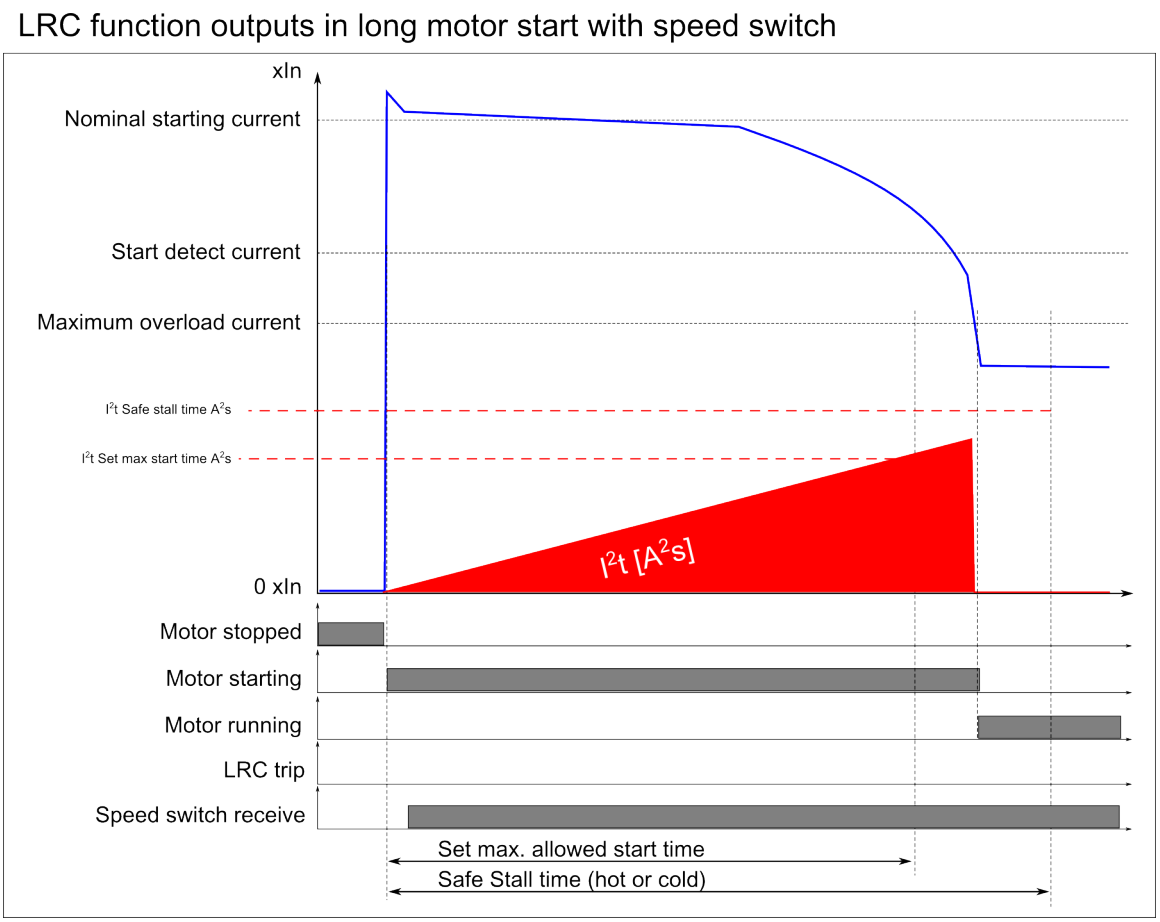
Figure 3.139 Motor starting is too long.



Reasons for too long starting may be in the drive and application as well as in the feeding network if started motor is very large and the feeding network is weak the voltage may drop so that the motor cannot provide needed torque for normal starting and the start-up situation is prolonged. For this reason the I^2t mode is suggested since it will compensate the voltage drop in taking to account the lower voltage caused lower starting current. If definite time is preferred for the LRC function it may be so that the starting is well in action but the user allowed time is spent due to low network voltage caused lower current and lower torque the function may trip before the starting is over even the motor is not stressed yet too much and could still continue the starting.

If in the application is available so called speed switch which activates when the motor shaft is rotating / accelerating it can be used to prolong the allowed starting of the motor to longer than the set maximum starting duration. If the speed switch is used and similar situation happens that the motor is starting longer than it should the speed switch is noting that the startup of the motor is still going ok and LRC function lets the starting situation continue.

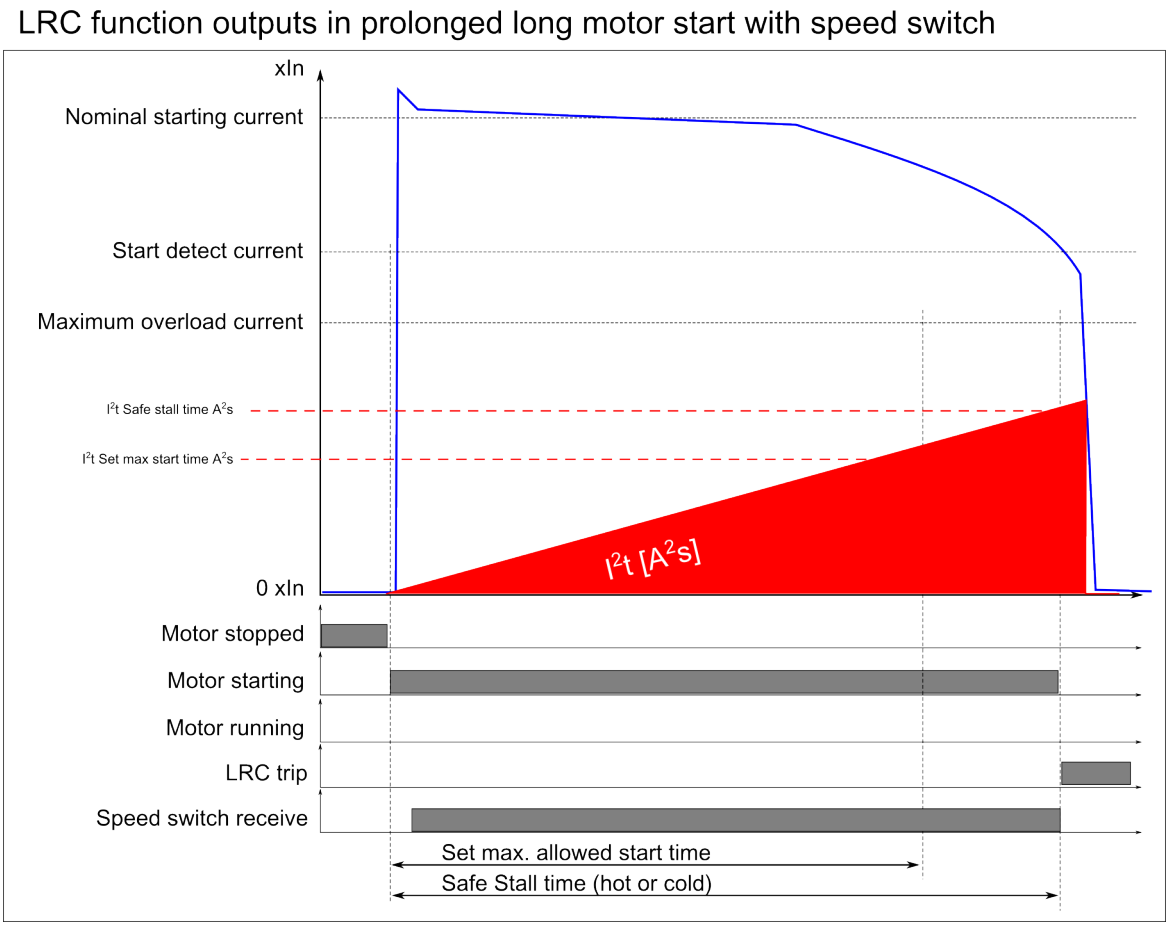
Figure 3.140 Long start with speed switch available.



Speed switch is useful also in cases if the motor start is naturally very long due to high accelerating mass. In such application it is impossible to note without speed switch if the startup is actually happening or if the load is jammed and the motor is standing still with its rotor locked.

If the motor startup with speed switch is taking more time than safe stall time of the motor specification allows the LRC function will trip.

Figure 3.141 Motor start with speed switch, too long starting.

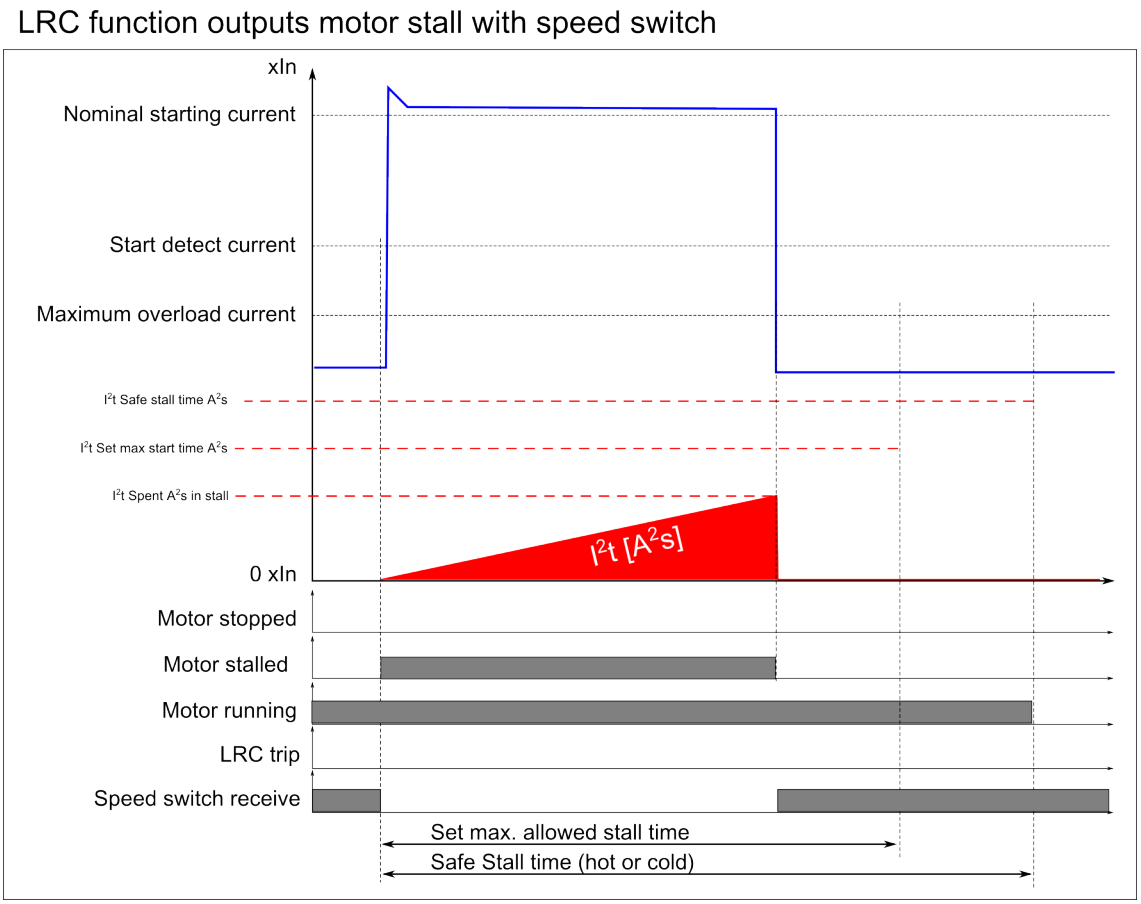


If the starting condition lasts longer than the set safe stall time of the motor the LRC function will trip the breaker. In this case the motor is either too small to accelerate in time given for the motor for safe stall time or the load has some problem even the motor is able to rotate. If the starting would let to continue it would endanger the motor.

If the motor stalls after it is started the LRC function may be set to monitor this situation also. In the motor protection module is available “Mechanical jam” function as well as the “Motor stalled” signal of the MST function may be used for direct tripping of the motor.

In stall detection and monitor mode the LRC function shall use same given settings for the motor stall than for starting conditions. The function monitors either given definite time or I2t value and speed switch input and if given time is exceeded during the stall time the LRC function shall initiate tripping of the motor from stall condition.

Figure 3.142 Motor stall monitoring.



Settings and signals

Settings of the motor status monitor (MST) function are mostly shared with motor protection functions in the motor module of the IED. In following table are shown the functions which use these settings also.

Table 3.169 Motor data Settings of the LRC function.

Name	Range	Step	Default	Prot.funcs.	Description
Motor Start	0:DOL 1:StarDelta 2:Softstart	-	0:DOL	MST Ist> (48)	Motor starting mode selection. Direct On Line, Star-Delta or soft started application will be selectable in future releases.
Motor In Scaled	0.1... 40.0xIn	0.1xIn	-	MST TM> (49M) Ist> (48) I< (37) Im> (50M)	Motor nominal current scaled to per unit. If in the CT settings “Object In” is selected this value should be 1.00. If scale to CT nominal then this value may vary.
Motor In A	0.1 ... 5000A	0.1A	-	MST TM> (49M) Ist> (48) I< (37) Im> (50M)	Motor nominal current in amperes.
Nominal starting current	0.1...40.0xIn	0.1xIn	6.0xIn	MST TM> (49M) Ist> (48) Im> (50M)	Motors locked rotor current with nominal voltage. This setting is used for the automatic curve selection and calculation. Also nominal starting capacity calculation is made with this value.

Name	Range	Step	Default	Prot.funcs.	Description
Nominal starting current A	0.1 ... 5000A	0.1A	-	MST TM> (49M) Ist> (48) Im> (50M)	Motors locked rotor current in amperes.
Start detect current	0.1...40.0xIn	0.1xIn	1.5xIn	MST Ist> (48)	Motor starting current detection limit. When in DOL or Start delta mode this setting defines the starting situation when measured current exceeds this and no load current setting in 10 ms time.
Start detect current A	0.1 ... 5000A	0.1A	-	MST Ist> (48)	Motor starting current detection limit in amperes.
Min locked rotor current	0.1...40.0xIn	0.1xIn	3.5xIn	MST TM> (49M) Ist> (48) Im> (50M)	Minimum locked rotor current of the motor. This setting defines the current limit when in the automatic curve selection and control only short time constant (stall) is used if this current is exceeded.
Min locked rotor current A	0.1 ... 5000A	0.1A	-	MST TM> (49M) Ist> (48) Im> (50M)	Minimum locked rotor current of the motor. This setting defines the current limit when in the automatic curve selection and control only short time constant (stall) is used if this current is exceeded.
Max locked rotor current	0.1...40.0xIn	0.1xIn	7.5xIn	MST TM> (49M) Ist> (48) Im> (50M)	Maximum locked rotor current of the motor. This setting defines the current limit which is maximum current for the motor to draw in locked rotor situation (starting or stalled). If the measured current exceeds this setting limit it is considered to be overcurrent fault and corresponding measures can be applied to disconnect the feeder and motor from the supply.
Max locked rotor current A	0.1 ... 5000A	0.1A	-	MST TM> (49M) Ist> (48) Im> (50M)	Maximum locked rotor current in amperes.
Max overload current	0.1...40.0xIn	0.1xIn	2.0xIn	MST TM> (49M) Ist> (48) Im> (50M)	Max overload current of the motor. Over this setting motor is stalled. This setting defines when the thermal replica switches to short (stall) time constant if exceeded. Under this setting value the motor should be running still even overloaded.
Max overload current A	0.1 ... 5000A	0.1A	-	MST TM> (49M) Ist> (48) Im> (50M)	Max overload current of the motor in amperes.
Hot condition theta limit	0.0...100.0%	0.1%	70%	MST N> (48) TM> (49M) Ist> (48) Im> (50M)	Setting of the thermal limit Hot / Cold situation of the motor. When this setting value is not exceed and locked rotor situation occurs cold stall curve adjusted with actual used thermal capacity is utilized. After this setting value hot stall curve is utilized. Applies also for Starts when hot / cold selection. NOTE:Usage requires that the Thermal protection TM> is activated and in use.
Safe stall time cold	0.1...600.0s	0.1s	20.0s	MST TM> (49M) Ist> (48) Im> (50M) N> (48)	Safe stall time when motor is cold. If this value is not informed then set to same than hot stall time. This leads most probably to overprotection with cold motor stall but is best guess in such case. This setting value is used for the cold thermal stall curve selection in automatic control. Also motor start-up and number of starts calculations use this parameter.
Safe stall time hot	0.1...600.0s	0.1s	15.0s	MST TM> (49M) Ist> (48) Im> (50M) N> (48)	Safe stall time when motor is hot. This setting value is used for the hot thermal stall curve selection in automatic control. Also motor start-up and number of starts calculations use this parameter.

Table 3.170 Settings of the LRC function.

Name	Range	Step	Default	Description
Starting time	0.000... 1800.000s	0.005s	0.040s	User settable motor starting time. This setting should include the expected normal starting time of the protected motor including the operating marginal.
Definite time or I2t	0:Definite 1:I2t mode	-	0:Definite	Selection of the operating mode. If I2t mode is selected the function shall monitor the heating effect in function of the measured current. In Definite mode the function shall monitor only the start / stall signal duration and compare it to user given “Starting time” setting.
Speed switch in use	0:No 1:Yes	-	0:No	Selection whether speed switch is used or not in the application.
Speed SW wait time	0.000... 1800.000s	0.005s	0.040s	Setting which time the speed switch is waited to give signal from starting of the motor. If the speed switch is not activating during this given time the starting of the motor is halted. This setting is visible only if “Speed switch in use” setting is “1:Yes”.
Speed SW NO/NC	0:NO 1:NC	-	0:NO	Polarity of the speed switch signal, normally open NO or normally closed NC. This setting is visible only if “Speed switch in use” setting is “1:Yes”.
Operate mode	0:Starts only 1:Starts and stall	-	0:Starts only	Operating mode selection of the LRC function. This setting defines if the function monitors only start-up or start-up and stall conditions of the motor.

Table 3.171 Output signals of the MST function

Name	Range	Step	Default	Description
Ist> START	0:Not active 1:Active	-	0:Not active	Start output of the LRC function. This signal activates when the starting conditions are met for the function and it is about to initiate trip after the time calculation is finished.
Ist> TRIP	0:Not active 1:Active	-	0:Not active	Trip output of the LRC function. This signal activates when the pick-up and time conditions are met.
Ist> BLOCKED	0:Not active 1:Active	-	0:Not active	Blocked output of the LRC function. This signal activates when the start function is activated but the function is blocked from operating.

Events & registers

MST function generates events from detected motor status. From changes of the events also data register is available.

Table 3.172 Event codes of the LRC function.

Event Number	Event channel	Event block name	Event Code	Description
3648	57	LCR1	0	Max.Start time exceed On
3649	57	LCR1	1	Max.Start time exceed Off
3650	57	LCR1	2	Set start time exceed On
3651	57	LCR1	3	Set start time exceed Off
3652	57	LCR1	4	Speed Switch not received On
3653	57	LCR1	5	Speed Switch not received Off
3654	57	LCR1	6	Start On
3655	57	LCR1	7	Start Off

Event Number	Event channel	Event block name	Event Code	Description
3656	57	LCR1	8	Set time Trip On
3657	57	LCR1	9	Set time Trip Off
3658	57	LCR1	10	Max cap Trip On
3659	57	LCR1	11	Max cap Trip Off
3660	57	LCR1	12	Blocked On
3661	57	LCR1	13	Blocked Off

In the table below is presented the structure of LRC function register content. This information is available in 12 last recorded events.

Figure 3.143 Register content.

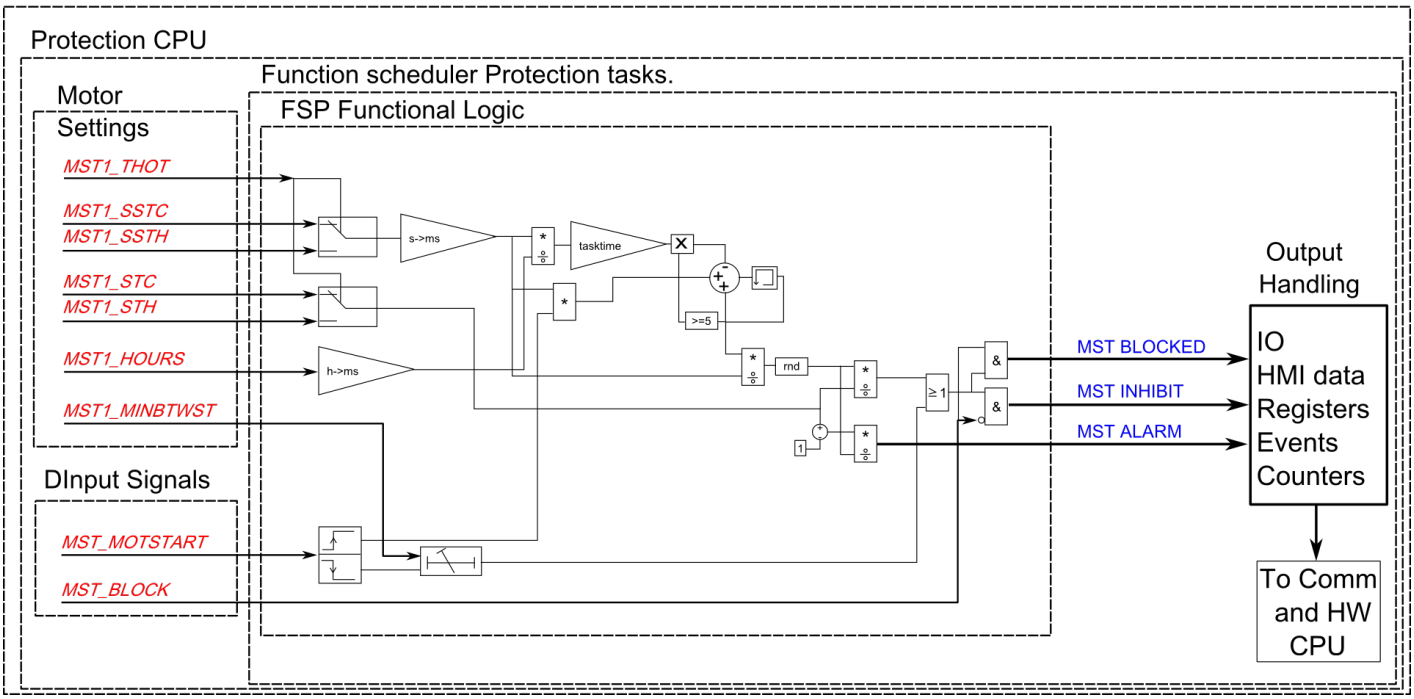
Date & Time	**Event code**	**Start Stall time**	**Max. time used**	**Set. time used**	**Therm cap used**	**L1 current**	**L2 current**	**L3 current**	**SG used**
dd.mm.yyyy hh:mm:ss.mss	3648-3659 Descr.	Recorded duration of stall/start	Percentage used from max safe stall time	Percentage used from user set max time	Thermal capacity used	Phase L1 current xIn	Phase L2 current xIn	Phase L3 current xIn	Used setting group

3.8.5 Frequent start protection (FSP) N>

Frequent start protection (FSP) function is used for monitoring and preventing too frequent starting of the motor. This function monitors the used starts of the motor in given time so that the start stress is not exceeding the manufacturer given limits. For direct-on-line started motors the start-up situation is the most stressful normal operation situation and the motor manufacturer has given safe starts limits for cold and hot motor in some given time so that the motor lifetime still is guaranteed. Also the time in between of consequent starts usually is specified by motor manufacturers. If the given amount of starts is used or time since previous start or start attempt is too short further starting attempts should be blocked by using FSP function, allowing the motor to cool down enough before next start attempt.

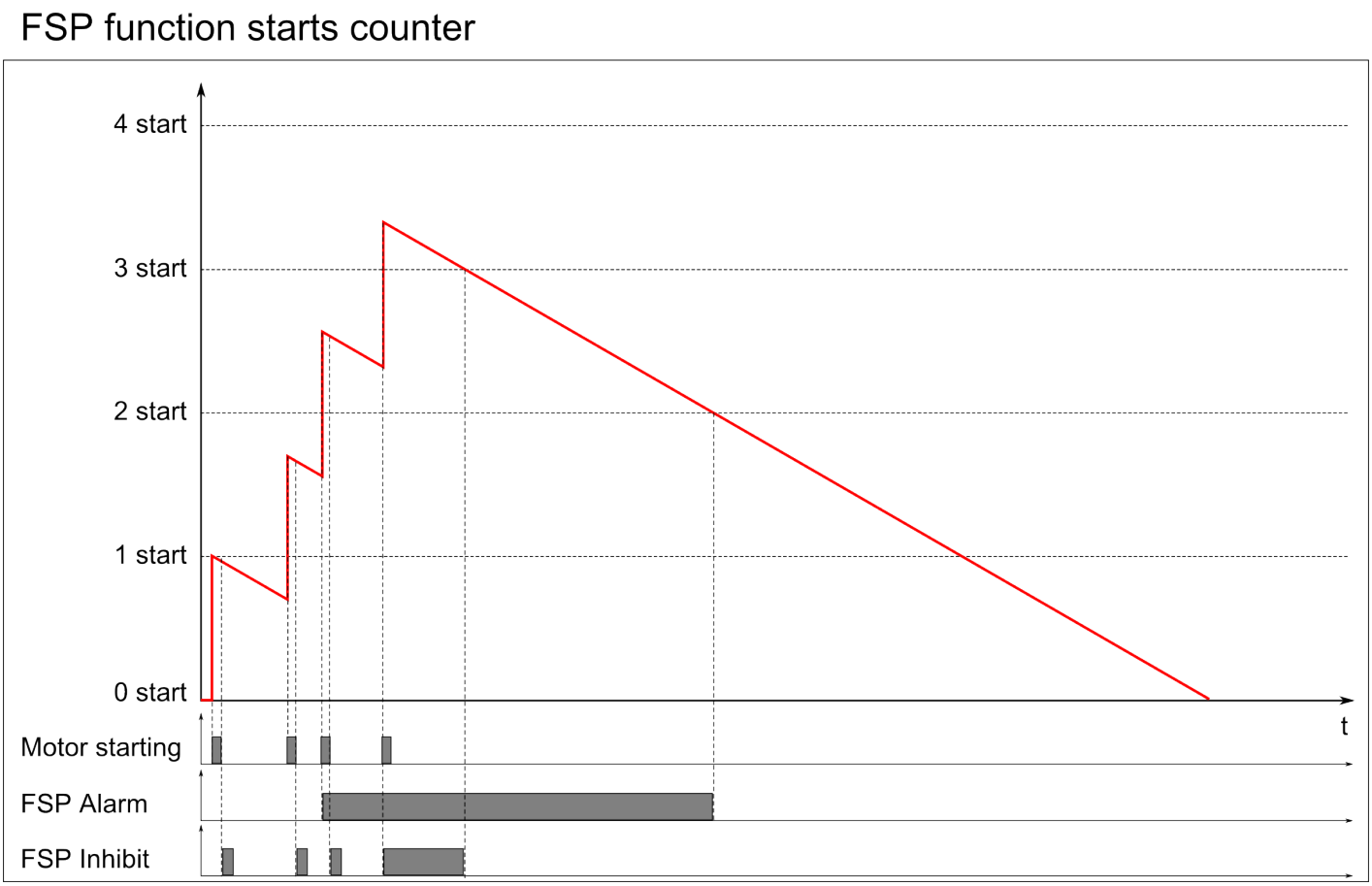
FSP function in motor protection module operates with MST motor status monitoring function and follows the motor data set there. Motor starting is monitored internally (MST signal out) in the FSP function and the user only needs to set the FSP into Activated state and set allowed starts for hot and cold situation as well as the minimum time in between of consequent starts and the limit of “Hot” and “Cold” situations. If the separation of hot and cold motor status is wanted to be used the thermal overload for motors (TOLM) function needs to be activated and set also.

Figure 3.144 Simplified function block diagram of the FSP function.



Operating principle of the FSP function is to calculate in each start a equivalent start stress given by the set starts per hour and safe stall time settings (hot and cold) regardless of the actual start duration. In each start attempt time equivalent to safe stall time is added to the starts counter which is then deduct by the safe stall time divided by given starts time in hours. By this way the start counter can be applied so that it will follow the motor thermal status and given starts per hours accurately.

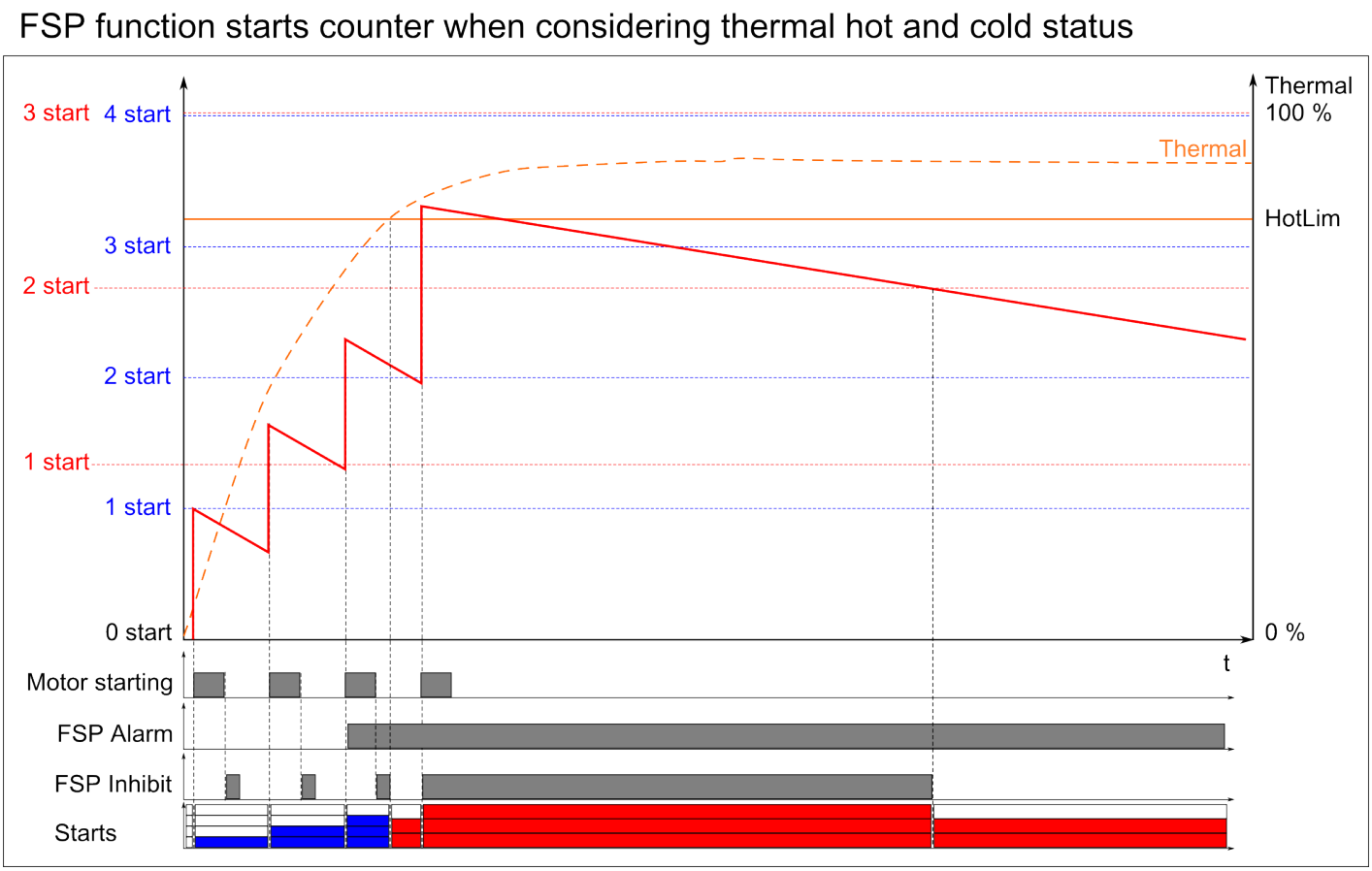
Figure 3.145 FSP Starts counter update (picture is not in actual time-scale).



In the example above the motor is allowed four starts in given time (t), motor is started 4 times and the counter is updated accordingly. When only one start is left in the start counter the FSP alarm is activated to note that only one start is allowed. After this start is used, the restart inhibit is activated until the motor can be started again.

Cumulative start-up counter is updated constantly in each program cycle and the time for inhibit/alarm and amount of used and available starts can be read from the IED. The counter is updated in every start by safe stall time multiplied by nominal start-up current. In each start the counter is increased by this product which is then in every cycle deduct by starts/given time divided by program cycle time. By this way the start up counter can be set precisely for each motor.

Figure 3.146 FSP Starts counter update when thermal hot and cold status is considered.



If the motor thermal load is monitored, the available starts can be updated on-line in the IED and the precise follow up of the motor status can be monitored and correct amount of starts can be allowed for the motor. In the figure above the motor is allowed for 4 starts when it is cold, while 3 starts are allowed when the motor is hot. In the figure described situation motor is started 3 times when it is cold and the hot limit is reached before the motor is started 4th time. Now the motor was allowed for 4 cold and 3 hot starts and due to the 3 cold starts the counter accumulated used starts amount allows only 1 start to be done due to motor has been started previously already 3 times when cold. When the motor in this situation is started again while the thermal status is “hot” the restarts inhibit is activated and the start cooling time is counted according to hot starts reduction rate. If the motor would be stopped now and the thermal load would let to count under the “hot” limit the starts reduction would be counted according to “cold” motor status.

Settings and signals

Settings of the frequent start protection (FSP) function are directly the given motor data from the motor module of the IED. In following table are shown the functions which use these settings also. If these settings are edited from the FSP setting view they will also change to all other mentioned functions simultaneously.

Table 3.173 Motor data Settings of FSP function.

Name	Range	Step	Default	Prot.funcs.	Description
Hot condition theta limit	0.0... 100.0%	0.1%	70%	MST N> (48) TM> (49M) Ist> (48) Im> (50M)	Setting of the thermal limit Hot / Cold situation of the motor. When this setting value is not exceed and locked rotor situation occurs cold stall curve adjusted with actual used thermal capacity is utilized. After this setting value hot stall curve is utilized. Applies also for Starts when hot / cold selection. NOTE:Usage requires that the Thermal protection TM> is activated and in use.
Safe stall time cold	0.1...600.0s	0.1s	20.0s	MST TM> (49M) Ist> (48)	Safe stall time when motor is cold. If this value is not informed then set to same than hot stall time. This leads most probably to overprotection with cold motor stall but is best guess in such

Name	Range	Step	Default	Prot.funcs.	Description
				Im> (50M) N> (48)	case. This setting value is used for the cold thermal stall curve selection in automatic control. Also motor start-up and number of starts calculations use this parameter.
Safe stall time hot	0.1...600.0s	0.1s	15.0s	MST TM> (49M) Ist> (48) Im> (50M) N> (48)	Safe stall time when motor is hot. This setting value is used for the hot thermal stall curve selection in automatic control. Also motor start-up and number of starts calculations use this parameter.
Starts when cold	1...100st	1st	3st	MST N> (48)	Allowed starts per x hours for cold motor.
Starts when hot	1...100st	1st	2st	MST N> (48)	Allowed starts per x hours for hot motor.
Starts in hours	1...100h	1h	1h	MST N> (48)	Hours when the allowed given hot and cold starts applies.
Min time betw. starts	0.1...600.0s	0.1s	20.0s	MST N> (48)	Minimum time in between of starts or start attempts.

Table 3.174 Output signals of the FSP function

Name	Range	Step	Default	Description
N> Alarm on	0:Not active 1:Active	1	0	Alarm output of the FSP function. This signal activates when there is 1 start available for the motor.
N> Inhibit on	0:Not active 1:Active	1	0	Inhibit output of the FSP function. This signal activates when all available starts are used and the motor is not allowed to start before the starts counter has 1 or more starts available.
N> BLOCKED	0:Not active 1:Active	1	0	Blocked output of the FSP function. This signal activates when the function is activated but it is blocked from operating.

Events

MST function generates events from detected motor status. From changes of the events also data register is available.

Table 3.175 Event codes of the FSP function.

Event Number	Event channel	Event block name	Event Code	Description
3968	62	FSP1	0	Motor Stopped On
3584	56	FSP1	0	Alarm On
3585	56	FSP1	1	Alarm Off
3586	56	FSP1	2	Inhibit On
3587	56	FSP1	3	Inhibit Off
3588	56	FSP1	4	Blocked On
3589	56	FSP1	5	Blocked Off

In the table below is presented the structure of FSP function register content. This information is available in 12 last recorded events.

Table 3.176 Register content.

Date & Time	Event code	Inhibit time on	Time since last start	Start count
dd.mm.yyyy hh:mm:ss.mss	3584-3589 Descr.	If on, shows how long the inhibit is active	Time elapsed from last starting	Starts used at the triggering moment

3.8.6 Transformer differential Idb> Idi> I0dhv> I0dLv> (87T,87N)

See **Protections, Transformer protections, Transformer differential**.

3.9 Generator protections

3.9.1 Underimpedance protection Z< (21)

Underimpedance protection is an alternative for voltage restrained overcurrent protection which can be used to detect short circuit faults near the generator even when the short circuit current is small. Additionally under impedance protection can be used as a back up protection for transformer protection.

Figure 3.147 Pick-up characteristics of the underimpedance protection

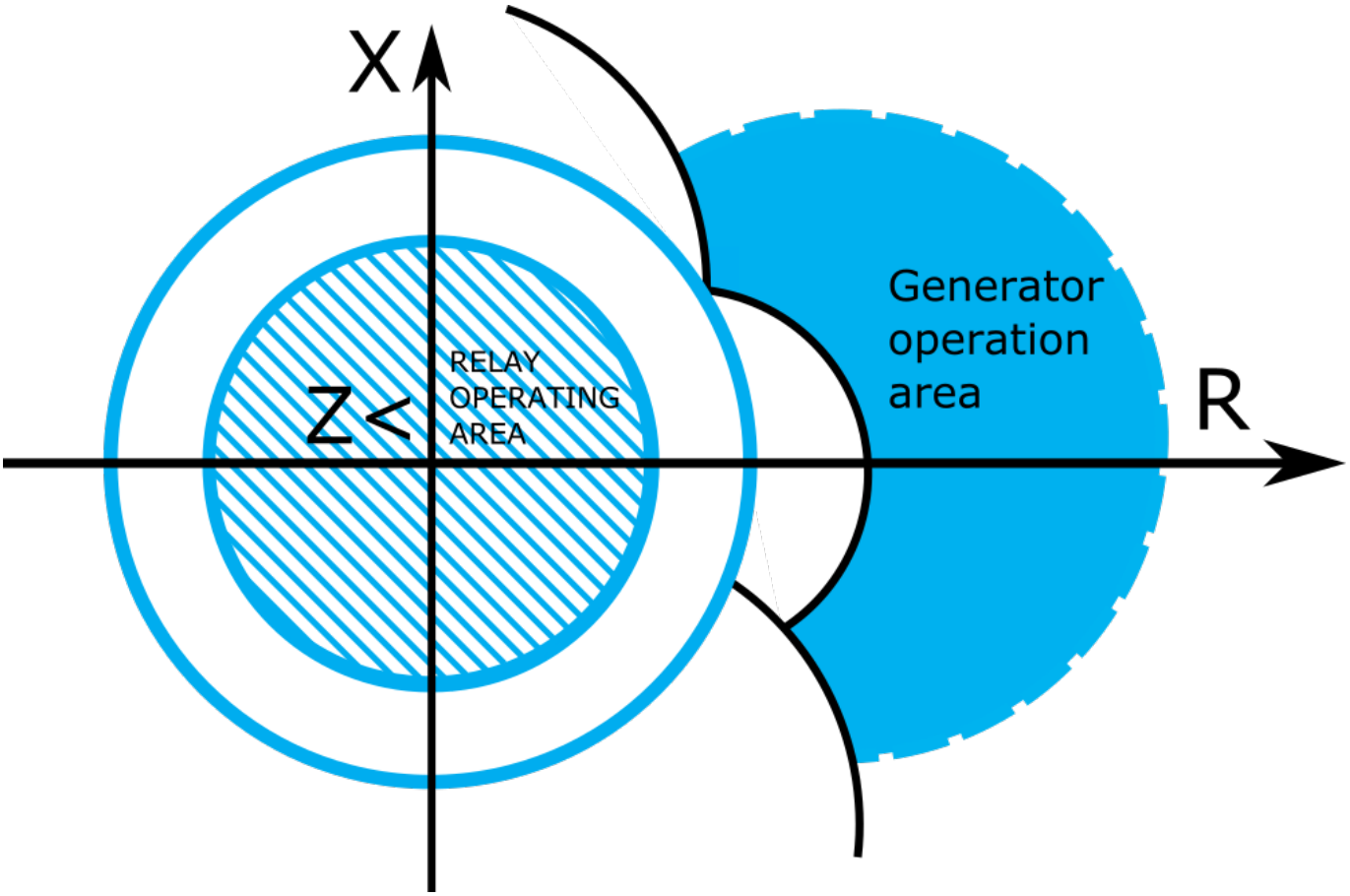
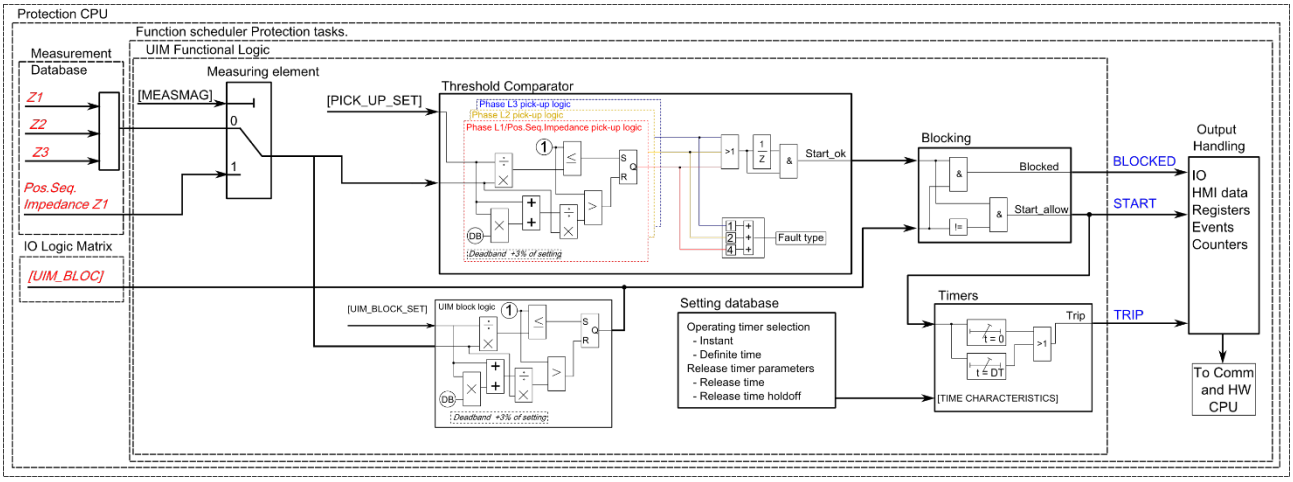


Figure 3.148 Simplified function block diagram of the UIM function.



Measured input values

Sufficient current and voltage measurements are required for the impedance measurement to work properly. By user selection the monitored magnitude can be P-E impedance loops, P-P impedance loops or positive sequence impedance. For the pre-fault data registering -20 ms averaged value of the selected magnitude is used.

NOTE: To make sure that the protection function is calculating the listed values enable impedance calculations in *Measurement → Impedance Calculations → Impedance calc. settings*.

Table 3.177 Measurement magnitudes used by the UIM function.

Signal	Description	Time base
Z1	Impedance of phase 1 to ground	5 ms
Z2	Impedance of phase 2 to ground	5 ms
Z3	Impedance of phase 3 to ground	5 ms
Z12	Impedance of phase 1 to phase 2	5 ms
Z23	Impedance of phase 2 to phase 3	5 ms
Z31	Impedance of phase 3 to phase 1	5 ms
Pos.Seq.Imp	Positive sequence of the impedances	5 ms

Pick-up characteristics

Pick-up level of the UIM function is controlled by setting parameters *Zset(pri)<*. Pick-up level defines the minimum allowed measured impedance before action from the function. The function constantly calculates the ratio in between of the impedance pick-up level and calculated impedance per all three stages or positive sequence impedance. Reset ratio of 103 % is inbuilt in the function and is always related to thecurrent pick-up value.

Table 3.178 Pick-up characteristics setting

Name	Description	Range	Step	Default
ZSet(pri)<	Pick-up setting as primary side impedance	0.10...150.00Ohm	0.01Ohm	10Ohm

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Function blocking

In the blocking element the block signal is checked at the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup voltage values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Events and registers

The UIM function generates events and registers from the status changes of start, trip and blocked. To main event buffer is possible to select status “On” or “Off” messages. The UIM function offers four independent instances which events are segregated for each instance operation.

12 last registers are available in the function where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values.

Table 3.179 Event codes of UIM function

Event Number	Event channel	Event block name	Event Code	Description
7104	111	UIM1	0	Start ON
7105	111	UIM1	1	Start OFF
7106	111	UIM1	2	Trip ON
7107	111	UIM1	3	Trip OFF
7108	111	UIM1	4	Block ON
7109	111	UIM1	5	Block OFF
9536	149	UIM2	0	Start ON
9537	149	UIM2	1	Start OFF
9538	149	UIM2	2	Trip ON
9539	149	UIM2	3	Trip OFF
9540	149	UIM2	4	Block ON
9541	149	UIM2	5	Block OFF

In the register of the UIM function is recorded start, trip or blocked “On” event process data. In the table below is presented the structure of UIM function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 3.180 Register content

Date & Time	Event	Fault type	Pretrg impedance	Fault impedance	Trip time remaining	Setting Group in use	Prefault impedance
dd.mm.yyyyhh:mm:ss.mss	7104 - 9541	A-G...A-B-C	Start average impedance	Trip -20ms averages	0...1800s	1...8	Start -200ms averages

3.9.2 Volts-per-Hertz overexcitation protection V/Hz (24)

Generators, transformers, and motors have a specific volts-per-hertz ratios under which these machines are expected to operate. If the V/Hz ratio is exceeded, result is machine overexcitation which causes generators and transformers iron core saturation which will result in breakdown of core inter-lamination insulation due to excessive voltage and eddy current heating. Also stray flux will be induced into non-laminated components which are not designed to carry flux caused currents. For generator overexcitation typically occurs if the V/Hz ratio exceeds 5% of the nominal V/Hz ratio and the possible damage may happen within seconds. Most common situation for overexcitation to the machine is when it is off-line prior to synchronization.

V/Hz protection is based into the ratio of maximum phase to phase voltage and measured system frequency calculated ratio. Both inverse and definite operating characteristics can be applied simultaneously for the V/Hz protection.

Blocking signal and setting group selection controls the operating characteristics of the function during normal operation.

Outputs of the function are Start Trip and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. Overexcitation function utilizes total of eight separate setting groups which can be selected from one common source.

The operational logic consists of input magnitude processing, input magnitude selection, threshold comparator, block signal check, time delay characteristics and output processing.

Inputs for the function are the operating mode selections, setting parameters and measured and pre-processed voltage magnitudes and binary input signals. Function outputs START, TRIP and BLOCKED signals which can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the three output signal. In instant operating mode the function outputs START and TRIP events simultaneously with equivalent time stamp. Time stamp resolution is 1ms. Function provides also cumulative counters for START, TRIP and BLOCKED events.

Measured input values

Analog system voltages and system frequency measurement values are used for the function block.

Table 3.181 Analog magnitudes used by the V/Hz function.

Signal	Description	Time base
U12 RMS	U12 System voltage RMS	5 ms
U23 RMS	U23 System voltage RMS	5 ms
U31 RMS	U31 System voltage RMS	5 ms
f	Measured system frequency f	5 ms

Pick-up characteristics

Pick-up of the V/Hz function is controlled by Pick-up V/Hz > nominal setting parameter, which defines the maximum measured voltage allowed in relation to the measured frequency before action from the function. The function constantly calculates the ratio in between of the Pick-up V/Hz nominal and calculated Umeas/fmeas. Reset ratio of 97% of the pick-up setting is inbuilt in the function and is always related to the Pick-up V/Hz nominal value.

Table 3.182 Pick-up characteristics setting

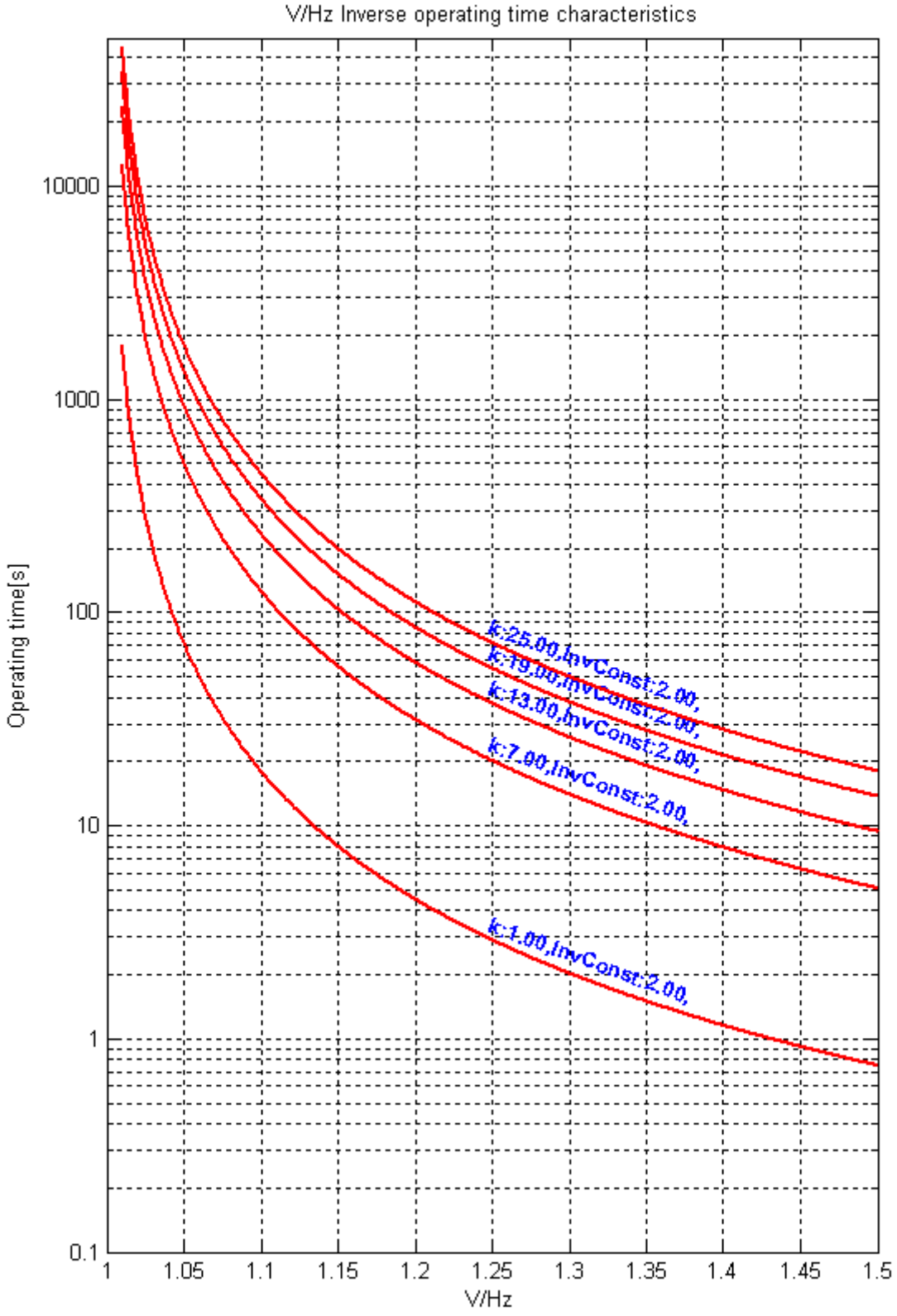
Name	Description	Range	Step	Default
Pick-up V/Hz > nominal	Maximum allowed measured V/Hz ratio increase to nominal V/Hz ratio.	0.01 ... 30.00%	0.01%	5.00%
Delay type	Selected delay type	0:DT 1:Inverse 2:DT and inverse	-	0:DT
Definite operating time delay (visible when Delay type either 0 or 2)	Definite operating time delay which is applied no matter how much the V/Hz ratio is exceeded	0.000...1800.000s	0.005s	0.040s
TimeDial k (visible when Delay type either 1 or 2)	Inverse operating characteristics time dial setting	0.01...65.00	0.01	0.01
IDMT Multiplier (visible when Delay type either 1 or 2)	Inverse operating characteristics multiplier	0.50...3.00	0.01	2.00
Inverse/Definite limit V/Hz > (visible when Delay type 2)	Defines inverse definite time breakpoint if selected both characteristics inverse and definite time	0.01...25.00	0.01	10.00%

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Inverse operating time characteristics are calculated with following equation:

$$t_{Inverse} = DTset + \frac{0.18 \times TimeDial\ k}{\left(\frac{V}{Hz_{measured}} - 1\right)^{IDMTmultiplier}}$$

Figure 3.149 Inverse and inverse with definite time characteristics with the TimeDial k setting effect.



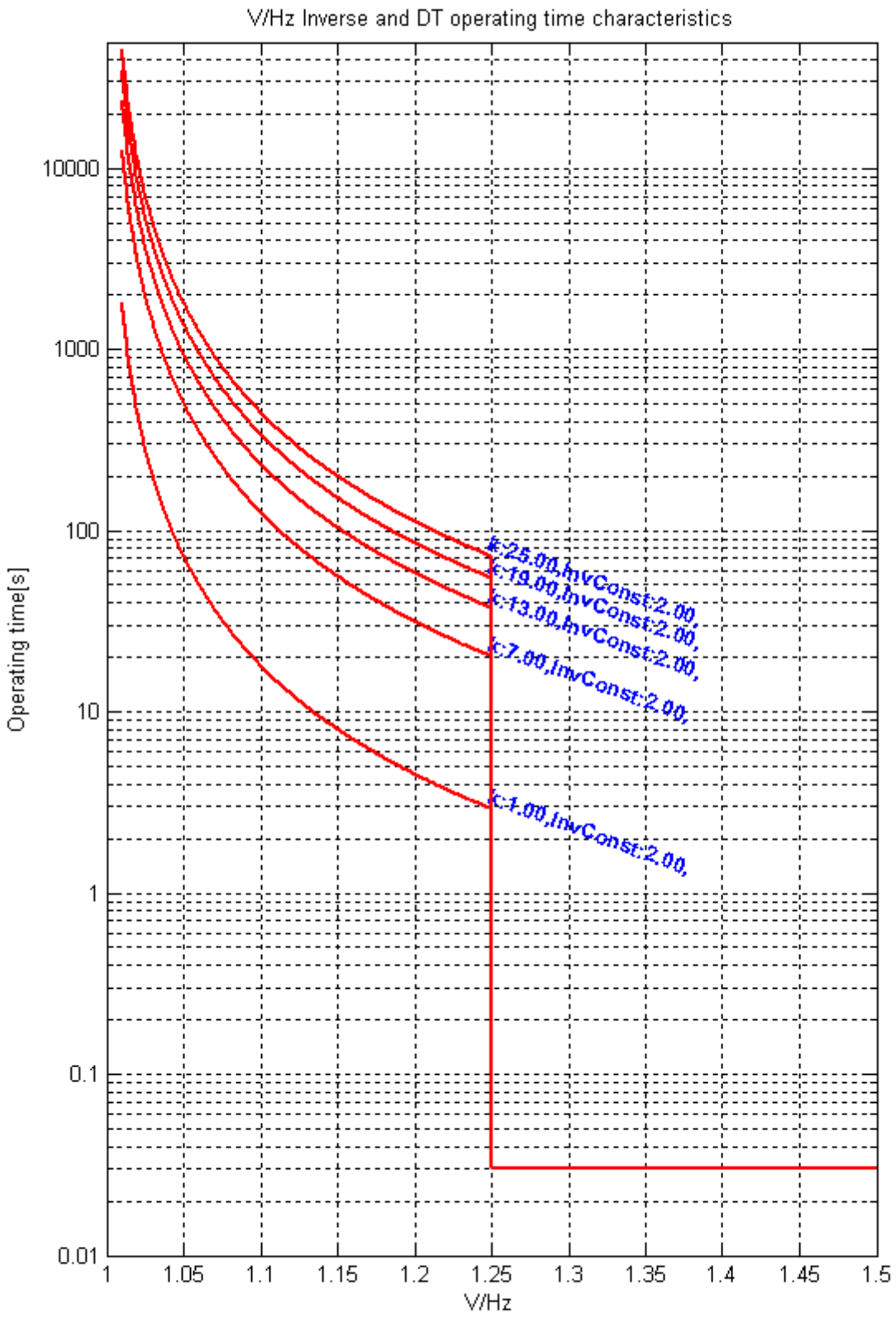
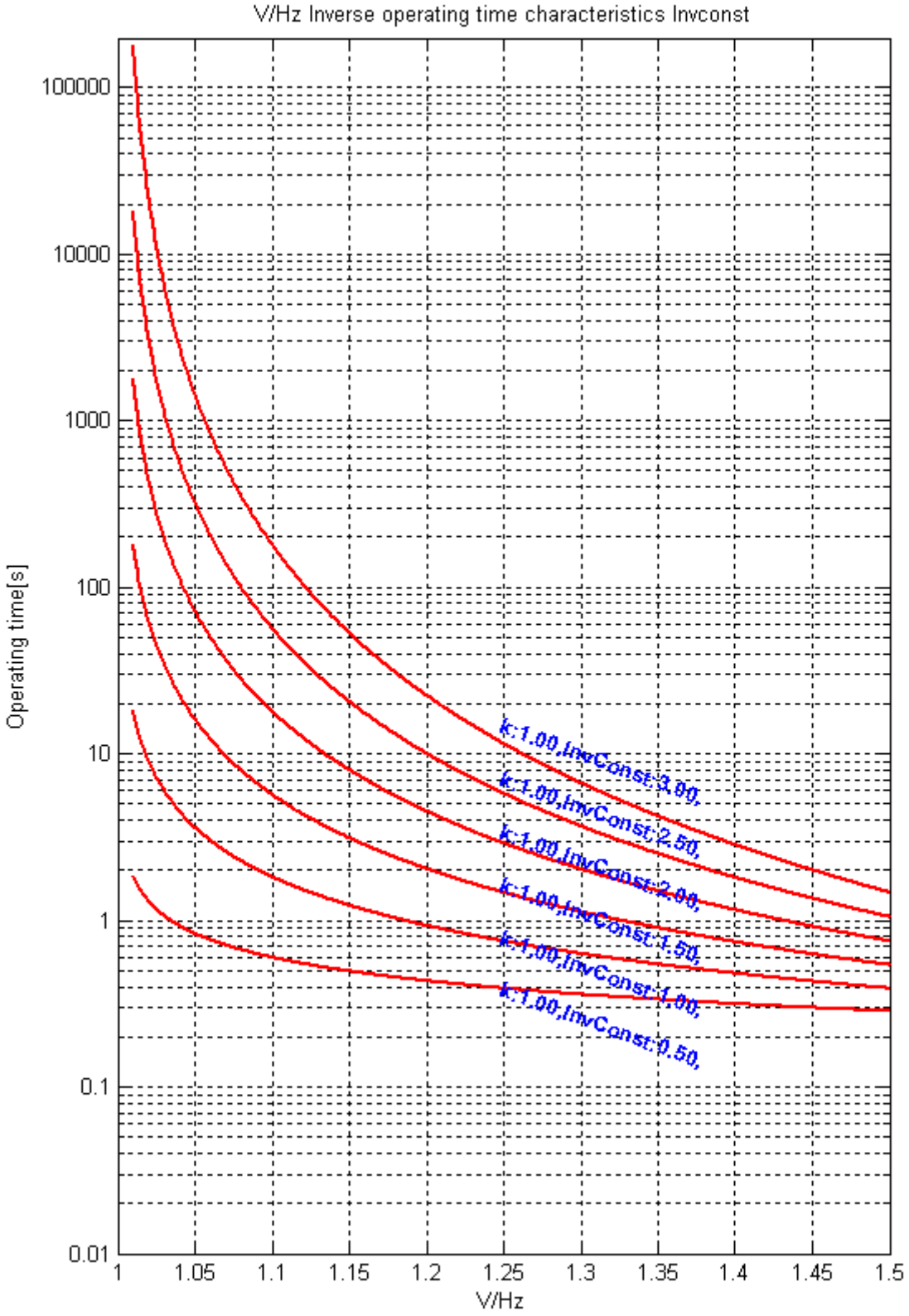

V/Hz Inverse and DT operating time characteristics
Operating time[s]
10000
1000
100
10
1
0.1
0.01
1
1.05
1.1
1.15
1.2
1.25
1.3
1.35
1.4
1.45
1.5
V/Hz
k:25.00,InvConst:2.00,
k:19.00,InvConst:2.00,
k:13.00,InvConst:2.00,
k:7.00,InvConst:2.00,
k:1.00,InvConst:2.00,

Figure 3.150 Inverse and inverse with definite time characteristics with the InvConst setting effect.



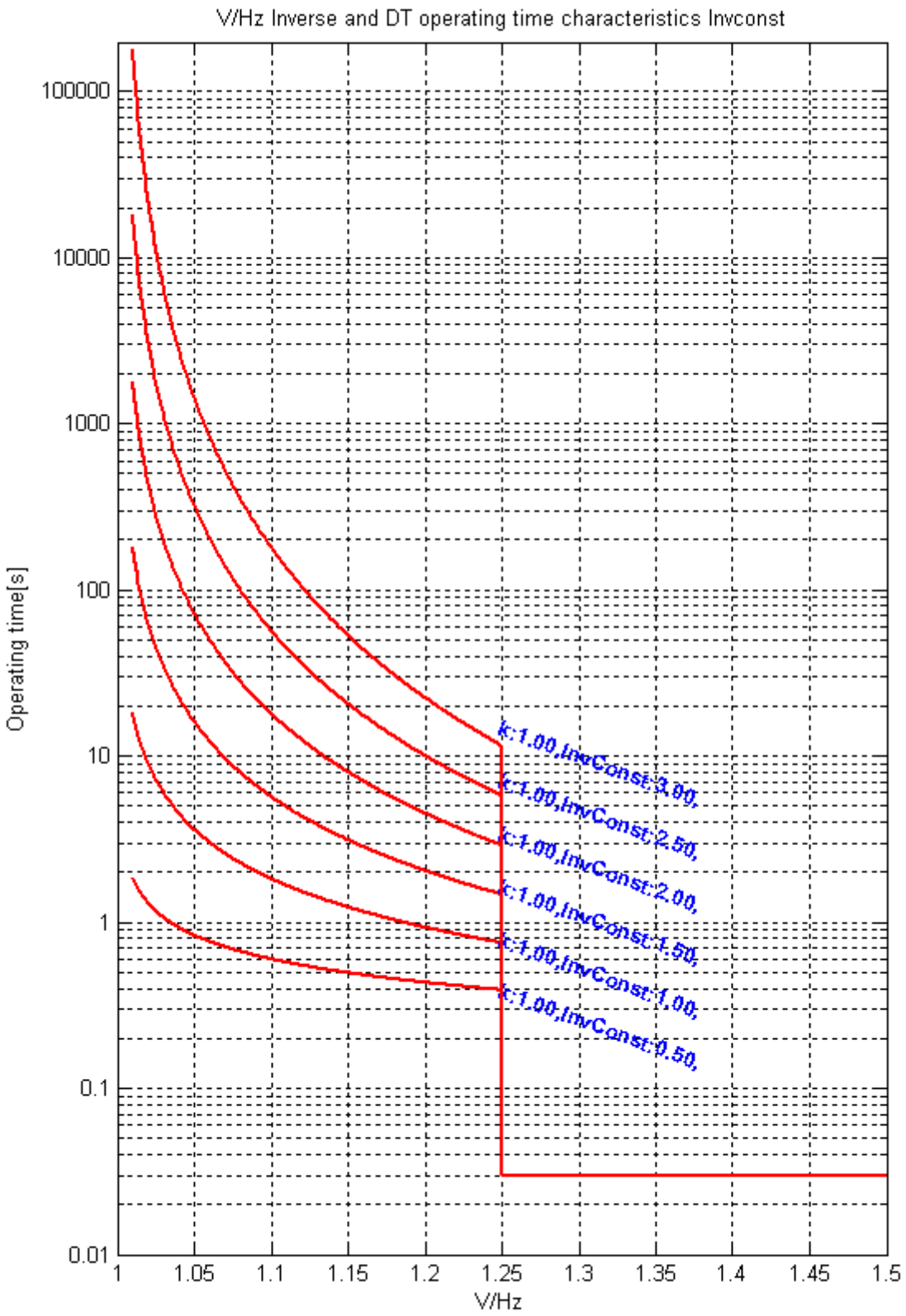

V/Hz Inverse and DT operating time characteristics Invconst
Operating time[s]
100000
10000
1000
100
10
1
0.1
0.01
1
1.05
1.1
1.15
1.2
1.25
1.3
1.35
1.4
1.45
1.5
V/Hz
k:1.00,InvConst:3.00,
k:1.00,InvConst:2.50,
k:1.00,InvConst:2.00,
k:1.00,InvConst:1.50,
k:1.00,InvConst:1.00,
k:1.00,InvConst:0.50,

Table 3.183 Reset time characteristics setting parameters.

Name	Range	Step	Default	Description
Release Time delay	0.000... 150.000s	0.005s	0.06s	Resetting time. Time allowed in between of pick-ups if the pick-up has not lead into trip operation. During this time the start signal is held on for the timers if delayed pick-up release is active.
Delayed Pick-up release	No Yes	-	Yes	Resetting characteristics selection either time delayed or instant after pick-up element is released. If activated the start signal is reset after set release time delay.
Time calc reset after release time	No Yes	-	Yes	Operating timer resetting characteristics selection. When active the operating time counter is reset after set release time if pick-up element is not activated during this time. When disabled the operating time counter is reset directly after the pick-up element reset.
Continue time calculation during release time	No Yes	-	No	Time calculation characteristics selection. If activated the operating time counter is continuing until set release time even the pick-up element is reset.

Resetting characteristics can be set according to the application. Default setting is delayed with 60 ms and the time calculation is held during the release time.

When using the release delay option where the operating time counter is calculating the operating time during the release time, function will not trip if the input signal is not activated again during the release time counting.

Function blocking

In the blocking element the block signal is checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup voltage values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Events and registers

The V/Hz function generates events and registers from the status changes of start, trip and blocked. To main event buffer is possible to select status “On” or “Off” messages. The V/Hz function offers one stage which can be set to definite or/and inverse operating time characteristics.

In the function is available 12 last registers where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values.

Table 3.184 Event codes of the VHZ function instance.

Event Number	Event channel	Event block name	Event Code	Description
8192	128	VHZ1	0	(1)Start ON
8193	128	VHZ1	1	(1)Start OFF
8194	128	VHZ1	2	(1)Alarm ON
8195	128	VHZ1	3	(1)Alarm OFF
8196	128	VHZ1	4	(1)Trip ON
8197	128	VHZ1	5	(1)Trip OFF
8198	128	VHZ1	6	(1)Block ON
8199	128	VHZ1	7	(1)Block OFF
8200	128	VHZ1	8	(2)Start ON
8201	128	VHZ1	9	(2)Start OFF
8202	128	VHZ1	10	(2)Alarm ON
8203	128	VHZ1	11	(2)AlarmOFF
8204	128	VHZ1	12	(2)Trip ON
8205	128	VHZ1	13	(2)Trip OFF
8206	128	VHZ1	14	(2)Block ON
8207	128	VHZ1	15	(2)Block OFF

Table 3.185 Register content of the V/Hz function instance.

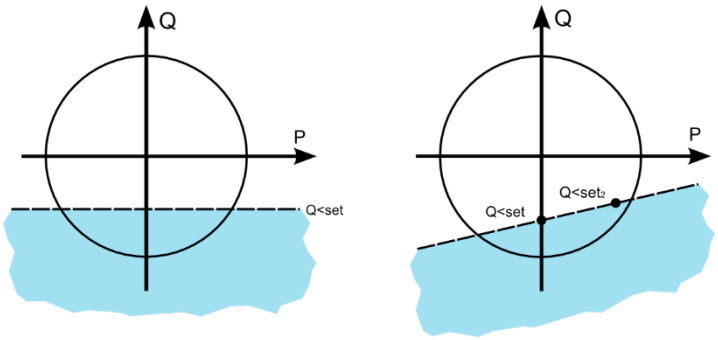
Date & Time	Event code	Voltages (AB/BC/CA) pretrig	Frequency pretrig	Voltages (AB/BC/CA) fault
dd.mm.yyyy hh:mm:ss.mss	8192-8207 Descr.	Pre triggering voltages	Pre triggering frequency	In fault voltages
Frequency fault	Voltages (AB/BC/CA) prefault	Frequency prefault	Trip time remaining	Used SG
In fault frequency	Pre fault voltages	Pre fault frequency	0ms -1800s	1 - 8

3.9.3 Underexcitation Q> (40)

Synchronous machines require a certain minimum excitation in order to stay stable. If the excitation drops too low synchronous machine can drop out of step. One way to for the relay to sense under excitation is by measuring reactive power.

When the generator induces capacitive power the value of reactive power is negative in which case the excitation current can be so low that the synchronous machine drops out of step. Under excitation protection supervises capacitive power and picks up when the set kvar value is exceeded.

Figure 3.151 Protection area in Fixed and P dependent modes.



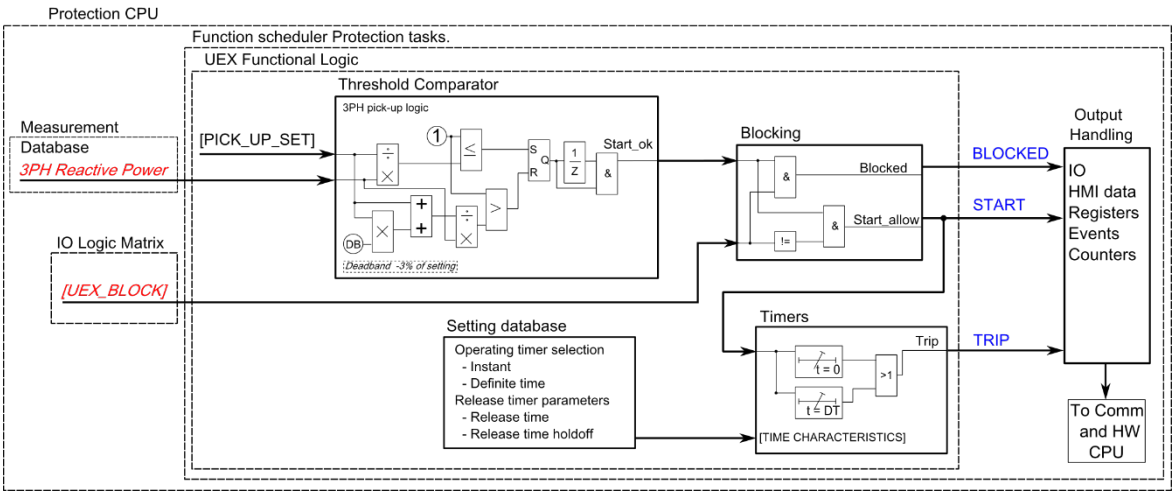
Outputs of the function are Start Trip and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. Under excitation function utilizes total of eight separate setting groups which can be selected from one common source.

The operational logic consists of input magnitude processing, threshold comparator, two block signal check, time delay characteristics and output processing.

Inputs for the function are the operating mode selections, setting parameters and measured and pre-processed power magnitudes and binary input signals. Function outputs START, TRIP and BLOCKED signals which can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the three output signal. In instant operating mode the function outputs START and TRIP events simultaneously with equivalent time stamp. Time stamp resolution is 1ms. Function provides also cumulative counters for START, TRIP and BLOCKED events.

In the following figure is presented the simplified function block diagram of the UEX function.

Figure 3.152 Simplified function block diagram of the UEX function.



Measured input values

Three phase active power value is used for the function block. For pre-fault data registering -20ms averaged value is used. If the protection relay has more than one CT module parameter Measured side determines which current measurement is used for the power measurement.

Table 3.186 Measurement magnitudes used by the UEX function.

Signal	Description	Time base
3PH Reactive power (P)	Total 3 phase reactive power	5 ms

Pick-up characteristics

Pick-up of the UEX function is controlled by Qset< setting parameter, which defines the minimum allowed measured three phase reactive power before action from the function. The function constantly calculates the ratio in between of the Qset< and measured magnitude (Qm). Reset ratio of 97 % is inbuilt in the function and is always related to the Qset< value.

Table 3.187 Pick-up characteristics setting

Name	Range	Step	Default	Description
Qset mode	0:Fixed 1:P dependent	-	Fixed	Decision if the pick-up area is defined only by Qset< parameter or by two points set in the PQ-plane.
Qset<	0.0 ... -100000kvar	0.01kvar	-100kvar	In Fixed-mode: Set the pick-up value for the function.In P dependent mode: Choose the reactive power for the first point.
Pick-up P1 for Qset<	0.0 ... -100000kW	0.01kW	100kW	Value for the active power for Qset< when P dependent-mode is in use.
Qset2<	0.0 ... -100000kvar	0.01kvar	-100kvar	Choose the reactive power for the second point when P dependent-mode is in use.
Pick-up P2 for Qset<	0.0 ... -100000kW	0.01kW	100kW	Value for the active power for Qset2< when P dependent-mode is in use.

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Function blocking

In the blocking element the block signal is checked at the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup voltage values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Operating time characteristics for trip and reset

This function supports definite time delay (DT). For detailed information on this delay type refer to chapter General properties of a protection function.

Events and registers

The UEX function generates events and registers from the status changes of start, trip and blocked. To main event buffer is possible to select status “On” or “Off” messages. The UEX function offers four independent instances which events are segregated for each instance operation.

12 last registers are available in the function where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values.

Table 3.188 Event codes of UEX function.

Event Number	Event channel	Event block name	Event Code	Description
6976	109	UEX1	0	Start ON
6977	109	UEX1	1	Start OFF
6978	109	UEX1	2	Trip ON
6979	109	UEX1	3	Trip OFF
6980	109	UEX1	4	Block ON
6981	109	UEX1	5	Block OFF

In the register of the UEX function is recorded start, trip or blocked “On” event process data. In the table below is presented the structure of UEX function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 3.189 Register content.

Date & Time	Event code	Trigger power (P&Q)	Fault power (P&Q)	Prefault power (P&Q)	Trip time remaining	Used SG
dd.mm.yyyy hh:mm:ss.mss	6976-6979 Descr.	Start average power	Trip -20 ms averages	Start -200 ms averages	0ms -1800s	1 - 8

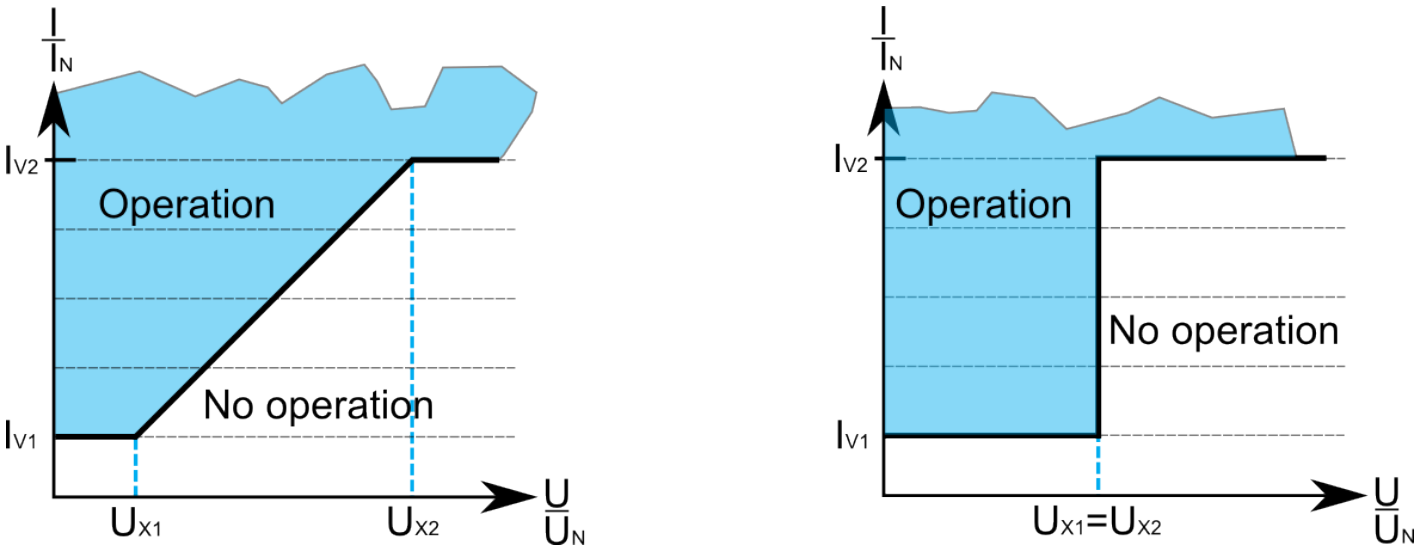
3.9.4 Voltage restrained overcurrent protection VOC (51V)

Short circuits occurring close to the generator decrease fault current which inhibit the operation of high set over current stage. To provide improved sensitivity decreasing voltage caused by these faults can be used to decrease the current pick-up level. Voltage restrained overcurrent voltage can be used as an alternative for under impedance function for more sensitive short circuit detection in generator protection applications.

When there is a short circuit near the generator voltage decreases which in VOC functions case decreases the overcurrent pick-up level according to set parameters. VOC function can work in two ways: as a voltage controlled overcurrent protection or voltage restrained overcurrent protection. When parameter value set Ux2 is greater than Ux1 protection function is working as voltage restrained overcurrent protection. In this case overcurrent pick-up value increases as the voltage increases between set values Ux1 and Ux2. The protection function uses positive sequence voltage to define the pick-up level at the moment.

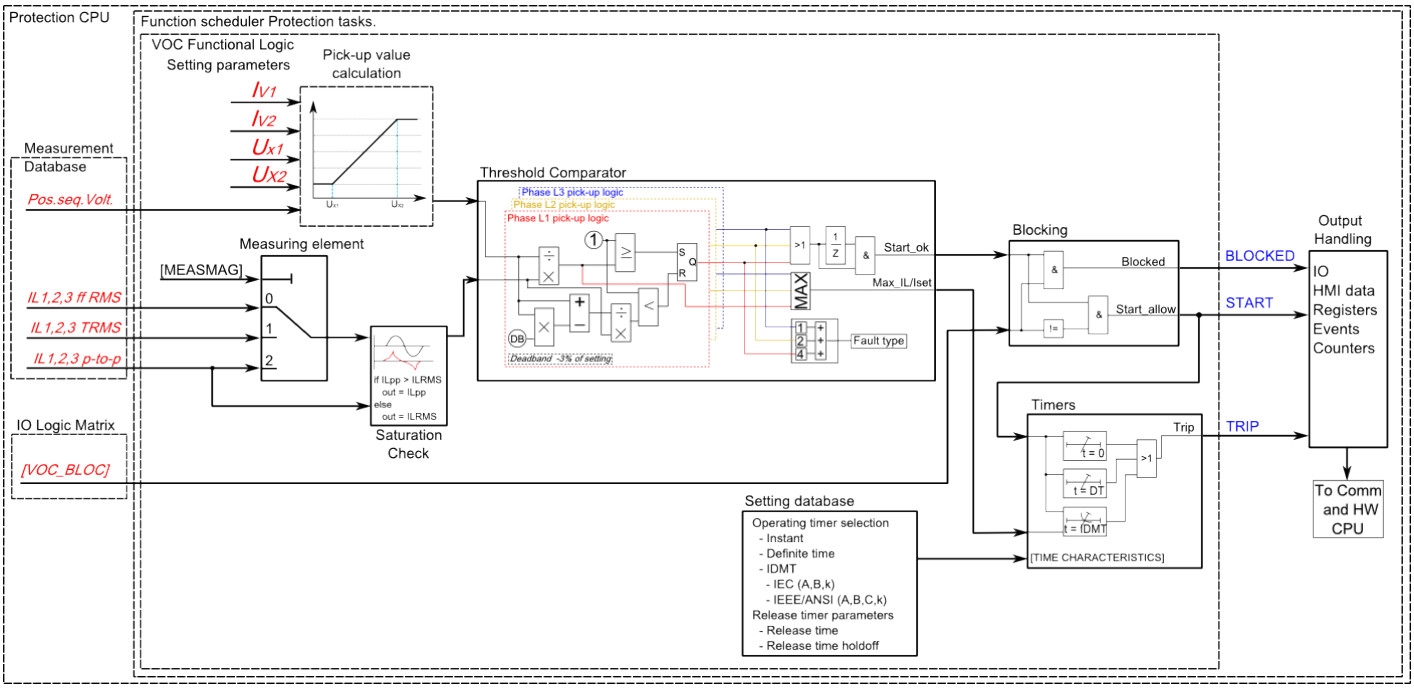
When the set Ux1 value is equal to Ux2 function is working as a voltage controlled overcurrent protection. Now the overcurrent protection doesn’t operate until fault reduces the voltage below a set value, which is usually about 80% of normal. Fixed pick-up level of voltage controlled overcurrent protection is easier to coordinate with other relays. However voltage restraint overcurrent isn’t as prone to make unwanted operations on motor starting currents and system swings.

Figure 3.153 Pick-up level in voltage restrained overcurrent mode and voltage controlled overcurrent mode.



Just like the other overcurrent protection functions this function can be set to inverse curves or definite time delay. But if in this functions case inverse time delay is selected, the time delay depends on the ratio between the measured current and the current pick-up level at the moment. This means operation time can also shorten as a result of reduced voltage.

Figure 3.154 Simplified function block diagram of the VOC function.



Measured input values

Calculated positive sequence voltage is used to determine the pick-up level. Analog current measurement values are used to detect faults. By user selection the monitored magnitude can be either fundamental frequency RMS values, True TRMS values from the whole harmonic specter of 32 components or peak to peak values. For the pre-fault data registering -20 ms averaged value of the selected magnitude is used.

Table 3.190 Measurement magnitudes used by the VOC function.

Signal	Description	Time base
IL1PP	Peak-to-peak measurement of phase L1/A current	5 ms
IL2PP	Peak-to-peak measurement of phase L2/B current	5 ms
IL3PP	Peak-to-peak measurement of phase L3/C current	5 ms
IL1RMS	Fundamental RMS measurement of phase L1/A current	5 ms
IL2RMS	Fundamental RMS measurement of phase L2/B current	5 ms
IL3RMS	Fundamental RMS measurement of phase L3/C current	5 ms
IL1TRMS	TRMS measurement of phase L1/A current	5 ms
IL2TRMS	TRMS measurement of phase L2/B current	5 ms
IL3TRMS	TRMS measurement of phase L3/C current	5 ms
U1	Positive sequence voltage	5 ms

Pick-up characteristics

Pick-up level of the VOC function is controlled by setting parameters Iv1, Iv2, Ux1, Ux2 and positive sequence voltage measurement. Pick-up level defines the maximum allowed measured current before action from the function. The function constantly calculates the ratio in between of the current pick-up level and measured magnitude (Im) per all three stages. Reset ratio of 97 % is inbuilt in the function and is always related to thecurrent pick-upvalue.

Table 3.191 Pick-up characteristics setting

Name	Description	Range	Step	Default
Iv1>	1st knee point Iv1>	0.10...40.00xIn	0.01xIn	0.6xIn
Iv2>	2nd knee point Iv2>	0.10...40.00xIn	0.01xIn	2.0xIn
Ux1	1st knee point voltage	0.00...150.00%Un	0.01%Un	30%Un
Ux2	2nd knee point voltage	0.00...150.00%Un	0.01%Un	80%Un

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Function blocking

In the blocking element the block signal is checked at the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup voltage values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Operating time characteristics for trip and reset

This function supports definite time delay (DT) and inverse definite minimum time (IDMT) delay types. For detailed information on these delay types refer to chapter General properties of a protection function.

Events and registers

The VOC function generates events and registers from the status changes of start, trip and blocked. To main event buffer is possible to select status “On” or “Off” messages. The VOC function offers four independent instances which events are segregated for each instance operation.

12 last registers are available in the function where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values.

Table 3.192 Event codes of the VOC function.

Event Number	Event channel	Event block name	Event Code	Description
7168	112	VOC1	0	Start ON
7169	112	VOC1	1	Start OFF
7170	112	VOC1	2	Trip ON
7171	112	VOC1	3	Trip OFF
7172	112	VOC1	4	Block ON
7173	112	VOC1	5	Block OFF

In the register of the VOC function is recorded start, trip or blocked “On” event process data. In the table below is presented the structure of VOC function register content. This information is available in 12 last recorded events for all provided instances separately.

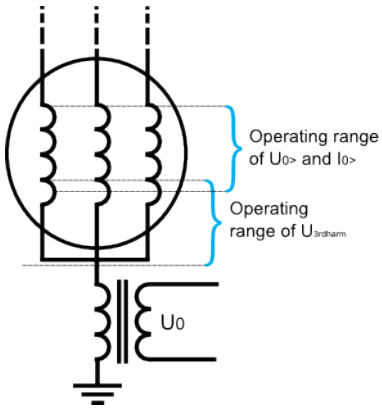
Table 3.193 Register content.

Date & Time	Event code	Fault type	Trigger current	Fault current	Prefault current	Trip time remaining	Used SG
dd.mm.yyyy hh:mm:ss.mss	7168-7171 Descr.	L1-G ... L1-L2-L3	Start average current	Trip -20ms averages	Start -200ms averages	0ms -1800s	1 - 8

3.9.5 100% stator earth fault protection U0f3 (64S)

Earth fault near the neutral doesn’t result in high enough neutral voltage for conventional earth fault protection to react. Even in the best scenario at least 5% outside of neutral overvoltages range. Generators induce some amount of third harmonic neutral voltage. When there’s an earth fault near the neutral point 100% stator earth fault protection measures this voltage and trips if the third harmonic neutral voltage drops under the set value. If the third harmonic neutral voltage induced by the generator is high enough the whole stator can be protected with the combination of neutral overvoltage and 100% stator earth fault protection.

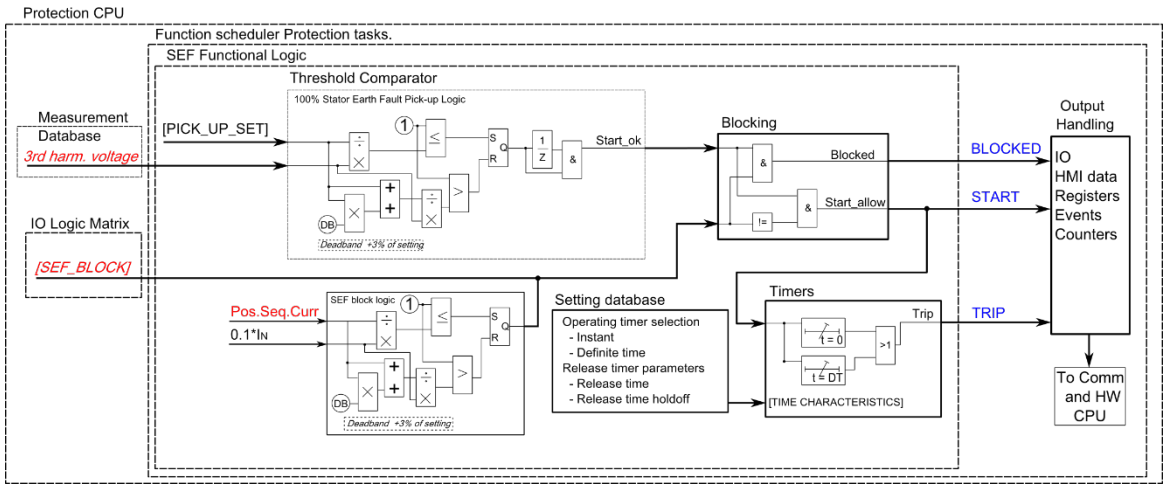
Figure 3.155 Demonstration of the overlapping range of neutral overvoltage and 100% stator earth fault protection.



Inputs for the function are the operating mode selections, setting parameters and measured and pre-processed voltage and current magnitudes and binary input signals. Function outputs START, TRIP and BLOCKED signals which can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the three output signal. In instant operating mode the function outputs START and TRIP events simultaneously with equivalent time stamp. Time stamp resolution is 1ms. Function provides also cumulative counters for START, TRIP and BLOCKED events.

In the following figure is presented the simplified function block diagram of the SEF function.

Figure 3.156 Simplified function block diagram of the SEF function.



Measured input values

Function block uses analog voltage measurement values for third harmonic voltage measurement and three phase current measurement for positive sequence current blocking. -20ms averaged value is used for pre-fault data registering.

Table 3.194 Measurement magnitudes used by the SEF function.

Signal	Description	Time base
3rd.Harm.Voltage (U0)	3rd.Harm. Neutral Voltage	5 ms

Pick-up characteristics

Function has an inbuilt low current blocking feature to prevent faulty trips. It is set by parameter *Low current blocking I1< set*. If this parameter is set above zero measured positive sequence current must be over the set limit so that the function will trip.

Pick-up of the SEF function is controlled by *Pick up setting U03h< set* setting parameter, which defines the minimum allowed measured neutral third harmonic voltage before action from the function. The function constantly calculates the ratio in between of the Uset< and measured magnitude. Reset ratio of 103% is inbuilt in the function and is always related to the Uset<value.

Table 3.195 Pick-up characteristics setting

Name	Description	Range	Step	Default
Uset<	Pick-up setting	1.00 ... 100.00%UN	0.01%UN	20%UN
I1< block	If measured positive sequence current is below this tripping is not allowed. 0*In setting disables block.	0.00...100.00*In	0.01*In	0%Un

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Function blocking

In the blocking element the block signal is checked at the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup voltage values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Operating time characteristics for trip and reset

This function supports definite time delay (DT). For detailed information on this delay type refer to chapter General properties of a protection function.

Events and registers

The SEF function generates events and registers from the status changes of start, trip and blocked. To main event buffer is possible to select status “On” or “Off” messages. The SEF function offers four independent instances which events are segregated for each instance operation.

In the function is available 12 last registers where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values.

Table 3.196 Event codes of the SEF function.

Event Number	Event channel	Event block name	Event Code	Description
7040	110	SEF1	0	Start ON
7041	110	SEF1	1	Start OFF
7042	110	SEF1	2	Trip ON
7043	110	SEF1	3	Trip OFF

Event Number	Event channel	Event block name	Event Code	Description
7044	110	SEF1	4	Block ON
7045	110	SEF1	5	Block OFF

In the register of the SEF function is recorded start, trip or blocked “On” event process data. In the table below is presented the structure of SEF function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 3.197 Register content.

Date & Time	Event code	Trigger Voltage	Fault voltage	Prefault voltage	Trip time remaining	Used SG
dd.mm.yyyy hh:mm:ss.mss	7040-7043 Descr.	Start average voltage	Trip -20 ms averages	Start -200 ms averages	0ms -1800s	1 - 8

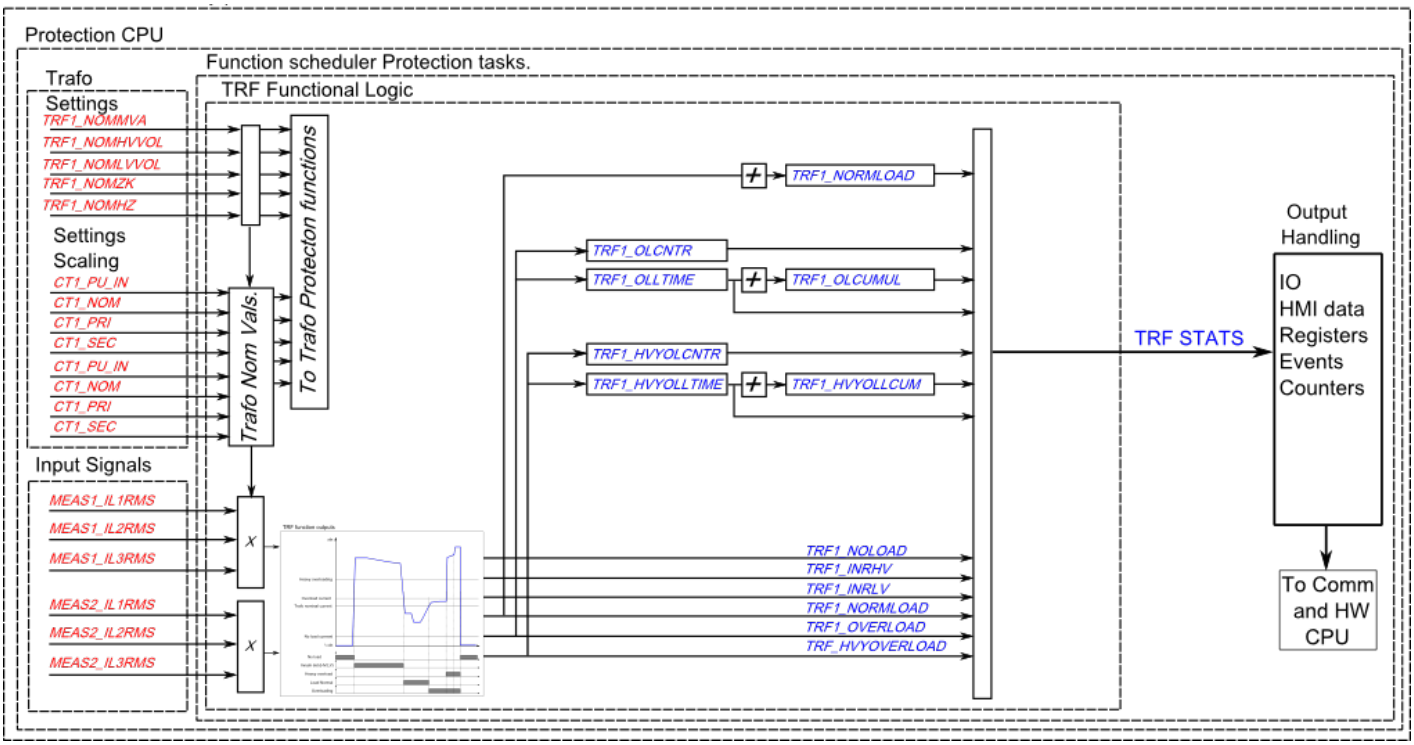
3.10 Transformer protections

3.10.1 Transformer status monitoring (TRF)

Transformer status monitoring function (TRF) is designed to be the common place for set up all necessary transformer data and to select the used transformer protection functions. Settings related to the protection functions can be edited also inside of each related function and after changed they will be updated into TRF function also. TRF function calculates many transformer related properties which are used in functions for protecting and monitoring the transformer. Basically for standard transformer only name plate data and CT scalings are needed to get the relay scale automatically all measurement signals to the transformer. For special transformers manual set values can be applied to cover rarely met transformers properties. In addition to this TRF function counts transformer cumulative overloading and high overcurrent time.

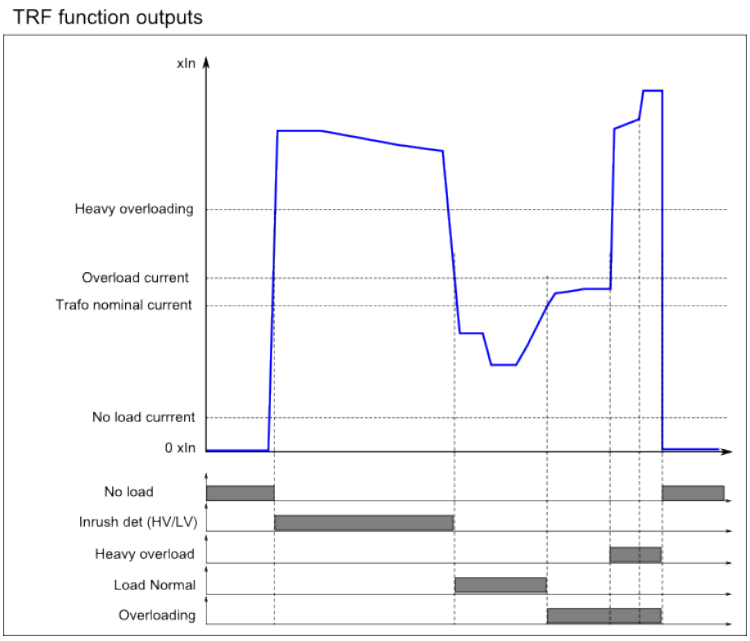
TRF function can output light/no load, HV side inrush, LV side inrush, normal load, overloading and heavy overloading signals to be used in indication or in logic programming. From these signals TRF also generates events if so wanted.

Figure 3.157 Simplified function block diagram of the TRF function.



The TRF function outputs are dependent of the set transformer data in that sense that per unitized measured currents are related to transformer nominal values. Following diagram presents the TRF function outputs in various situations.

Figure 3.158 TRF function outputs activation.



"No load" signal is activated when the current is under "No load current" limit (0.2 xIn)" for more than 10 ms time. If the current increases from this situation to "Heavy overloading limit (> 1.3 x In) then "HV/LV inrush detection" signals are activated. If measured current is in between of low detection and nominal current the "Load normal" signal is activated. If measured current is in between of nominal and heavy overloading current "Overloading" signal is activated.

These signals can be used for informational and also for transformer related logics and monitoring usage. For example constant long duration heavy overloading may cause the transformer oil ageing and thus the maintenance should be applied before scheduled in order to prevent possible problems in the transformer.

Settings and signals

Settings of the transformer status monitor (TRF) function are mostly shared with transformer protection functions in the transformer module of the IED. In following table are shown the functions which use these settings also.

Table 3.198 Settings of the TRF function.

Name	Range	Step	Default	Funcs.	Description
Transformer nominal MVA	0.1...500.0MVA	0.1MVA	1.0MVA	All	Nominal MVA of transformer. This value is used to calculate nominal currents of HV, and LV side.
HV side nominal voltage	0.1...500.0kV	0.1kV	110.0kV	All	HV side nominal voltage of the transformer. This value is used to calculate nominal currents of HV side.
LV side nominal voltage	0.1...500.0kV	0.1kV	110.0kV	All	LV side nominal voltage of the transformer. This value is used to calculate nominal currents of LV side.
Transformer Zk%	0.01...25.00%	0.01%	3.00%	Info	Transformer short circuit impedance in %. Used for calculation of the short circuit currents
Transformer nom. freq	10...75Hz	1Hz	50Hz	Info	Transformer nominal frequency. Used for calculation of transformer nominal short circuit inductance.

Name	Range	Step	Default	Funcs.	Description
Transf. Vect. group	0:Manual 1:Yy0 2:Yyn0 3:YNy0 4:YNyn0 5:Yy6 6:Yyn6 7:YNy6 8:YNyn6 9:Yd1 10:YNd1 11:Yd7 12:YNd7 13:Yd11 14:YNd11 15:Yd5 16:YNd5 17:Dy1 18:Dyn1 19:Dy7 20:Dyn7 21:Dy11 22:Dyn11 23:Dy5 24:Dyn5 25:Dd0 26:Dd6	-	1:Yy0	TRF, DIFF	Selection of the transformer vector group. Selection values from 1 to 26 are predefined so that just by selecting correct vector group the scaling and vector matching is applied in the relay automatically. In the predefinitions it is assumed that the HV side is connected to CT1 module and LV side is in CT2 module. If the protected transformer vector group is not found in the predefined list, manual set can be applied by selecting 0: Manual set.
HV side Star or Zigzag / Delta	0:Star/Zigzag 1:Delta	-	0:Star/ Zigzag	TRF, DIFF	Selection of the HV side connection, star or zigzag or delta. Selection is visible only if vector group is set to “0:Manual set”
HV side grounded	0:Not grounded 1:Grounded	-	0:Not grounded	TRF, DIFF	Selection whether the zero sequence compensation should be applied into HV side currents calculation. Selection is visible only if vector group is set to “0:Manual set”
HV side lead or lag LV	0:Lead 1:Lag	-	0:Lead	TRF, DIFF	Selection for HV side leads or lags LV side. Selection is visible only if vector group is set to “0:Manual set”
LV side Star or Zigzag / Delta	0:Star/Zigzag 1:Delta	-	0:Star/ Zigzag	TRF, DIFF	Selection of the LV side connection, star or zigzag or delta. Selection is visible only if vector group is set to “0:Manual set”
LV side grounded	0:Not grounded 1:Grounded	-	0:Not grounded	TRF, DIFF	Selection whether the zero sequence compensation should be applied into LV side currents calculation. Selection is visible only if vector group is set to “0:Manual set”
LV side lead or lag HV	0:Lead 1:Lag	-	0:Lead	TRF, DIFF	Selection for LV side leads or lags LV side. Selection is visible only if vector group is set to “0:Manual set”
HV-LV side phase angle	0.0...360.00deg	0.1deg	0.0deg	TRF, DIFF	Angle correction factor for HV LV sides, looked from HV side. e.g. if transformer is Dy1 then set here 30 degrees. Selection is visible only if vector group is set to “0:Manual set”
HV-LV side mag correction	0.0...100.0xIn	0.1xIn	0.0xIn	TRF, DIFF	Magnitude correction for HV-LV side currents per unitizing if the currents are not directly matched

Name	Range	Step	Default	Funcs.	Description
					via calculation of the nominal values. Selection is visible only if vector group is set to “0:Manual set”
Check online HV-LV configuration	0:- 1:Check	-	0:-	TRF, DIFF	Check online on energized trafo the configuration success. (Trafo needs to have current flowing on both sides as well as there should not be faults seen in order this to work). Selection is visible only if vector group is set to “0:Manual set”

Table 3.199 Calculations of the TRF function.

Name	Range	Step	Default	Funcs.	Description
HV side nominal current(pri)	0.01...50000.00A	0.01A	0.00A	Info	Calculated transformer HV side primary current.
HV side nominal current(sec)	0.01...250.00A	0.01A	0.00A	Info	Calculated transformer HV side secondary current.
HV CT nom to TR nom factor	0.01...250.00p.u.	0.01p.u.	0.00A	Info	Calculated transformer HV side nominal to CT primary rate.
LV side nominal current(pri)	0.01...50000.00A	0.01A	0.00A	Info	Calculated transformer LV side primary current.
LV side nominal current(sec)	0.01...250.00A	0.01A	0.00A	Info	Calculated transformer LV side secondary current.
LV CT nom to TR nom factor	0.01...250.00p.u.	0.01p.u.	0.00p.u.	Info	Calculated transformer LV side nominal to CT primary rate.
Transformer nom impedance	0.01...250.00ohm	0.01ohm	0.00ohm	Info	Calculated transformer nominal impedance.
Transformer nom Zk ohm	0.01...250.00ohm	0.01ohm	0.00ohm	Info	Calculated transformer nominal short circuit impedance.
Transformer nom SC inductance	0.001...250.000uH	0.01uH	0.000uH	Info	Calculated transformer nominal short circuit inductance.
Transformer ratio	0.01...250.00	0.01	0.00	Info	Calculated transformer ratio. (HV/LV)
LV side max 3ph SC curr	0.001...500.000kA	0.001kA	0.000kA	Info	Calculated maximum three phase short circuit current in the LV poles of the trafo.
LV side 3ph SC to HV side	0.001...500.000kA	0.001kA	0.000kA	Info	Calculated max three phase short circuit current in LV side shows to HV side.
LV side max 2ph SC curr	0.001...500.000kA	0.001kA	0.000kA	Info	Calculated maximum two phase short circuit current in the LV poles of the trafo.
LV side 2ph SC to HV side	0.001...500.000kA	0.001kA	0.000kA	Info	Calculated max two phase short circuit current in LV side shows to HV side.

Table 3.200 Output signals of the TRF function

Name	Range	Step	Default	Description
No/Light load	0:Not active 1:Active	1	0	Signal is active, when the TRF function detects current below “No load current”. This signal presents situation when there is very light load or only one or neither side of trafo is energized.
HV side inrush detected	0:Not active 1:Active	1	0	Signal is active, when the detected current rises over the “High overcurrent” limit in the HV side.
LV side inrush detected	0:Not active 1:Active	1	0	Signal is active, when the detected current rises over the “High overcurrent” limit in the LV side.

Name	Range	Step	Default	Description
Load normal	0:Not active 1:Active	1	0	Signal is active when the measured current is below nominal and over no load limit current.
Overloading	0:Not active 1:Active	1	0	Signal is active when the measured current is in between nominal and high overcurrent limits.
HVY Overloading	0:Not active 1:Active	1	0	Signal is active when the measured current is over high overcurrent limit.

Events

TRF function generates events from detected transformer energizing status. From changes of the events also data register is available.

Table 3.201 Event codes of the TRF function

Event Number	Event channel	Event block name	Event Code	Description
4608	72	TRF1	0	Light/No load On
4609	72	TRF1	1	Light/No load Off
4610	72	TRF1	2	HV side inrush On
4611	72	TRF1	3	HV side inrush Off
4612	72	TRF1	4	LV side inrush On
4613	72	TRF1	5	LV side inrush Off
4614	72	TRF1	6	Load normal On
4615	72	TRF1	7	Load normal Off
4616	72	TRF1	8	Overloading On
4617	72	TRF1	9	Overloading Off
4618	72	TRF1	10	High overload On
4619	72	TRF1	11	High overload Off
4620	72	TRF1	12	Setting changes, calculating new trafo data
4621	72	TRF1	13	Calculation finished, possible restart

In the table below is presented the structure of TRF function register content. This information is available in 12 last recorded events.

Table 3.202 Register content.

Date & Time	Event code	HVL1 current	HVL2 current	HVL3 current	LVL1 current	LVL2 current	LVL3 current
dd.mm.yyyy hh:mm:ss.mss	4608-4621 Descr.	HV side Phase L1 current xIn	HV side Phase L2 current xIn	HV side Phase L3 current xIn	LV side Phase L1 current xIn	LV side Phase L2 current xIn	LV side Phase L3 current xIn

3.10.2 Transformer thermal overload protection TT> (49TR)

Thermal overload function for transformers (TOLT) is used for power transformers thermal capacity monitoring and protection.

TOLT function constantly monitors phase TRMS currents (including harmonics up to 31st) instant values and calculates the set thermal replica status in 5 ms cycles. TOLT function includes total memory function of the load-current conditions according to IEC 60255-8

TOLT function is based into thermal replica, which represents the protected object or cable thermal loading in relation to the current going through the object. Thermal replica includes the calculated thermal capacity used in the “memory” since it is integral function which tells apart this function from normal overcurrent function operating principle for the overload protection applications.

Thermal image for the TOLT function is calculated according to equation described below:

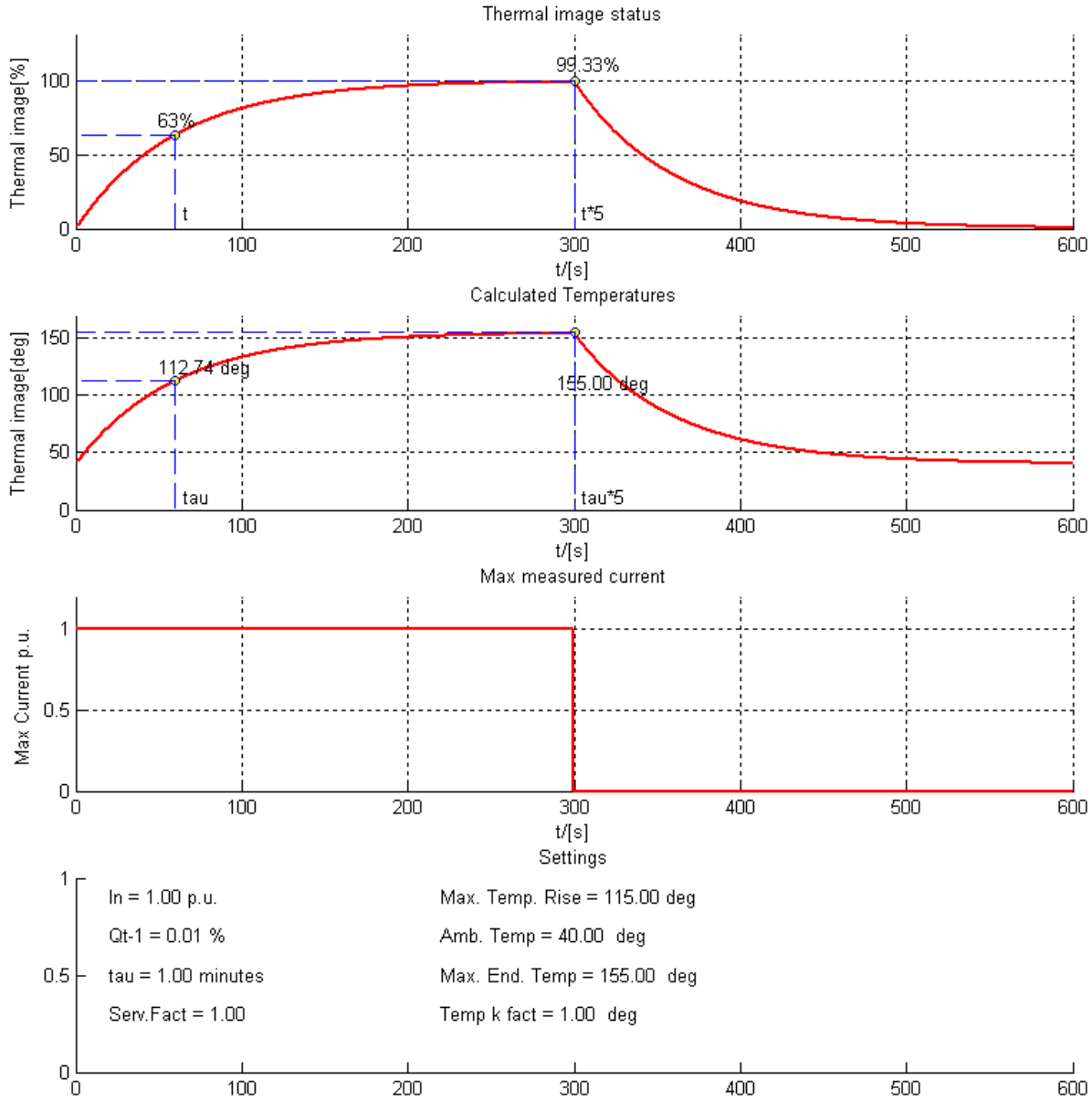
$$\theta_{t\%} = \left(\left(\theta_{t-1} - \left(\frac{I_{MAX}}{I_N \times k_{SF} \times k_{AMB}} \right)^2 \times e^{-\frac{t}{\tau_1/\tau_2}} \right) + \left(\frac{I_{MAX}}{I_N \times k_{SF} \times k_{AMB}} \right)^2 \right) \times 100\%$$

, where

- $\theta_{t\%}$ = Thermal image status in percent of the maximum thermal capacity available
- θ_{t-1} = Thermal image status in previous calculation cycle (the memory of the function)
- I_{MAX} = Measured maximum of the three TRMS phase currents
- I_N = Current for the 100 % thermal capacity to be used (pick-up current in p.u., with this current t_{max} will be achieved in time t x 5)
- k_{SF} = Loading factor (service factor) coefficient, maximum allowed load current in per unit value depend of the protected object or cable/line installation
- k_{AMB} = Temperature correction factor either from linear approximation or settable 10 point thermal capacity curve.
- τ_1 = Thermal heating time constant of the protected object (in minutes)
- τ_2 = Thermal heating time constant of the protected object (in minutes)
- e = Euler’s number
- t = Calculation time step in seconds (0.005s)

The basic operating principle of the thermal replica is based into that the nominal temperature rise is achieved when the protected object is loaded with nominal load in nominal ambient temperature. When the object is loaded with nominal load for time equal its heating constant tau (τ), 63% of the nominal thermal capacity is used. When the loading continues until five times this given constant the used thermal capacity indefinitely approaches to 100% but never exceeds it. With a single time constant model cooling of the object follows this same behavior reversible to the heating when the current feeding is completely zero.

Figure 3.159 Thermal image calculation with nominal conditions, example.



This described behavior is based into that assumption that the monitored object, whether cable, line or electrical device has a homogenous body which is generating and dissipating heat with a rate which is proportional to temperature rise caused by current squared. This usually is the case with cables and objects while overhead lines heat dissipation is dependent of current weather conditions. Weather conditions considering the prevailing conditions in the thermal replica are compensated with ambient temperature coefficient which is constantly calculated and changing when using RTD sensor for the measurement. When the ambient temperature of the protected object is stable it can be set manually (e.g. in case of ground dug cables).

Ambient temperature compensation takes into account the set minimum and maximum temperature and load capacity of the protected object and measured or set ambient temperature. The calculated coefficient is linear correction factor which is presented with following formulas:

$$t_{Amb<t_{min}} = k_{min}$$

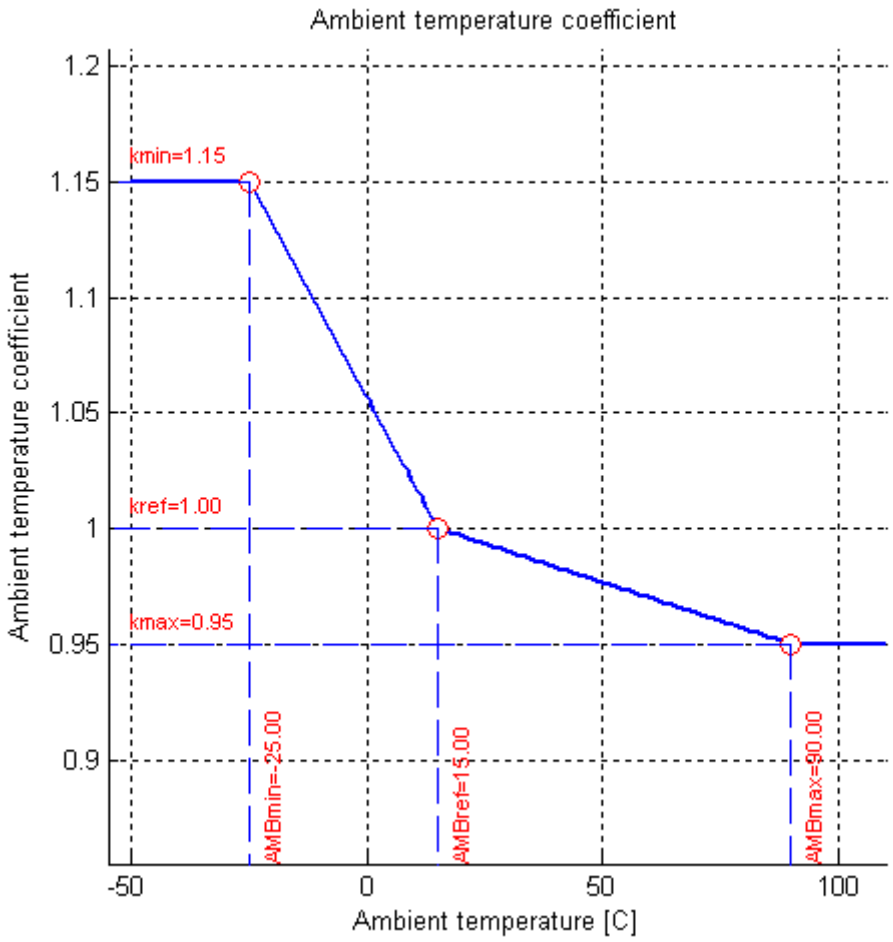
$$t_{Amb<t_{ref}} = \left(\frac{1 - k_{min}}{t_{ref} - t_{min}} \times (t_{AMB} - t_{min})\right) + k_{min}$$

$$t_{Amb>t_{ref}} = \left(\frac{k_{max} - 1}{t_{max} - t_{ref}} \times (t_{AMB} - t_{ref})\right) + 1.0$$

$$t_{Amb>t_{max}} = k_{max}$$

- t_{amb} = Measured (set) ambient temperature (can be set in˚C or˚F)
- t_{max} = Maximum temperature (can be set in˚C or˚F) for the protected object
- k_{max} = Ambient temperature correction factor for the maximum temperature
- t_{min} = Minimum temperature (can be set in˚C or˚F) for the protected object
- k_{min} = Ambient temperature correction factor for the minimum temperature
- t_{ref} = Ambient temperature reference (can be set in˚C or˚F, the temperature in which the given manufacturer presumptions apply and the temperature correction factor is 1.0)

Figure 3.160 Ambient temperature coefficient calculation examples when reference temperature is +15 C with 3 point linear approximation and settable correction curve.



Thermal overload function IO

Blocking signal and setting group selection controls the operating characteristics of the function during normal operation.

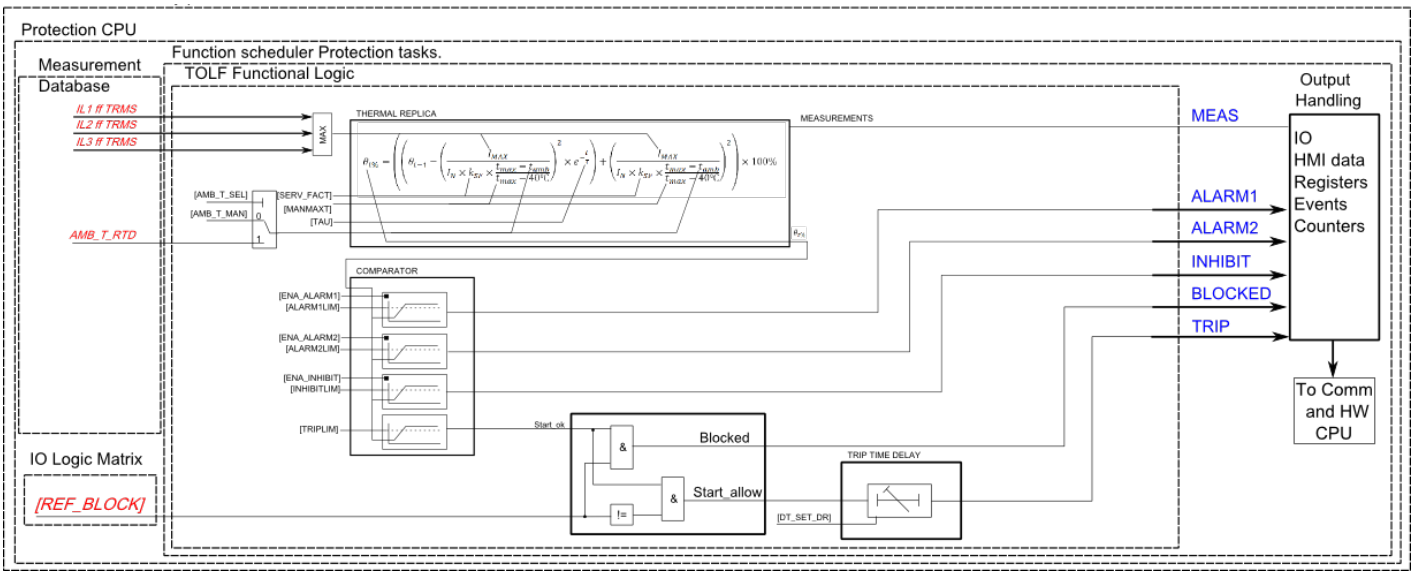
Outputs of the function are TOLT Trip and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. TOLT function utilizes total of eight separate setting groups which can be selected from one common source. Also the operating mode of the TOLT can be changed by setting group selection.

The operational logic consists of input magnitude processing, thermal replica, comparator, block signal check and output processing.

Inputs for the function are setting parameters and measured and pre-processed current magnitudes. Function output signals can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the two output signal. Time stamp resolution is 1ms. Function provides also cumulative counters for TOLT Trip, Alarm 1, Alarm 2, Inhibit and BLOCKED events.

In the following figure is presented the simplified function block diagram of the TOLT function.

Figure 3.161 Simplified function block diagram of the TOLT function.



Measured input value

For the function block is used analog current measurement values. Function uses the fundamental frequency magnitude of the current measurement inputs and calculated residual current with residual current measurement. For residual current measurement can be selected I01 or I02.

Table 3.203 Analogic magnitudes used by the TOLT function.

Signal	Description	Time base
IL1RMS	Fundamental TRMS measurement of phase L1/A current	5 ms
IL2RMS	Fundamental TRMS measurement of phase L2/B current	5 ms
IL3RMS	Fundamental TRMS measurement of phase L3/C current	5 ms
RTD	Temperature measurement for the ambient correction	5 ms

Table 3.204 General settings of the TOLT stage (not SG selectable)

Name	Range	Step	Default	Description
TT> mode	0:Disabled 1:Activated	-	0:Disabled	Selection of the function is activated or disabled in the configuration. Default setting 0:Disabled (Not in use).
Temp C or F deg	0: C 1: F	-	0:C	Selection whether the temperature values of the thermal image and RTD compensation are shown in Celsius or Fahrenheit degrees.

Table 3.205 Thermal replica settings.

Name	Range	Step	Default	Description
IN thermal cap current	0.10...40.00xIn	0.01xIn	1.00xIn	Current for the 100 % thermal capacity to be used (pick-up current in p.u., with this current t_{max} will be achieved in time t x 5). Default setting is 1.00 xIn.
tau h (t const)	0.1...500.0min	0.1min	10.0min	Time constant setting. This time constant is used for heating of the protected object.
tau c (t const)	0.1...500.0min	0.1min	10.0min	Time constant setting. This time constant is used for cooling of the protected object.

Name	Range	Step	Default	Description
kSF (service factor)	0.01...5.00	0.01	1.00	Service factor which corrects the maximum allowed current value according to installation etc. conditions which vary from the presumption conditions.
Cold Reset default theta	0.0...150.0%	0.1%	60.0%	Thermal image status in the restart of the function / IED in percentage of used thermal capacity of the protected object. Default setting is 60% of thermal capacity used. Also, possible to fully reset thermal element. This parameter can be used when testing the function to manually set the current thermal cap to any value.

Table 3.206 Environmental settings

Name	Range	Step	Default	Description
Object max temp (tmax = 100%)	0...500deg	1 deg	90	Maximum allowed temperature for the protected object. Default setting is +90 degrees and it suits for Celsius range and for PEX insulated cables
Ambient temp sel	0:Manual set 1:RTD	-	0:Manual set	Selection whether fixed or measured ambient temperature should be used for the thermal image biasing.
Man.Amb.Temp.Set	0...500deg	1deg	15deg	Manual fixed ambient temperature setting for the thermal image biasing. For underground cables commonly is used 15 degrees Celsius. Setting is visible if Ambient temp sel is set to “Manual set”.
RTD Amb.Temp.Read	0...500deg	1deg	15deg	RTD ambient temperature reading for the thermal image biasing. Setting is visible if Ambient temp sel is set to “RTD”.
Ambient lin. or curve	0:Linear est. 1:Set curve	-	0:Linear est	Selection of ambient temperature correction either by internally calculated compensation based into end temperatures or user settable curve. Default setting is 0:Linear corr, which means internally calculated correction for ambient temperature.
Temp.reference (tref) k_{amb}=1.0	-60...500deg	1deg	15deg	Temperature reference setting. In this temperature manufacturer presumptions apply and the thermal correction factor is 1.00 (rated temperature). For ground dug cables this is usually 15˚C and in air 25˚C. Setting is visible if Ambient lin. or curve is set to *Linear est*.
Max ambient temp	0...500deg	1deg	45deg	Maximum ambient temperature setting. If measured temperature is more than maximum set temperature the set correction factor for maximum temperature shall be used. Setting is visible if Ambient lin. or curve is set to “Linear est.”
k at max amb temp	0.01...5.00xIn	0.01xIn	1.00xIn	Temperature correction factor for maximum ambient temperature setting. Setting is visible if Ambient lin. or curve is set to “Linear est.”
Min ambient temp	-60...500deg	1deg	0deg	Minimum ambient temperature setting. If measured temperature is less than minimum set temperature the set correction factor for minimum temperature shall be used. Setting is visible if Ambient lin. or curve is set to “Linear est.”
k at min amb temp	0.01...5.00xIn	0.01xIn	1.00xIn	Temperature correction factor for minimum ambient temperature setting. Setting is visible if Ambient lin. or curve is set to “Linear est.”

Name	Range	Step	Default	Description
Amb.Temp.ref1...10	-50.0... 500.0deg	0.1deg	15deg	Temperature reference points for the user settable ambient temperature coefficient curve. Setting is visible if Ambient lin. or curve is set to “Set curve”.
Amb.Temp.k1...k10	0.01...5.00	1.00	0.01	Coefficient value for the temperature reference point. Coefficient and temperature reference points must be set as pairs. Setting is visible if Ambient lin. or curve is set to “Set curve”.
Add curvepoint 3...10	0:Not used 1:Used	-	0:Not used	Selection whether the curve temperature / coefficient pair is in use. Minimum amount is two pairs to be set for the temperature / coefficient curve and maximum is ten pairs. If measured temperature is less than set minimum temperature reference or more than maximum set temperature reference the used temperature coefficient shall be the first or last value in the set curve. Setting is visible if Ambient lin. or curve is set to “Set curve”.

Operation characteristics

The operating characteristic of the TOLT function is completely controlled by the thermal image. From the thermal image calculated thermal capacity used value can be set IO controls with Alarm 1, Alarm 2, Inhibit and Trip signals.

Table 3.207 Pick-up characteristics setting (SG selectable)

Name	Range	Step	Default	Description
Enable TT> Alarm 1	0:Disabled 1:Enabled	-	0:Disabled	Enabling / Disabling of the Alarm 1 signal and IO
TT> Alarm 1 level	0.0...150.0%	0.1%	40%	Alarm 1 activation threshold. Default setting is 40%.
Enable TT> Alarm 2	0:Disabled 1:Enabled	-	0:Disabled	Enabling / Disabling of the Alarm 2 signal and IO
TT> Alarm 2 level	0.0...150.0%	0.1%	40%	Alarm 2 activation threshold. Default setting is 40%.
Enable TT> Rest Inhibit	0:Disabled 1:Enabled	-	0:Disabled	Enabling / Disabling of the Inhibit signal and IO
TT> Inhibit level	0.0...150.0%	0.1%	80%	Inhibit activation threshold. Default setting is 80%.
Enable TT> Trip	0:Disabled 1:Enabled	-	0:Disabled	Enabling / Disabling of the Inhibit signal and IO
TT> Trip level	0.0...150.0%	0.1%	100%	Inhibit activation threshold. Default setting is 80%.
TT> Trip delay	0.000...3600.000s	0.005s	0.000s	Trip signal additional delay. This delay will prolong the trip signal generation for the set time. Default setting is 0.000s which will not give added time delay for the trip signal.

Function blocking

In the blocking element the block signal is checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a Trip signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If Trip function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup current values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Measurements and indications of the function

TOLT function outputs measured process data from following magnitudes:

Table 3.208 General status codes

Name	Range	Description
TT> Condition	0:Normal 1:Alarm1 On 2:Alarm2 On 3:Inhibit On 4:Trip On 5:Blocked	TOLT function operating condition at the moment considering binary IO signal status. When the status is “Normal” no outputs are controlled.
Thermal status	0:Light / No load 1:High overload 2:Overloading 3:Load normal	TOLT function thermal image status. When the measured current is below 1 % of nominal status “Light / No load” will be shown, when the measured current is below trip limit status “Load normal” will be shown, when the measured current is over pick-up limit but under 2 xIn status “Overloading” will be shown and when measured current is over 2 xIn status “High overload” will be shown.

Table 3.209 Measurements

Name	Range	Description / values
Currents	0:Primary A 1:Secondary A 2:Per unit	Active phase current measurement from IL1(A), IL2(B) and IL3(C) phases in given scalings.
Thermal Image	0:Thermal image calc.	TT> Trip expect mode: No trip expected / Trip expected TT> time to 100% theta: Time to reach 100% thermal cap TT> reference T curr.: Reference / pick-up value (IEQ) TT> Active meas curr.: Measured max TRMS current at the moment TT> T est.with act curr.: Estimate of used thermal capacity with current at the moment TT> T at the moment: Thermal capacity used at the moment
	1: Temp estimates	TT> Used k for amb.temp: Ambient correction factor at the moment TT> Max.Temp.Rise All: Maximum temperature rise allowed TT> Temp.Rise atm: Calculated temperature rise at the moment TT> Hot Spot estimate: Estimated hot spot temperature including the ambient temperature TT> Hot Spot Max. All: Maximum allowed temperature for the object
	2: Timing status	TT> Trip delay remaining: Time to reach 100% theta TT> Trip time to rel.: Time to theta to reach under trip limit when cooling TT> Alarm 1 time to rel.: Time to theta to reach under Alarm 1 limit when cooling TT> Alarm 2 time to rel.: Time to theta to reach under Alarm 2 limit when cooling TT> Inhibit time to rel.: Time to theta to reach under Inhibit limit when cooling

Table 3.210 Counters

Name	Description / values
Alarm1 inits	Times the TOLT function has activated the Alarm 1 output
Alarm2 inits	Times the TOLT function has activated the Alarm 2 output
Restart inhibits	Times the TOLT function has activated the Restart inhibit output

Name	Description / values
Trips	Times the TOLT function has tripped
Trips Blocked	Times the TOLT function trips has been blocked

Events and registers

The TOLT function generates events and registers from the status changes of the Trip activated and blocked signals. To main event buffer is possible to select status “On” or “Off” messages.

In the function is available 12 last registers where the triggering event of the function (Trip activated or blocked) is recorded with time stamp and process data values.

Table 3.211 Event codes of TOLT function.

Event Number	Event channel	Event block name	Event Code	Description
4672	73	TOLT1	0	Alarm1 On
4673	73	TOLT1	1	Alarm1 Off
4674	73	TOLT1	2	Alarm2 On
4675	73	TOLT1	3	Alarm2 Off
4676	73	TOLT1	4	Inhibit On
4677	73	TOLT1	5	Inhibit Off
4678	73	TOLT1	6	Trip On
4679	73	TOLT1	7	Trip Off
4680	73	TOLT1	8	Block On
4681	73	TOLT1	9	Block Off

In the register of the TOLT function is recorded activated, blocked etc. “On” event process data. In the table below is presented the structure of TOLT function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 3.212 Register content

Date & Time	Event code	Time to reach 100% theta	Ref. T current	Active meas current	T at the moment
dd.mm.yyyy hh:mm:ss.mss	4672- 4681 Descr.	seconds	xIn	xIn	%
Max temp rise allowed	Temp rise at the moment	Hot Spot estimate	Hot spot max all.	Trip delay rem	Used SG
deg	deg	deg	deg	s	1 - 8

3.10.3 Resistance temperature detectors (Modbus IO) (RTD) (49T)

Resistance Temperature Detectors (RTD) can be used to measure temperatures from the motor as well as ambient temperature. Typically RTD is PT100 type or thermocouple. External Modbus based RTD modules are supported up to three separate modules which each can hold up to eight measurement elements. For the alarm function (RTD / 49T) can be set 12 individual element monitors which each can be set to alarm two separate alarms from the selected input. Alarms and measurements can be set in either degrees Centigrade or Fahrenheit.

The principal structure of RTD alarm function is shown in following figure.

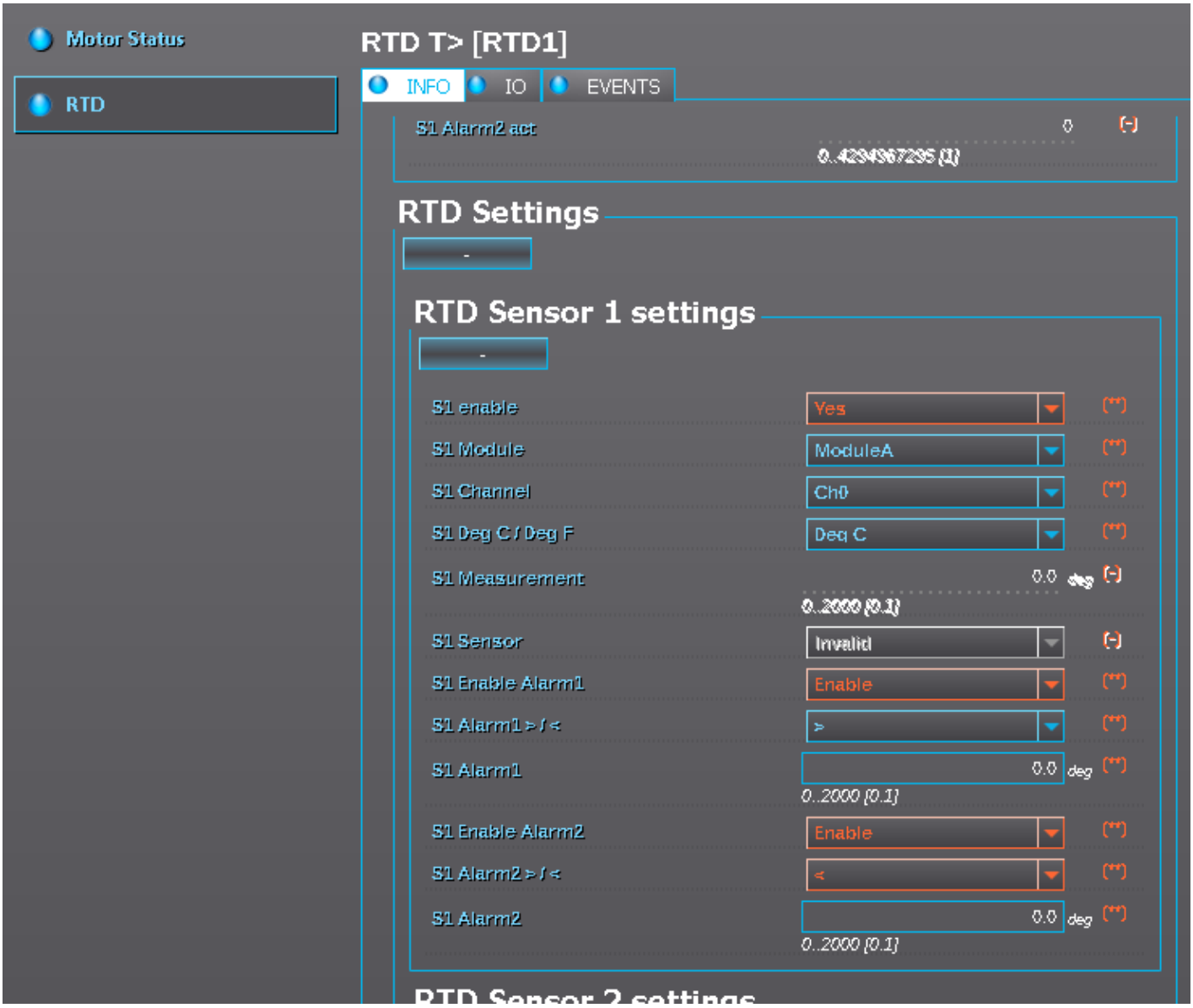
To set the RTD measurement first the measurement module needs to be set to scan the wanted RTD elements. Currently Modbus based modules are supported. For the communication first needs to be set bitrate, databits, parity, stopbits and ModbusIO protocol. These are set at *Communication → Connections*.

After the communication is set the wanted channels are selected from the ModbusIO tab under *Communication → Protocols*. There are three separate modules available for selection.

Used measurement module is selected first and the poll address. Module type needs to be set also as well as the polled channels.

In case of thermocouple module the thermo element type needs to be set per each measurement channel. After these settings the RTD:s are available for other functions.

Figure 3.162 RTD alarm set up.



In the motor module RTD alarm function can be set to monitor previously set RTD channels measurement data. A single channel can be set to have several alarms by selecting the channel to multiple sensor inputs. In each sensor setting can be selected the monitored module and channel. Also the monitoring and alarm setting units (C/F) can be selected here. Alarms can be enabled either “over” or “under” and the setting value is input as degrees. In the RTD alarm function are 12 sensor inputs available. For the alarm to be active channel measurement must be valid. Channel measurement can be invalid if the communication is not working or sensor is broken.

Settings

Table 3.213 Settings of the RTD function for channel x/12.

Name	Range	Step	Default	Description
Sx enable	0:No 1:Yes	-	0:No	Enable / Disable selection of the sensor measurements and alarms
Sx module	0:ModuleA 1:ModuleB 2:ModuleC	-	0:ModuleA	Selection of the measurement module
Sx channel	0:Ch0 1:Ch1 3:Ch2 4:Ch3 5:Ch4 6:Ch5 7:Ch6 8:Ch7	-	0:Ch0	Selection of measurement channel in the selected module.
Sx Deg C/Dec F	0:Deg C 1:Deg F	-	0:Deg C	Selection of the measurement temperature scale in between of Celsius and Fahrenheit.
Sx Measurement	-	-	-	Display of the measurement value in selected degrees.
Sx sensor	Ok Invalid	-	-	Display of the measured sensor data validity. If the sensor reading has any problems the sensor data is set to “Invalid” and the alarms are not activated.
Sx Enable alarm 1	0:Disable 1:Enable	-	0:Disable	Enable / Disable selection of the Alarm 1 for the measurement channel x
Sx Alarm1 >/<	0:> 1:<	-	0:>	Selection of the measurement higher or lower than setting value mode.
Sx Alarm1	-101.0...2000.0deg	0.1deg	0.0deg	Alarm 1 setting value. Alarm shall be activated if the measurement is over or under this setting depend of the selected mode.
Sx sensor	Ok Invalid	-	-	Display of the measured sensor data validity. If the sensor reading has any problems the sensor data is set to “Invalid” and the alarms are not activated.
Sx Enable alarm 2	0:Disable 1:Enable	-	0:Disable	Enable / Disable selection of the Alarm 2 for the measurement channel x
Sx Alarm2 >/<	0:> 1:<	-	0:>	Selection of the measurement higher or lower than setting value mode.
Sx Alarm2	-101.0...2000.0deg	0.1deg	0.0deg	Alarm 2 setting value. Alarm shall be activated if the measurement is over or under this setting depend of the selected mode.

When the RTD:s are set for measuring the values can be read to scada etc. and also the set alarms can be used for direct output control from the RTD module or the alarms can be used in the logics as well.

Events and registers

The RTD function generates events and registers from the status changes of start, trip and blocked. To main event buffer is possible to select status “On” or “Off” messages. The RTD function offers four independent instances which events are segregated for each instance operation.

In the function is available 12 last registers where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values.

Table 3.214 Event codes of the RTD alarms

Event Number	Event channel	Event block name	Event Code	Description
4416	69	RTD1	0	S1 Alarm1 On
4417	69	RTD1	1	S1 Alarm1 Off
4418	69	RTD1	2	S1 Alarm2 On
4419	69	RTD1	3	S1 Alarm2 Off
4420	69	RTD1	4	S2 Alarm1 On
4421	69	RTD1	5	S2 Alarm1 Off
4422	69	RTD1	6	S2 Alarm2 On
4423	69	RTD1	7	S2 Alarm2 Off
4424	69	RTD1	8	S3 Alarm1 On
4425	69	RTD1	9	S3 Alarm1 Off
4426	69	RTD1	10	S3 Alarm2 On
4427	69	RTD1	11	S3 Alarm2 Off
4428	69	RTD1	12	S4 Alarm1 On
4429	69	RTD1	13	S4 Alarm1 Off
4430	69	RTD1	14	S4 Alarm2 On
4431	69	RTD1	15	S4 Alarm2 Off
4432	69	RTD1	16	S5 Alarm1 On
4433	69	RTD1	17	S5 Alarm1 Off
4434	69	RTD1	18	S5 Alarm2 On
4435	69	RTD1	19	S5 Alarm2 Off
4436	69	RTD1	20	S6 Alarm1 On
4437	69	RTD1	21	S6 Alarm1 Off
4438	69	RTD1	22	S6 Alarm2 On
4439	69	RTD1	23	S6 Alarm2 Off
4440	69	RTD1	24	S7 Alarm1 On
4441	69	RTD1	25	S7 Alarm1 Off
4442	69	RTD1	26	S7 Alarm2 On
4443	69	RTD1	27	S7 Alarm2 Off
4444	69	RTD1	28	S8 Alarm1 On
4445	69	RTD1	29	S8 Alarm1 Off
4446	69	RTD1	30	S8 Alarm2 On
4447	69	RTD1	31	S8 Alarm2 Off
4448	69	RTD1	32	S9 Alarm1 On
4449	69	RTD1	33	S9 Alarm1 Off
4450	69	RTD1	34	S9 Alarm2 On
4451	69	RTD1	35	S9 Alarm2 Off
4452	69	RTD1	36	S10 Alarm1 On
4453	69	RTD1	37	S10 Alarm1 Off
4454	69	RTD1	38	S10 Alarm2 On

Event Number	Event channel	Event block name	Event Code	Description
4455	69	RTD1	39	S10 Alarm2 Off
4456	69	RTD1	40	S11 Alarm1 On
4457	69	RTD1	41	S11 Alarm1 Off
4458	69	RTD1	42	S11 Alarm2 On
4459	69	RTD1	43	S11 Alarm2 Off
4460	69	RTD1	44	S12 Alarm1 On
4461	69	RTD1	45	S12 Alarm1 Off
4462	69	RTD1	46	S12 Alarm2 On
4463	69	RTD1	47	S12 Alarm2 Off
4464	69	RTD1	48	S13 Alarm1 On
4465	69	RTD1	49	S13 Alarm1 Off
4466	69	RTD1	50	S13 Alarm2 On
4467	69	RTD1	51	S13 Alarm2 Off
4468	69	RTD1	52	S14 Alarm1 On
4469	69	RTD1	53	S14 Alarm1 Off
4470	69	RTD1	54	S14 Alarm2 On
4471	69	RTD1	55	S14 Alarm2 Off
4472	69	RTD1	56	S15 Alarm1 On
4473	69	RTD1	57	S15 Alarm1 Off
4474	69	RTD1	58	S15 Alarm2 On
4475	69	RTD1	59	S15 Alarm2 Off
4476	69	RTD1	60	S16 Alarm1 On
4477	69	RTD1	61	S16 Alarm1 Off
4478	69	RTD1	62	S16 Alarm2 On
4479	69	RTD1	63	S16 Alarm2 Off
4480	70	RTD2	0	S1 Meas Ok
4481	70	RTD2	1	S1 Meas Invalid
4482	70	RTD2	2	S2 Meas Ok
4483	70	RTD2	3	S2 Meas Invalid
4484	70	RTD2	4	S3 Meas Ok
4485	70	RTD2	5	S3 Meas Invalid
4486	70	RTD2	6	S4 Meas Ok
4487	70	RTD2	7	S4 Meas Invalid
4488	70	RTD2	8	S5 Meas Ok
4489	70	RTD2	9	S5 Meas Invalid
4490	70	RTD2	10	S6 Meas Ok
4491	70	RTD2	11	S6 Meas Invalid
4492	70	RTD2	12	S7 Meas Ok
4493	70	RTD2	13	S7 Meas Invalid
4494	70	RTD2	14	S8 Meas Ok
4495	70	RTD2	15	S8 Meas Invalid

Event Number	Event channel	Event block name	Event Code	Description
4496	70	RTD2	16	S9 Meas Ok
4497	70	RTD2	17	S9 Meas Invalid
4498	70	RTD2	18	S10 Meas Ok
4499	70	RTD2	19	S10 Meas Invalid
4500	70	RTD2	20	S11 Meas Ok
4501	70	RTD2	21	S11 Meas Invalid
4502	70	RTD2	22	S12 Meas Ok
4503	70	RTD2	23	S12 Meas Invalid
4504	70	RTD2	24	S13 Meas Ok
4505	70	RTD2	25	S13 Meas Invalid
4506	70	RTD2	26	S14 Meas Ok
4507	70	RTD2	27	S14 Meas Invalid
4508	70	RTD2	28	S15 Meas Ok
4509	70	RTD2	29	S15 Meas Invalid
4510	70	RTD2	30	S16 Meas Ok
4511	70	RTD2	31	S16 Meas Invalid

3.10.4 Transformer differential Idb> Idi> I0dhv> I0dLv> (87T,87N)

Transformer differential function (DIF) is used for power transformer protection for two winding transformers and in some extent for three winding and two winding transformers with double outputs with summing application.

Power transformers are seen in the electric power generation, transmission, distribution and also applications network in wide range considering of the power, voltage levels and usage purposes. Most common use for transformer is as the name implies transform alternating voltage from one voltage level to another. Common for all transformers is that they are crucial and one most important single component in the network, because in many cases its failure will be seen in wide area. While transformers do not have many moving parts (except tap changers), their electric and mechanical properties are far from being simple.

Normal practice for transformer protection application design considers the usage of the transformer as well as the power level transformed since the economical aspect comes more significant when the transformer size increases. This means that the price of protection applied should be in line of the cost of the transformer. For example, there is no point to install high level multifunction transformer IED into few kVA distribution transformer which is feeding few farms in a rural area network as well as it is even more pointless to leave few hundred MVA transmission transformer feeding entire cities protected only with fuses.

When designing transformer protection, it should be considered which protection elements are necessary to apply sufficient and “good enough” protection. Following table gives a rough idea about protection methods and elements, which should be considered for each type of transformer, e.g. protection design below these mentioned suggestions increase risk of having costly problems with transformer.

Transformer	**Risks**	**Protection**
Pole mount < 100 kVA transformer	Mostly environmental, highest risk is lightning hit to overhead line. If broken, changing to new in hours is possible. Relatively cheap.	Feeder overcurrent and earth fault protection, no separate protection devices normally are applied.

Transformer	Risks	Protection
Distribution		
< 500 kVA transformer in industrial use, installation indoors. Distribution, applications.	Overloading biggest risk, possibly cooling if environmental conditions are difficult. If broken, changing to new in hours is possible. Possible fault extension to other parts of the network or to building should be reduced. Relatively cheap.	Feeder overcurrent and earth fault protection, fuses to limit the possible short circuit current.
>500 kVA <2 MVA Distribution, applications, motors, small generators.	Overload, overvoltage, transients, cooling. If broken changing to new is a bigger problem. Not so cheap, fixing could be considered if fault occurs. Monitoring is important due to most probably failure causes more costly problem than the monitor.	Overcurrent and earth fault protection. Fuses could be considered for short circuit current. Dedicated pressure guard (Buchholz gas relay), overload protection with winding temperature monitors. If transformer is oil insulated then oil level monitor should be applied.
>2MVA <100 MVA Distribution, generation, sub transmission <130 kV.	Overload, overvoltage, transients, cooling, environmental. If broken changing to new is bigger problem, normally off-line time long and replacement difficult. Relatively expensive, wide area effect if fails no matter where installed, in transmission, distribution or generation. Monitoring very important as well as fast fault clearing and limiting the transformer internal fault time.	Differential overcurrent and earth fault protection, back-up overcurrent and earth fault protection. Tap changer protection, Dedicated pressure guard (Buchholz gas relay), overload protection with numerical and winding temperature monitors. If transformer is oil insulated then oil level monitor should be applied. Monitoring of loading and oil ageing estimations. If transformer has forced cooling, monitor and protection for cooling systems should be applied. Protections and monitoring to multifunction relay and back-up, overcurrent –earthfault to dedicated relays.
>100 MVA Transmission > 130 kV	Overload, overvoltage, transients, cooling, environmental. If broken changing to new is bigger problem, normally off-line time long and replacement difficult. Extremely expensive, wide area effect if fails no matter where installed, in transmission, distribution or generation. Monitoring very important as well as fast fault clearing and limiting the transformer internal fault time.	Redundant differential overcurrent and earth fault protection, redundant back-up overcurrent and earth fault protection. Tap changer protection, Dedicated pressure guard (Buchholz gas relay), overload protection with numerical and redundant winding temperature monitors. Oil level monitor should be applied. Monitoring of loading and oil ageing estimations. If transformer has forced cooling, monitor and protection for cooling systems. Separated control, monitoring and protection relays.

Transformer faults are many, to mention few most likely causes to faults are dirty, watered or old transformer oil, oil leaking from the tank, prolonged and multiple heavy overloading and faults in cooling systems. These reasons can cause transformer windings earth faults, interturn faults or even phase to phase faults.

Why differential protection is needed in transformer protection?

Transformer differential function is based into calculation of ingoing and outgoing current difference, e.g. in normal operating status of the transformer the power which goes in must come out as well. If this is not the case, transformer has an internal fault which should be de-energized as soon as possible to avoid extensive damage to the transformer. Mostly can be said that if differential function operates the transformer which is faulty is going to be offline for a long time, if the fault is de-energized fast that can still save a lot of money since in most cases the transformer can be still repaired, and the cost is significantly lower than buying a new transformer. Exceptions to this are faults which occur in the differential protection zone but outside of the transformer like in the bus or cables connected into the transformer. Faults of this type are easily repaired, and the transformer can be energized quickly after the fault is cleared.

If transformer should be considered to be protected only with conventional overcurrent and earth-fault protection, operating time should be set to delayed tripping characteristics coordinated to the low voltage side relays due to the fact that transformer normal condition energizing and short circuit supply to high/low voltage side shall be directly seen on both sides of the transformer and overcurrent in instant operation would cause timing coordination problems or sensitivity problems if the instant protection should be set on high current starting criteria. This is not considered a big problem in smaller transformers in which the installation and maintenance of differential protection is considered more expensive than possibly not full coverage of protection.

Also, differential protection is very sensitive and internally scaled to the loading/fault current flowing through the transformer. When considering interturn faults in the transformer windings, overcurrent relay not necessarily even pick up for the fault which could have been already tripped with differential relay in first power cycle. Same goes for the transformer internal earth faults which with conventional earth fault protection in some cases are impossible to be noticed before the fault evolves so that it will cause heavier fault currents e.g. in cases where the fault location is close to the neutral inside the star winding.

These are the main arguments for using differential protection, sensitive and fast operation in internal in-zone faults and high stability on the out zone faults guarantee minimum unwanted power outages and minimized and reduced damage to the transformer itself.

On the other hand, differential protections negative properties are that it is not the easiest to set up to operate correctly and second set of current transformers are required thus increasing the installation cost. In bigger scale power transformers this still is marginal cost.

In following chapter, the principles of the transformer and how to set the differential protection correctly for an example application are presented.

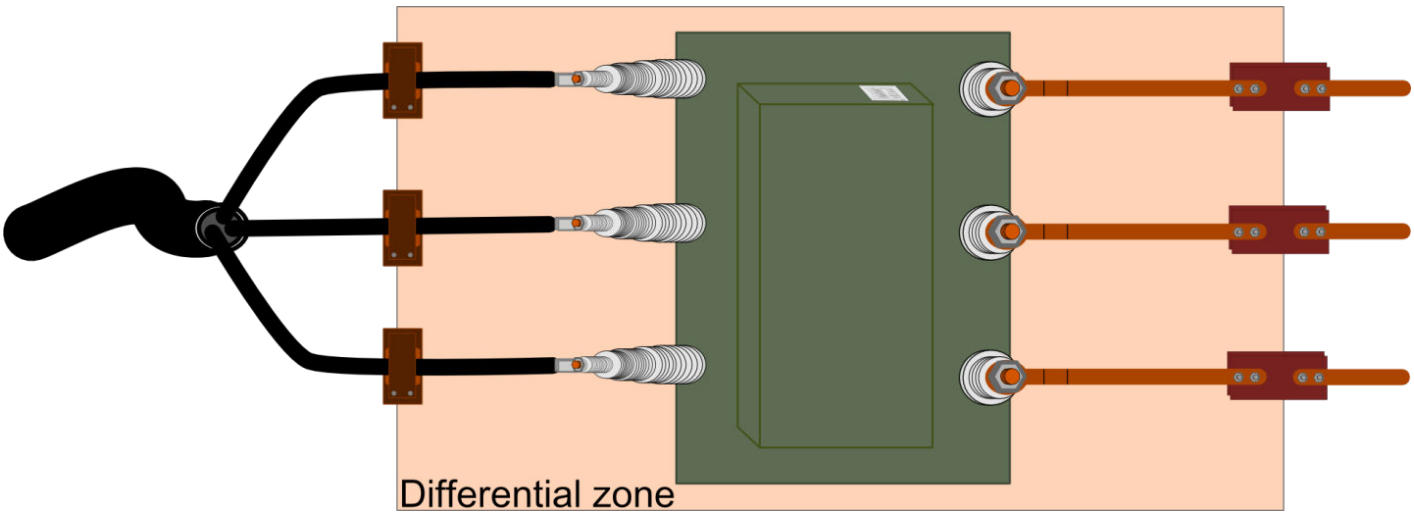
Transformer properties and basic concepts for differential protection

To set correct differential protection parameters at least transformer nominal data needs to be known. At least this data should be known:

- Transformer nominal power
- HV and LV side nominal voltages
- Transformer special properties like tap changer and auxiliary windings
- Transformer vector group (for matching the transformer per unitized vectors)
- HV and LV side current transformer ratios and properties.

In this chapter the setting and principle of transformer differential protection are shown step by step.

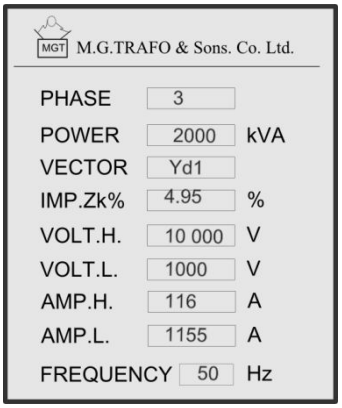
Figure 3.163 Transformer and its components forming the “differential zone”.



First let’s define the area we are working in is the area in between the CTs. This is called the “differential zone” which means that the currents going inside from another side must come out from the other side. It doesn’t matter if the signal is scaled either higher or lower or its phase angle is shifted, both side currents have to match. Otherwise there is problem within the protected zone which either blocks or keeps the current inside the zone.

Following example shows a typical minimum information from the transformer name plate data and what to do with it.

Figure 3.164 Transformer name-plate data.



According to name plate data this transformer is designed for three phase usage and it has two windings. Nominal design power of the transformer is 2 MVA and its vector group is Yd1 which means that the HV side is connected to star and LV side to delta so that the LV side has 30 degree lag to HV side. Also the HV side nominal voltage is 10 kV and LV side nominal voltage is 1kV. Transformer short circuit impedance is 4.95% which comes from the transformer final test and basically it presents how much the transformer shall be able to feed short circuit current. This information is normally available in the transformer name plate and documentation. If the transformer has a tap changer its information is normally also available in name plate data.

Nominal current matching is first thing to consider in the differential protection. Normally modern numerical protection relay can calculate these factors by itself when the transformer nominal power and voltage levels are known. However below are the formulas to calculate the amplitude matching coefficients.

Let’s say that in this example HV side CTs are 150/5A and LV side CTs are 1200/5A

Primary side per unit factor and current calculation

$$In_{HV} = \frac{Sn}{\sqrt{3} \times U_{HV}} = \frac{2000000VA}{\sqrt{3} \times 10000V} = 115.47\ A$$

$$IpuPRI_{HV} = \frac{In_{HV}}{CTpri_{HV}} = \frac{115.47A}{150\ A} = 0.77$$

$$IpuSEC_{HV} = IpuPRI_{HV} \times CTsec_{HV} = 0.77 \times 5A = 3.85\ A$$

Secondary side per unit factor and current calculation

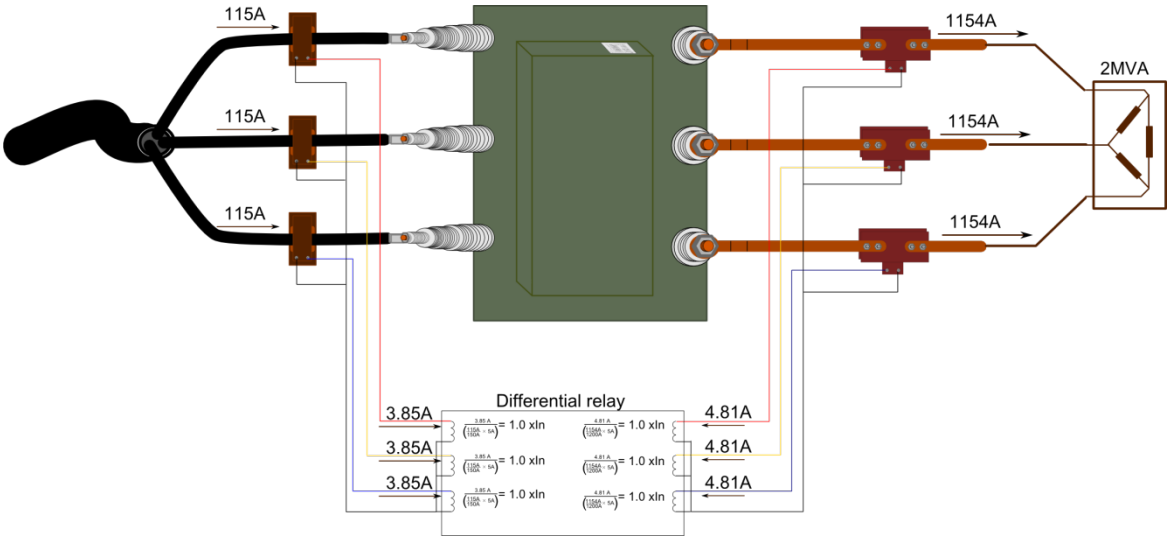
$$In_{LV} = \frac{Sn}{\sqrt{3} \times U_{LV}} = \frac{2000000VA}{\sqrt{3} \times 1000V} = 1154.7\ A$$

$$IpuPRI_{LV} = \frac{In_{LV}}{CTpri_{LV}} = \frac{1154.7A}{1200\ A} = 0.96$$

$$IpuSEC_{LV} = IpuPRI_{LV} \times CTsec_{LV} = 0.96 \times 5A = 4.81\ A$$

So now what this means is that if the transformer outputs power of 2 MVA through it the HV side CT secondary current will be 3.85A and LV side CT secondary current will be 4.81A. Differential function uses these values for per unitizing the measured currents so that in this case the HV side measurement will show 1.0 xIn and LV side measurement will show 1.0 xIn as well even the measured currents are different. This is called amplitude matching of HV and LV sides. In modern differential relay this is done automatically by setting the transformer nominal values and CT ratings so these calculations are not needed to be applied by used. This is just for informational purpose that where these values come from.

Figure 3.165 Amplitude scaling to match the nominal currents and CTs in the differential relay.

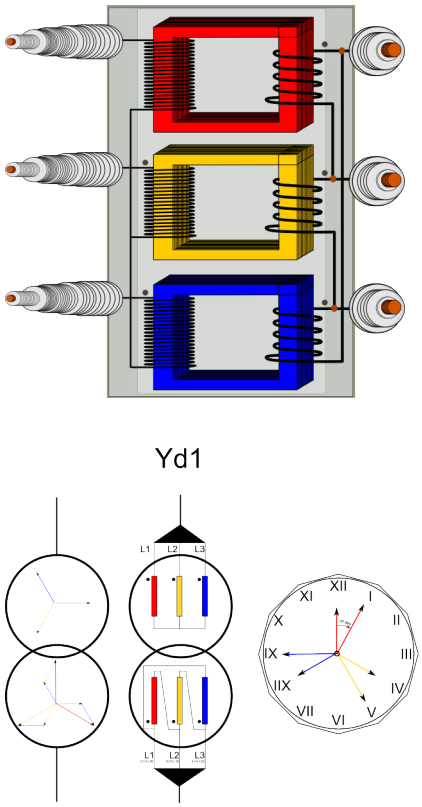


Nominal current matching is only part of the differential protection settings. Also the vector group of the transformer is important, since differential function is interested in the angle difference of the measured current vectors. In this example the transformer vector group is Yd1 which means that inside the transformer its HV side is connected to star and low voltage side is connected to delta so that the LV side is in 30 degree lag to HV side vectors.

The number “1” comes from the angle between the HV and LV side phase current difference. If imagined so that the HV side current is put on normal clock into “noon” position 12 o clock, the LV side shows to clock number “1”. Equally “11” means that the LV side is leading 30 degrees, “5” and “7” are just the other ends of the windings thus causing 180 degree difference into these “1” and “11” clock numbers.

In this example case the transformer current vectors and the transformer connection looks like in the following figure.

Figure 3.166 Yd1 transformer internal connection in principle.



In modern relays these standard vector groups (wye, delta, lead or lag) are defined by a setting selection and there is no need for interposing transformers. If the transformer vector group is not standard it should still be settable within the relay (in case of zigzag transformers).

In this case in differential relay the differential function applies following translation to delta side currents (note that the correction is not only to the angles but also to the amplitudes since the per unitized delta side has relation amplitude difference to star connected side)

$$\overline{IL1DS_{LV}} = \frac{(\overline{IL1_{LV}} - \overline{IL2_{LV}})}{\sqrt{3}}$$

$$\overline{IL2DS_{LV}} = \frac{(\overline{IL2_{LV}} - \overline{IL3_{LV}})}{\sqrt{3}}$$

$$\overline{IL3DS_{LV}} = \frac{(\overline{IL3_{LV}} - \overline{IL1_{LV}})}{\sqrt{3}}$$

This is the so called vector group matching for the per-unitized currents of the transformer. This matching is necessary when either of the transformer side is connected to delta but another is connected to star. In non numeric relays this matching was done with interposing CTs which were connected in the power transformer star side to delta and delta side to star to get the HV and LV side vectors matching each other. When these got currents were summed in the relay inputs HV and LV side currents negate each other when there is no difference thus not causing trip. If the currents would have difference then current should flow to relay input and if there is enough difference it would cause pick-up and trip. This is not the case with modern differential relay, which does this transformation by calculating internally the corrected vectors.

Figure 3.167 Expected phase shifts from HV side to LV side in symmetrical situation.

		Phase angles HV side			Phase angles LV side		
	Shift(deg)	IL1	IL2	IL3	IL1"	IL2"	IL3"
Yy0, Yyn0, YNy0, Dd0	0	0	240	120	0	240	120
Yy6,Yyn6, YNy6, YNyn6, Dd6	180	0	240	120	180	60	300
Yd1, YNd1, Dy1, Dyn1	-30	0	240	120	330	210	90
Yd11, YNd11, Dy11, Dyn11	30	0	240	120	30	270	150
Yd5, YNd5, Dy5, Dyn5	-150	0	240	120	210	90	330
Yd7, YNd7, Dy7, Dyn7	150	0	240	120	150	30	270

Now the direction of the CTs starpoint on the HV side and LV side has effect on how to set the differential calculation method. It is possible to set either “add” or to “subtract” which means that the CTs “current direction” has to be taken into account. Now in this example the correct setting would be “add” since the CTs in the main circuit are connected to opposite each other “the starpoints / groundings are “opposite” thus the measured currents from the CTs are opposite to each other. Now this is again up to the user which way the signals are wanted to be shown, it is possible also to negate the CTs currents when the “subtract” mode can be used for differential calculation and the both sides measurements could be shown as one star connected vector diagram.

As mentioned now the differential algorithm itself, it has calculating formula per each phase difference:

Subtracting formula:

$$L1DIFF_{Subt} = |\overline{IL1_{HV}} - \overline{IL1_{LV}}|$$

$$L2DIFF_{Subt} = |\overline{IL2_{HV}} - \overline{IL2_{LV}}|$$

$$L3DIFF_{Subt} = |\overline{IL3_{HV}} - \overline{IL3_{LV}}|$$

Or Additive formula:

$$L1DIFF_{Add} = |\overline{IL1_{HV}} + \overline{IL1_{LV}}|$$

$$L2DIFF_{Add} = |\overline{IL2_{HV}} + \overline{IL2_{LV}}|$$

$$L3DIFF_{Add} = |\overline{IL3_{HV}} + \overline{IL3_{LV}}|$$

Can be selected based into the CTs connections.

Figure 3.168 If current transformer starpoints are pointing towards each other or away from each other, “Add” differential calculation mode is used.

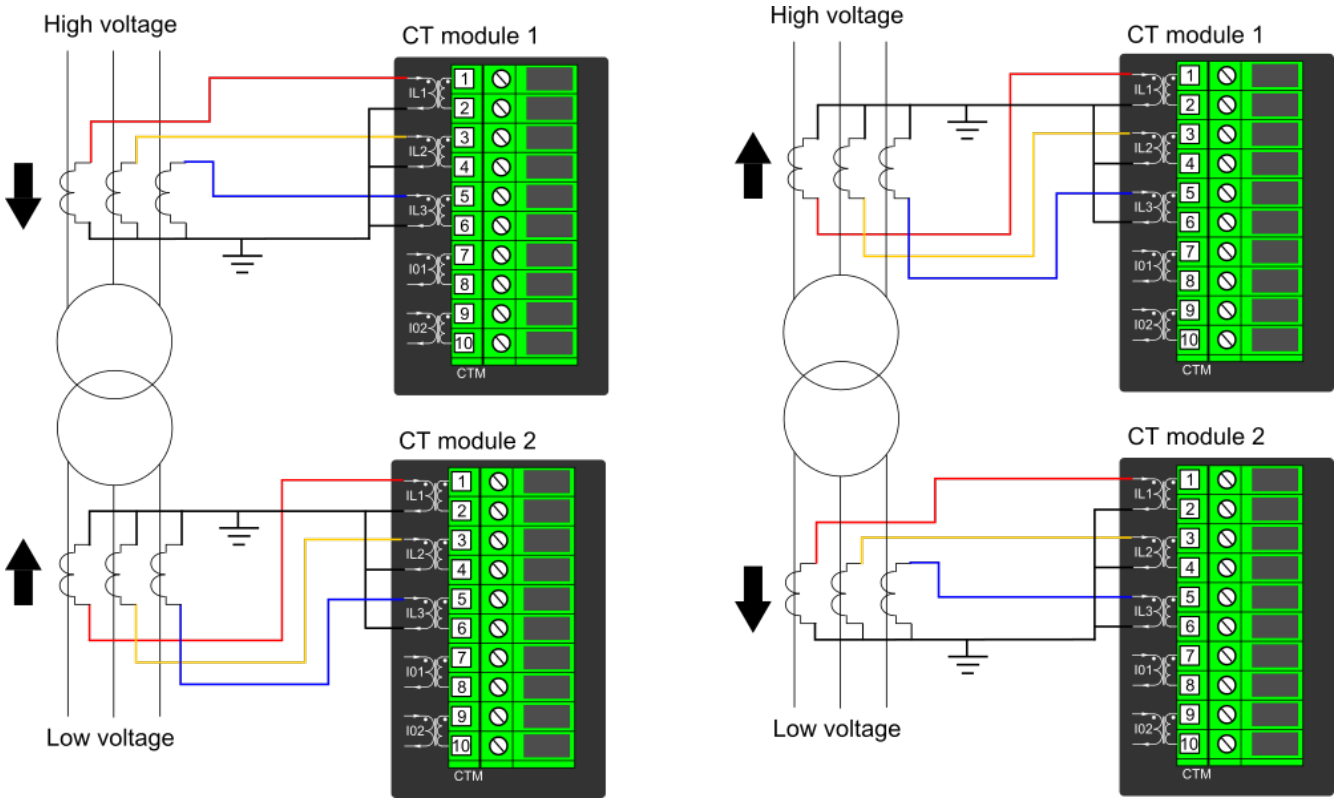
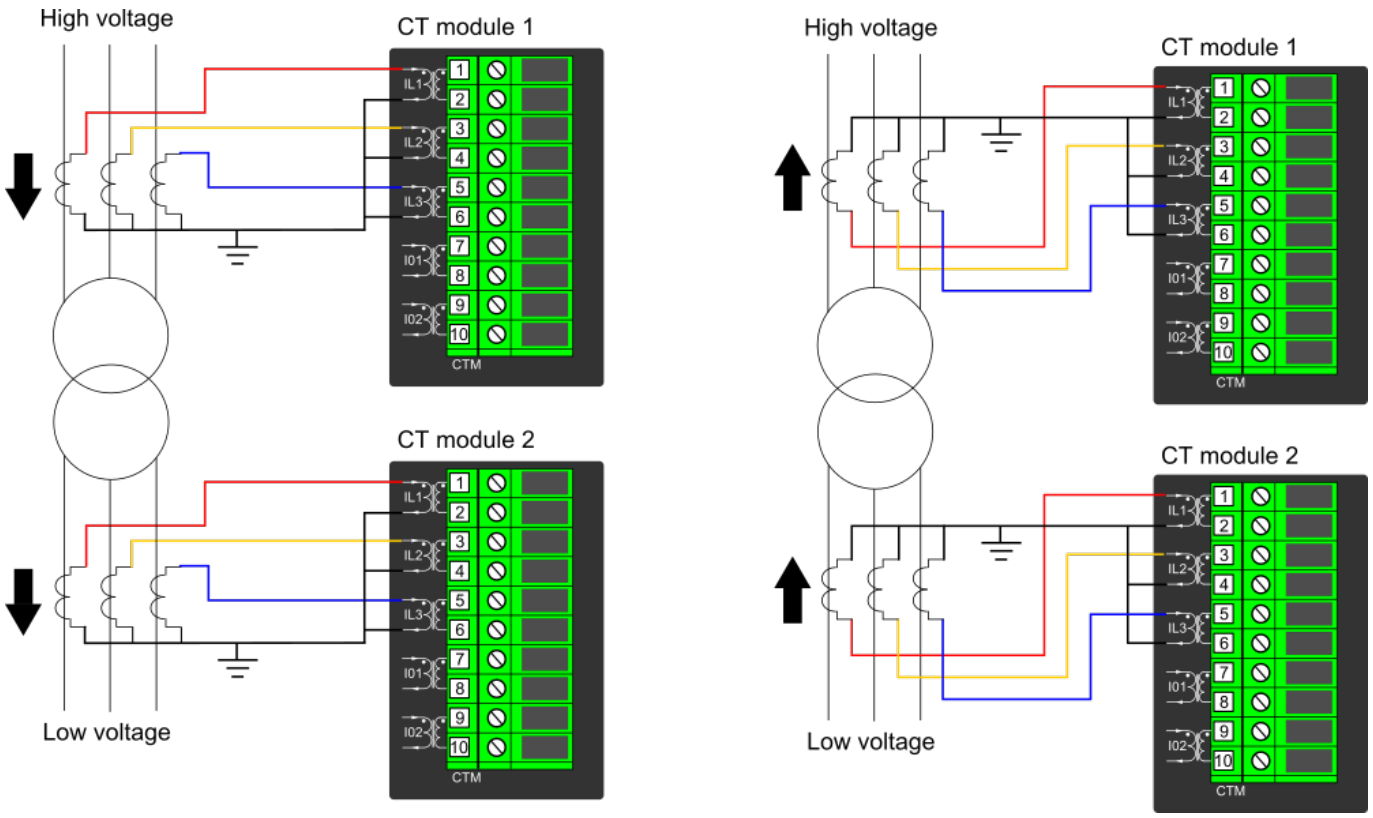


Figure 3.169 If current transformer starpoints are pointing towards the same direction, “Subtract” differential calculation mode is used.



Differential function has 2 separate stages inbuilt which of the non restraint uses only these formulas as comparison base. For the restraint characteristics also so called “Bias” calculation is made per each phase to adjust the sensitivity of the differential stage up to the measured currents.

For the bias calculation also two separate formulas are available.

Average mode (sensitive biasing):

$$L1BIAS_{AVG} = \frac{|IL1_{HV}| + |IL1_{LV}|}{2}$$

$$L2BIAS_{AVG} = \frac{|IL2_{HV}| + |IL2_{LV}|}{2}$$

$$L3BIAS_{AVG} = \frac{|IL3_{HV}| + |IL3_{LV}|}{2}$$

Max mode (coarse biasing):

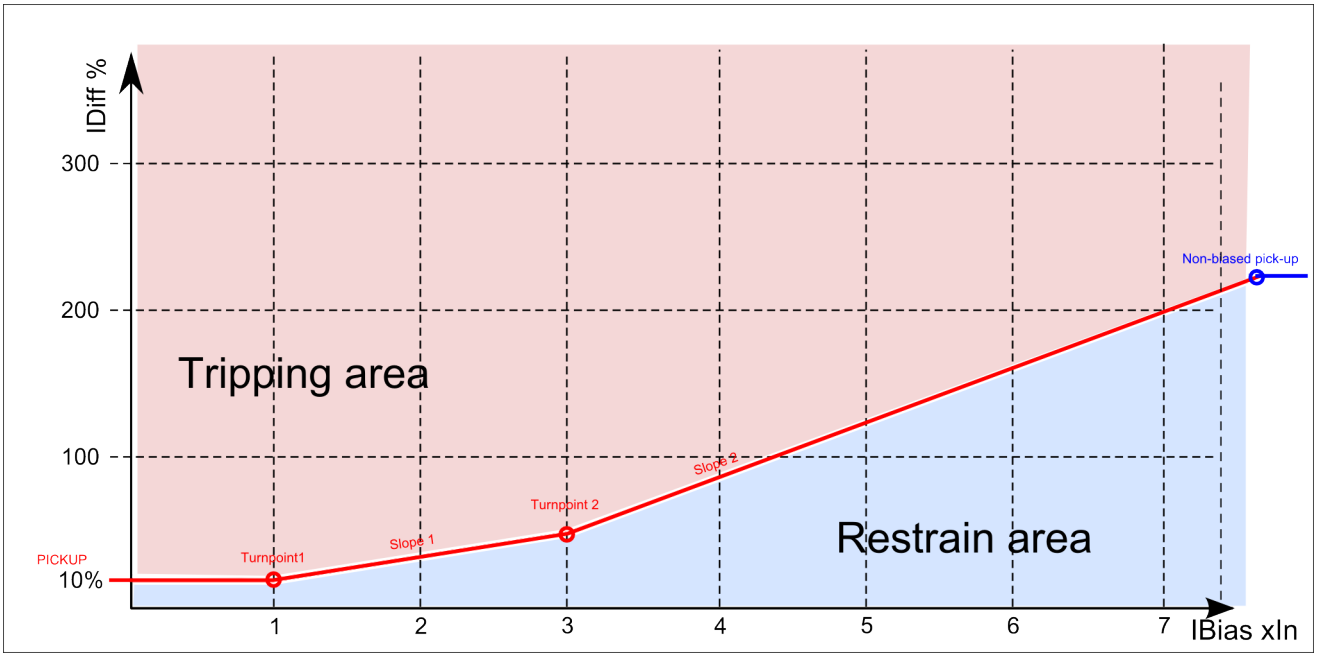
$$L1BIAS_{MAX} = \max\left(|\mathrm{IL1_{HV}}|, |\mathrm{IL1_{LV}}|\right)$$

$$L2BIAS_{MAX} = \max\left(|\mathrm{IL2_{HV}}|, |\mathrm{IL2_{LV}}|\right)$$

$$L3BIAS_{MAX} = \max\left(|\mathrm{IL3_{HV}}|, |\mathrm{IL3_{LV}}|\right)$$

Now these two mentioned formulas are combined in a way so that the y axle presents the differential current measured and the x axle present the bias current calculated.

Figure 3.170 Differential function characteristic, biased and non-biased.



In the characteristics the red line presents the allowed differential current in percentage in function of measured biasing current of the differential protection. In this example the non-biased pick-up is set to quite low what it would be in normal transformer application. Settings and ranges of the differential protection are presented in the settings chapter.

The biasing characteristic is formed with following formulas:

$$Diff_{Bias<TP1} = I_{d>Pick-up}$$

$$Diff_{Bias\,TP1...TP2} = SL1 \times (Ix - TP1) + I_{d>Pick-up}$$

$$Diff_{Bias>TP2} = SL2 \times (Ix - TP2) + SL1 \times (TP2 - TP1) + I_{d>Pick-up}$$

,thus forming a straight line from zero current to TP1 (Turn point 1). From there to TP2 (Turn point 2) is the first slope which causes the set biasing to be coarser when the measured current amplitude increases. When measured current is higher than TP2 set value, slope 2 is used.

Differential characteristics settings

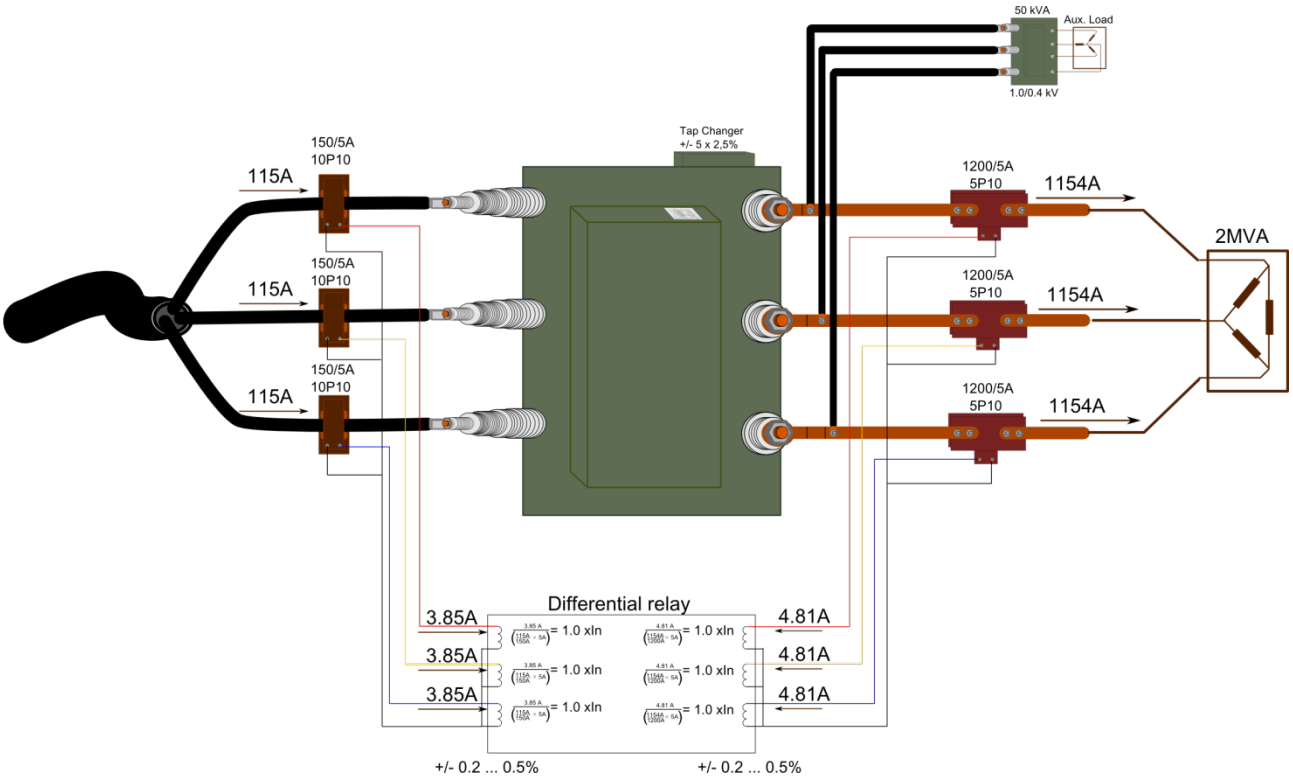
To set the characteristics for the transformer application first needs to be known what these parts of the characteristics mean.

First part is the $Diff_{bias<TP1} = I_{d>pick-up}$

the first straight line which represents the transformer normal operation created differential current. This part takes into account measurement errors, transformer possible tap changer (load side) caused current variation, and possible other application caused reasons for different load inside the protected differential zone. In differential relay this is known as pick-up current $I_{d>pick-up}$, a basic sensitivity limit which below measured differential current the transformer still operates normally and the differential protection should not activate. In other words $I_{d>pick-up}$ must be higher than all these differential current causing normal operation factors combined.

When calculating the basic normal situation differential current, following image illustrated parts should be considered. These transformer components errors need to be taken into account.

Figure 3.171 Natural differential current sources.



Differential current sources in normal operation:

- Primary side CT measurement accuracy (CTE pri)
- Secondary side CT measurement accuracy (CTE sec)
- Relay measurement accuracy (primary and secondary) (REm)
- Tap changer on load side (TCE)
- Possible auxiliary transformer or auxiliary winding, which currents are not measured separately (AUTE)
- Transformer core magnetizing current (TME)
- Safety margin (SME)

Now how to get the base sensitivity setting limit , errors have to be calculated part by part.

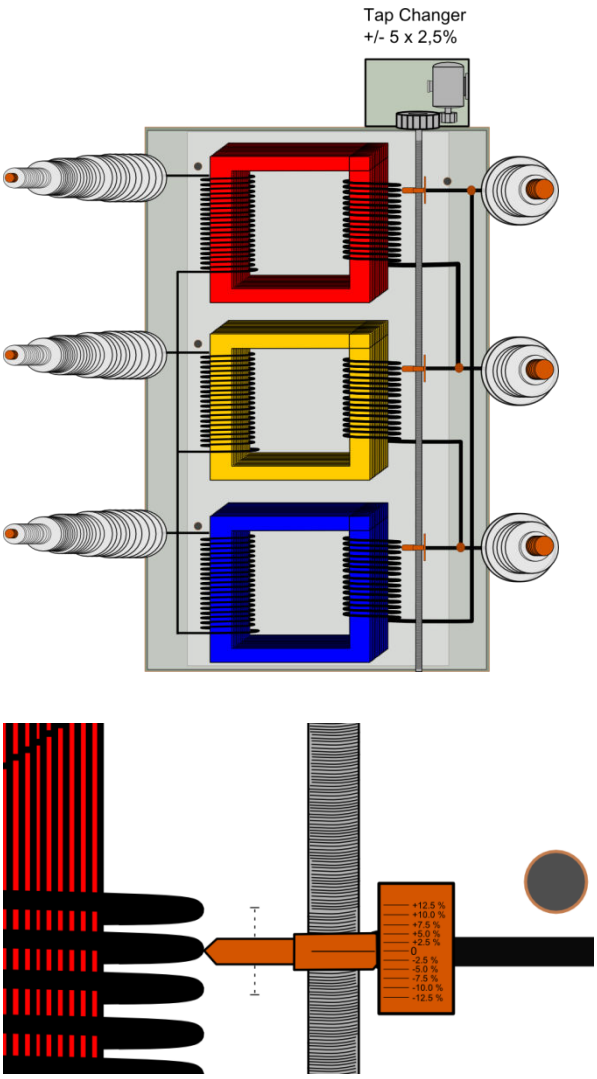
CTEpri: In this example case primary side CT:s are class 10P which means 10% of measurement error.

CTEsec: In this example case secondary side CT:s are class 5P which means 5% of measurement error.

REm: Relay measurement error is below 0.5% and with optional accuracy below 0.2% per measurement channel, so this value for both sides combined is either 1% or 0.4%.

TCE: In this example transformer there is tap changer with rating of +/- 5 x 2.5% which means that from nominal center position the secondary side windings can be set to + 5 x 2.5% or -5 x 2.5% position causing deviation max of 5 x 2.5% from the nominal conditions. So therefore TCE is in this case 12.5%. (Note that the tap position is not always necessarily nominal in center position, check from your application and calculate the maximum effect to worst side border).

Figure 3.172 Transformer tap changer



Generally tap changer means that the transformer transformation ratio can be adjusted in order to receive nominal voltage more accurately to the secondary side of the transformer. Reasons for voltage variations may be many for example heavy or light loading in the high voltage side. In practice this means that if more or less voltage is needed in the secondary side, more or less winding rounds in secondary side are utilized. This causes difference into the nominal current condition which can be noticed as differential current in the relay. Normally tap changer positions are presented as deviation steps of secondary voltage per step into + and – direction from the center which gives nominal output voltage.

AUTE: In this example there is 50kVA auxiliary transformer connected to the LV side output before the CTs so it has to be taken into account for the differential base sensitivity calculations. Same goes if in the transformer itself is found auxiliary power output and its currents are not measured.

To calculate auxiliary power output effect, calculate the percentage of auxiliary transformer/winding VA to transformer nominal VA.

$$AUTE = \frac{AUXVA}{NOMVA} \times 100\% = \frac{50000VA}{2000000VA} \times 100\% = 2.5\,\%$$

This represents the case when the auxiliary load is in nominal.

TME: Transformer magnetizing current is the current which flows in the primary winding. Since it is running only in the primary side this needs to be taken into account of the settings calculation. Magnetizing current value approximate can be calculated as follows:

$$I_{TM} = \frac{U_{PRI}}{j\omega L_P}$$

This is the case if the primary inductance is known. Magnetizing current is compared to HV side nominal current and the percentage is directly the TME value. If the transformers primary inductance is not known then can be used conservative estimate of 3% for the transformer magnetizing effect.

SME: For conservative settings up to 5% safety margin is used typically.

Now we have all necessary data to calculate naturally generated differential current based into the errors and possible variables known. Firstly the maximum uncertainty needs to be calculated from the varying magnitudes known inside the transformer. In this case there is tap changer which affects internal currents and its effect cannot be estimated on-line reliably because it may change any time. For this reason the currents maximum uncertainty has to be calculated. If there is no tap changer available just by summing the maximum inaccuracy of the HV and LV side CT is sufficient enough. Let's call the measurement uncertainty as $IMEAS_{UNC}$.

$$IMEAS_{UNC} = \frac{Absolute\ uncertainty}{Absolute\ measurement} \times 100$$

Now when looking at how to fill the formula, it is needed to sum in the absolute maximum uncertainty of the CT errors, tap changer maximum error and also the combined error of the secondary CT and tap changer maximum error. On the absolute measurement affecting factor is known the expected value as 1 xIn as well as it is correct that the tap changer is in maximum position thus causing the absolute measurement to be 1 xIn + TCE

$$IMEAS_{UNC} = \frac{\mathrm{CTEpri} + \mathrm{CTEsec} + \mathrm{TCE} + \mathrm{CTEsec} \times \mathrm{TCE}}{1 + TCE} \times 100$$

With our example configuration the calculation would be:

$$IMEAS_{UNC} = \frac{0.1 + 0.05 + 0.125 + (0.05 \times 0.125)}{1 + 0.125} \times 100 = 25\%$$

Now this value presents the transformer properties maximum caused differential current to nominal. Other uncertainties known now may be added to this got value and after this operation can be said that:

$$I_{db>Pick-up} > IMEAS_{UNC} + 2 \times REm + AUTE + TME \rightarrow 25\% + 2 \times 0.5\% + 2.5\% + 3\% = 31\%$$

This means that in worst case this differential current will flow while the operation is still normal in the transformer. Therefore normally this got combined result is increased with safety marginal to ensure stabile operation of the differential protection and to negate possible calculation errors.

With these values following base sensitivity (e.g. the minimum setting for the differential current required to operate the relay), is given for the differential protection characteristics:

$$I_{db>Pick-up} = \left(\frac{\mathrm{CTEpri} + \mathrm{CTEsec} + \mathrm{TCE} + \mathrm{CTEsec} \times \mathrm{TCE}}{1 + TCE} \times 100\right) + 2 \times REm + AUTE + TME + \mathrm{SME} = 36\%$$

Now this basic sensitivity is taking account the starting situation with no load to Turnpoint 1 in the characteristics. Next thing is to decide where to set the Turnpoint 1. In most of differential relays this point is either fixed or automatically defined based on base sensitivity and slope 1. In this IED type differential relay it is settable. For high sensitivity it may be set to 1 xIn since the calculated base sensitivity takes into account already the tap changer effect and all of the other normal operating caused differential current sources.

For coarse settings this Turnpoint 1 can be set to for example 0.5xIn or even 0.01xIn. How to determine this limit is the sum of the protection principle wanted. Smaller value leads to conservative and stabile operation, while bigger means highly sensitive and possibly unstable protection.

Also there if Turnpoint 1 is set to 0.01xIn, the Slope 1 will start directly from the setting. In such case there is no unbiased sensitive section available. This could be used in case when the tap changer effect is not wanted to be taken into account for basic sensitivity and the effect is wanted to be taken into account in the first slope directly. This can lead to optimal sensitivity and stabile settings for differential relay even there is no non biased sensitive section in the characteristics.

In this case the base sensitivity setting should be set as follows:

$$I_{db>Pick-up} = \mathrm{CTEpri} + \mathrm{CTEsec} + 2 \times REm + AUTE + TME + \mathrm{SME}$$

$$I_{db>Pick-up} = 10\% + 5\% + 2 \times 0.5\% + 2.5\% + 3\% + 5\% = 26\%$$

Now the Slope 1 settings, this part presents the relay restraint characteristics over the load current range of the transformer. This slope should be effective up to the maximum possible loading of the transformer. Normally for power transformer this value should be about 1.0 – 2.0xIn (for large power transformers) when typical value would be 1.5xIn. The functionality purpose is to compensate measurement errors caused by relative high current with the tap changer effect included. Slope 1 is calculated by using the transformer and CT nominal values in the maximum full load (Turnpoint 2) of the transformer with highest possible differential current causing tap position. Generally Slope 1 setting is calculated as below:

$$Slope\ 1 = \frac{Idiff\ TP2}{Ibias\ TP2} \times 100\%$$

Now the calculation of the maximum differential current in the Turnpoint 2 includes before calculated correction factors for HV and LV side CTs.

$$IpuPRI_{HV} = \frac{In_{HV}}{CTpri_{HV}} = \frac{115.47A}{150\ A} = 0.77$$

$$IpuPRI_{LV} = \frac{In_{LV}}{CTpri_{LV}} = \frac{1154.7A}{1200\ A} = 0.96$$

Also is needed the corrected transformation ratio effect due to the tap changer position on maximum voltage position (usually this generates the highest differential current).

$$TR_{CORR} = \frac{U_{HV_VOLTSMIN}}{U_{HV}} \times \left(\frac{U_{HV}}{U_{LV}}\right)$$

Now to get the HV volts minimum means that the calculation needs to be applied on situation when the tap changer on secondary side is at maximum output voltage and the output is nominal. In this example we had maximum of +12.5% increasing effect for the tap changer, and the result will be:

$$TR_{CORR} = \frac{U_{HV_VOLTSMIN}}{U_{HV}} \times \left(\frac{U_{HV}}{U_{LV}}\right)$$

Next is calculated the currents flowing in this situation at HV and LV sides, when the loading of the transformer is e.g. 1.5 times its rated power.

For LV side currents will be

$$I_{LV} = \frac{\left(\frac{I_{NLV} \times 1.5}{\left(\frac{CT_{LVPRI}}{CT_{LVSEC}}\right)}\right)}{CT_{LVSEC} \times IpuPRI_{LV}} = \frac{\left(\frac{1154.7A \times 1.5}{\left(\frac{1200A}{5A}\right)}\right)}{5A \times 0.96} = 1.5xIn$$

And for HV side currents will be

$$I_{HV} = \frac{\left(\frac{\left(\frac{I_{NLV} \times 1.5}{TR_{CORR}}\right)}{\left(\frac{CT_{HVPRI}}{CT_{HVSEC}}\right)}\right)}{CT_{HVSEC} \times IpuPRI_{HV}} = \frac{\left(\frac{\left(\frac{1154.7A \times 1.5}{8.75}\right)}{\left(\frac{150A}{5A}\right)}\right)}{5A \times 0.77} = 1.7xIn$$

By calculating this way these currents now present the worst possible case caused by tap changer effect into the differential relay measured currents.

Now there is two possible ways to use biasing calculation and in practice one way to calculate differential current (even there are add and subtract modes, the effect will be the same since the differential current shall basically always be calculated as:

$$|I_{HV} - I_{LV}|$$

, thus giving the absolute difference in measured currents, add and subtract just compensate differently connected CTs when the starpoint is either towards to transformer or away from it)

When more sensitive settings are wanted “Average” mode is selected

$$LxBIAS_{AVG} = \frac{|ILx_{HV}| + |ILx_{LV}|}{2}$$

If more stabile settings are wanted “Maximum” mode is selected:

$$LxBIAS_{MAX} = \max\left(|\mathrm{ILx_{HV}}|, |\mathrm{ILx_{LV}}|\right)$$

With “Average” mode selected the slope is calculated as follows:

$$Slope\ 1 = \frac{Idiff\ TP2}{LxBIAS_{AVG}} \times 100\% = \frac{|I_{LV} - I_{HV}|}{\left(\frac{I_{LV} + I_{HV}}{2}\right)} \times 100\% = \frac{1.5 - 1.7}{\left(\frac{1.5 + 1.7}{2}\right)} \times 100\% = 12.5\%$$

With “Maximum” mode selected the slope is calculated as follows:

$$Slope\ 1 = \frac{Idiff\ TP2}{LxBIAS_{max}} \times 100\% = \frac{|I_{LV} - I_{HV}|}{\max\left(\lfloor I_{LV} \rfloor, \lfloor I_{HV} \rfloor\right)} \times 100\% = \frac{1.5 - 1.7}{1.7} \times 100\% = 11.7\%$$

Now to be on safe side for this may be added yet another safety margin if so wished (even the base sensitivity settings include 5% already) to ensure stability.

One setting is still missing and it is the Slope 2. This setting is used for biasing the differential characteristics against heavy outside of differential zone faults which can cause heavy saturation on one or both sides (LV,HV) CTs causing heavy differential current in to measurements even the transformer itself does not have fault. There is one catch in the settings.

If there is heavy single end in zone fault thus causing the biasing current also to increase, this value should not be “up to max” since it may mean that the biasing blocks the differential characteristics so that the trip will not be applicable even there is in zone fault on single end.

Now when thinking the possible situation when feeding is from HV side and the differential current is directly the fault feeding end current following can be noted for the Slope 2 setting.

If in case of using “Average” mode for biasing (in case of single end fault) the bias current will be

$$LxBIAS_{AVG} = \frac{|ILx_{HV}|+|0|}{2}$$

, and the differential current will be directly

$$|ILx_{HV}|$$

$$Slope\ 2 = \frac{|ILx_{HV}|}{\frac{|ILx_{HV}|}{2}} \times 100\% = \frac{|1|}{\left(\frac{1}{2}\right)} \times 100\% = 200\%$$

and in case of using “Maximum” mode for biasing (in case of single end fault) the bias current will be same than the differential current so Slope 2 shall be calculated as:

$$Slope\ 2 = \frac{|ILx_{HV}|}{|ILx_{HV}|} \times 100\% = \frac{|1|}{|1|} \times 100\% = 100\%$$

Now the biased characteristic is set. Next should consider settings for the non biased/non restraint stage $I_{di>Pick\text{-}up}$.

The purpose of this stage is to ensure fast and also selective tripping of faults inside differential zone, yet stabile operation on heavy outside faults. This stage operates only on absolute differential current amount measured and is not blocked with harmonics or bias restraints.

Setting of the stage should be based into the weakest CT full saturation under worst case through fault condition (since this causes that only the other side current is measured then and that causes all seen current to be differential current).

For our example case the LV side maximum three phase short circuit current would be:

$$I_{3phSC_LV} = \frac{S_N}{\sqrt{3} \times Z_k} = \frac{S_N}{\sqrt{3} \times \left(\frac{{U_{LV}}^2}{S_N} \times \frac{Z_{k\%}}{100\%}\right)} = \frac{2000000\ VA}{\sqrt{3} \times \left(\frac{10000V^2}{2000000VA} \times \frac{4.95\%}{100\%}\right)} = 23327A$$

This current will be seen in HV side as:

$$I_{3phSC_{LV} \rightarrow HV} = \frac{I_{3phSC_LV}}{\left(\frac{U_{HV}}{U_{LV}}\right)} = \frac{23327A}{\left(\frac{10000V}{1000V}\right)} = 2332A$$

Now when looking at our example CT ratings:

HV side: 150/5A 10P10

LV side: 1200/5A 5P10

Let's calculate the secondary currents of this situation.

$$I_{HVMAX} = \frac{I_{3phSC_{LV \rightarrow HV}}}{CT_{HVPRI}} = \frac{2332A}{\frac{150A}{5A}} = 77.7A_{SEC}\ (20.18\ xIn)$$

$$I_{LVMAX} = \frac{I_{3phSC_{LV}}}{CT_{HVPRI}} = \frac{23327A}{\frac{1200A}{5A}} = 97.2A_{SEC}\ (20.2\ xIn)$$

This is now the theoretical maximum of the current flowing in the CTs when bolted symmetrical three phase fault occurs in the LV side of the transformer. As could be seen the HV side max current is about 15 times the CT rating and LV side about 19 times the CT rating, there should not be seen full saturation of the CT in neither side even the accuracy limit factor for both CTs is 10 times nominal. *(5/10P10 this last "10" tells that the CT output is in its given measurement class (5% and 10%) when the current is <10 times nominal. This however is related to the nominal burden, which is normally very high compared to modern protection relay CT input)*.

Now the next check should be into the burden of the CTs in both sides to see what the real CT accuracy limit factor is.

Important initial data for this check is the VA of the CTs on both sides, how long wiring to relay from the CTs, what is the cross-section and material of the wires and how the CTs are connected.

Let's start from the wiring caused burden for the relay.

Resistance in a conductor is calculated in following way:

$$R_{Cond} = \frac{\rho \times l}{A}, \text{where}$$

R_{Cond} = resistance of conductor in ohms
ρ = resistivity of the conductor material Ohm/meter
l = length of the wire in meters
A = conductor cross sectional area in m^2

Just for information when designing the CTs and wiring: 1. If you double the length of wire you will double the resistance of the wire. 2. If you double the cross sectional area of the wire you will cut its resistance in half. Most effect is in that if you use 1A secondary instead of 5A, all burdens will drop to level smaller to portion of $5A^2$ e.g. 1/25.

Now normally copper cables are used to connect CTs to relay, anyway in below table is presented also Aluminum resistivity and conductivity properties.

$R_{Cond} = \frac{\rho \times l}{A}$, where

R_{Cond} = resistance of conductor in ohms
ρ = resistivity of the conductor material Ohm/meter
l = length of the wire in meters
A = conductor cross sectional area in m^2

These values in this table present the resistivity in the given temperature +20°C. For calculation of the conductor resistivity in other temperatures use following formula:

Material	ρ (Ω•m) at 20 °C (68 °F, 293 K)	σ (S/m) at 20 °C	Temperature coefficient (K–1)
Copper	1.68×10^{-8}	5.96×10^{7}	0.003862
Aluminum	2.82×10^{-8}	3.5×10^{7}	0.0039

These values in this table present the resistivity in the given temperature +20°C. For calculation of the conductor resistivity in other temperatures use following formula:

Change in resistivity:

$\Delta_\rho = ((\alpha \times \Delta T) \times \rho_0$, where

Δ_ρ = Change of resistivity (Ohm per meter)
α = Temperature coefficient (K-1)
ΔT = Temperature change (t_1-t_0)
ρ_0 = Resistivity in given temperature +20 °C

For example copper resistivity in +75 would be calculated as follows:

$$\rho_0 + \Delta_\rho = \rho_0 + (\alpha \times \Delta T \times \rho_0)$$

$$1.68 \times 10^{-8} + \left((0.003862 \times (75°C - 20°C)) \times 1.68 \times 10^{-8} \right) = 0.0203\ \mu\Omega/m$$

With this given value most common used copper wires resistance per meter in 75 are:

1.5 mm^2	2.5 mm^2	4 mm^2	6 mm^2
0.0135 Ω/m	0.00812 Ω/m	0.00508 Ω/m	0.00338 Ω/m

These values were calculated with formula:

$$R_{Cond} = \frac{\rho \times l}{A}$$

Suggestion is that for calculating the CT burden the worst case scenario is used. For most cases these 75°C values can be used. If in your application ambient temperature is higher than 75°C , then the resistance should be calculated for that temperature.

Important is also to know the wiring of the CTs in that point that is there common return wire used or are the CTs both ends wired to the terminal connector. If the case is as usual that four wires come from the CTs to terminal then length per phase is distance from the CT to relay added with the distance to common coupling point. If from all CTs are both sides wires connected to relay or to the terminal then the length of the wiring is two times the distance from the CTs to relay. In case if the connection is mixture of these then the length can be estimated by increasing the distance by proportion of the six wires / four wires connection. For example if 30% of the wiring is made from the CTs to terminal with six wires and from the terminal wiring continues with four wires then the wire length estimate should be 1.3 times the distance between of relay and CTs.

Next loading factor is the resistance of the relay measuring input. In this IED type it is 0.0005 for current input. This gives about 0.001VA with 1A current.

Now how to calculate the accuracy limit factor first the CT nominal accuracy limit factor needs to be known. As mentioned before that number in the CT rating (after the P) gives the current overload as a factor of nominal rated value which can still be said that the CT output will be in its rated accuracy 5% (5P) or 10% (10P) gives the accuracy limiting factor applicable at that overload of the CT.

Actual accuracy limit factor can be calculated as follows (this is common method):

$$ALF_{ACT} = ALF_{RATED} \times \left| \frac{S_{CTRN} + S_{Rated}}{S_{CTRN} + S_{Actual}} \right|$$

, where
ALF_{RATED} = The “factor after P”. The rated accuracy limit factor.
S_{CTRN}= Internal burden of the CT secondary
S_{Rated}= Volt-Amp Rating of the current transformer
S_{Actual}=Actual taken power from the CT

In this formula the S values are in VA. Biggest problem in this equation is to know the internal resistance of the CT secondary for calculation of the S_{CTRN}.

The internal resistance is related to what is the CT rating and how long is the winding length and also what is the used winding wire dimension. However the internal burden of the ct should be considered minority in the calculations since majority of the CT burden in typical relay application comes from the wirings. If the secondary burden is known then of course it should be used (some CT manufacturers include this information in their end test documentation).

In this example let’s assume for the HV side CT the internal resistance to be 0.05Ω, it is rated 5VA and for the LV CT internal resistance to be 0.09Ω also rated 5VA. Wiring from the HV side to relay is 10m and from the LV side 5m, both sides have 30% of wiring made with 6-wire connection and 70% of wiring with 4-wire connection. Wirings of HV and LV sides are made with 4 mm^2 wires.

HV side: 150/5A 10P10 5VA

$$ALF_{RATED} = 10$$

$$S_{Rated} = 5\text{VA}$$

$$S_{CTRN} = {I_{NS}}^2 \times CT_{RS} = 5^2A \times 0.05\Omega = 1.25\text{VA}$$

$$R_{Wire} = (10m \times 1.3) \times 0.00508\frac{\Omega}{\text{m}} = 0.066\Omega$$

$$S_{Actual} = {I_{NS}}^2 \times \left(R_{Wire} + R_{Relay}\right) = 5^2A \times (0.066\Omega + 0.0005\ \Omega) = 1.65\ \text{VA}$$

$$ALF_{ACT} = ALF_{RATED} \times \left|\frac{S_{CTRN} + S_{Rated}}{S_{CTRN} + S_{Actual}}\right| = 10 \times \left|\frac{1.25VA + 5\text{VA}}{1.25VA + 1.65VA}\right| = 21.55$$

LV side: 1200/5A 5P10 5VA

$$ALF_{RATED} = 10$$

$$S_{Rated} = 5\text{VA}$$

$$S_{CTRN} = {I_{NS}}^2 \times CT_{RS} = 5^2A \times 0.09\Omega = 2.25\text{VA}$$

$$R_{Wire} = (5m \times 1.3) \times 0.00508\frac{\Omega}{\text{m}} = 0.033\Omega$$

$$S_{Actual} = {I_{NS}}^2 \times \left(R_{Wire} + R_{Relay}\right) = 5^2A \times (0.033\Omega + 0.0005\ \Omega) = 0.838\ \text{VA}$$

$$ALF_{ACT} = ALF_{RATED} \times \left|\frac{S_{CTRN} + S_{Rated}}{S_{CTRN} + S_{Actual}}\right| = 10 \times \left|\frac{2.25VA + 5\text{VA}}{2.25VA + 0.838VA}\right| = 23.5$$

Now when comparing the corrected CT ALF factors to estimated maximum through fault currents can be seen that the current will not saturate CT:s since they can repeat on HV side 21.6 xIn current while the calculated HV current in through fault will be maximum of 20.2 xIn. In the LV side also the maximum output current will be 20.2 xIn when the LV side CT is able to repeat 23.5 xIn current.

From this notation can be expected that the through fault will not be causing problems with this power transformer and CT combination. Thus this note the non biased differential stage can be set to operate sensitively in in-zone faults. If the CTs would have possibility to saturate (calculated through fault current is bigger than the ALF of either side CT) the setting of the instant stage should be set high enough so that it will not operate on through fault saturation.

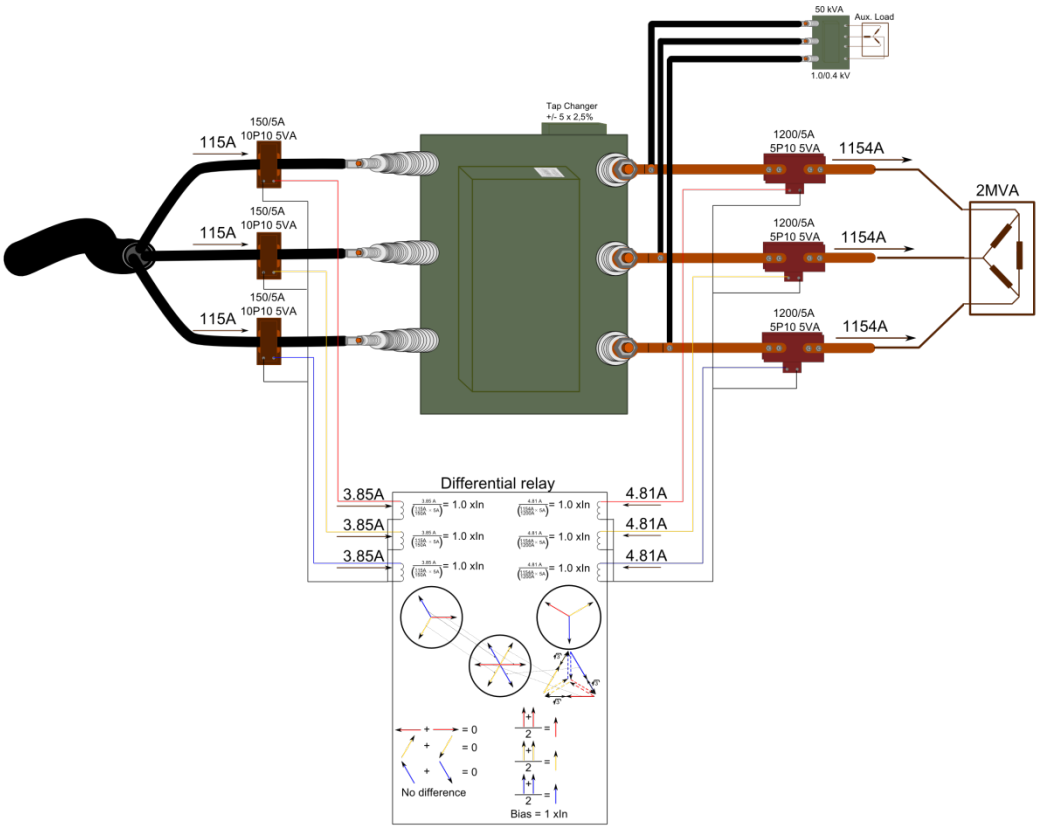
For setting of the instant stage should be considered the inrush peak current also, with normal power transformer the energizing inrush current may be 10 xIn peak, while the measured current is fft-filtered for fundamental component which is used for differential calculation the found differential current shall be 50% of the maximum peak current typically. If the setting should be according to theoretical maximum + margin, then 5 xIn + margin should be considered for the instant

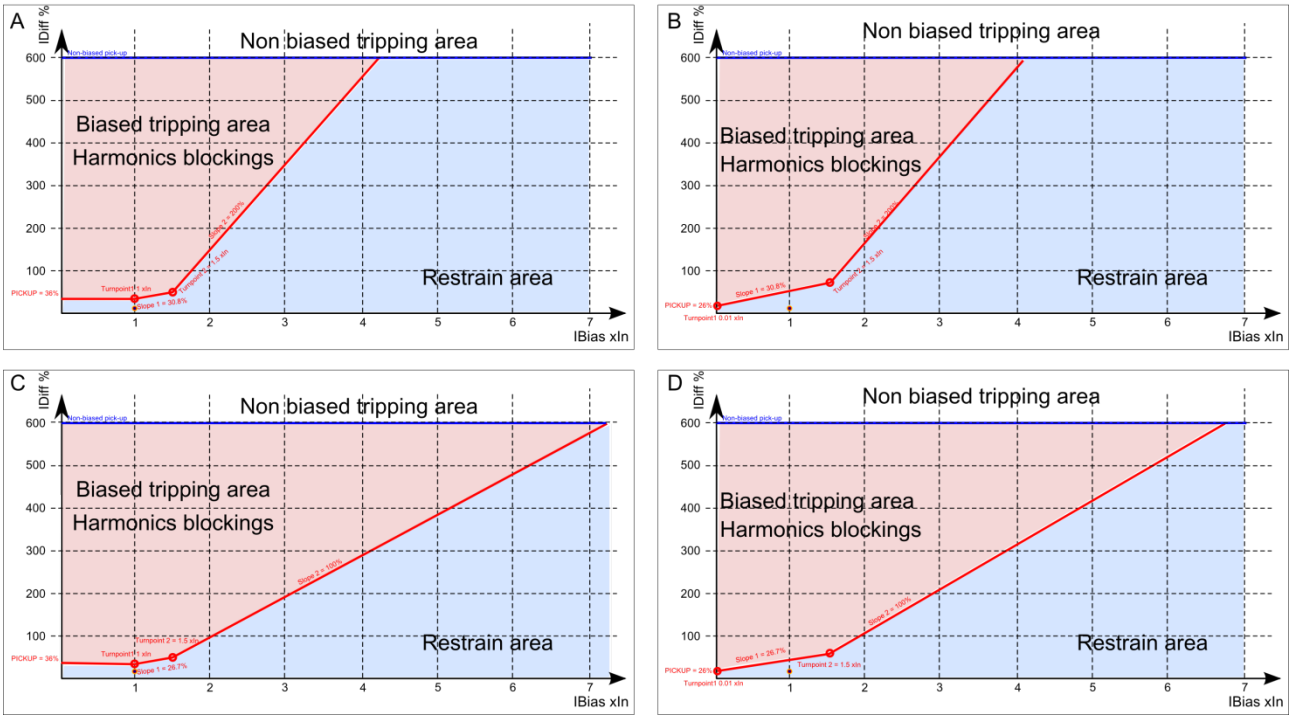
stage. For conservative settings 10 xIn can be used. This value should never cause trips for energizing and yet it will operate fast on in energisation fault cases (this stage usually is never blocked in application, thus it's settings should be considered on absolute differential current possible on normal operation yet it should be sensitive also for inrush currents especially on energisation cases).

Setting suggestion for this $I_{di>Pick\text{-}up}$ stage is 6.0 xIn ... 10 xIn for sensitive and conservative operation.

Now basic settings for the differential stages are applied and basically the differential protection is ready to operate. In this example the transformer used is very small, however the formulas presented in this manual can be applied to any size power transformers. In the TRF module, relay calculates these settings automatically if so wanted. Relay uses exactly these same formulas for the setting calculations.

Figure 3.173 When everything is set up correctly in the relay and when the transformer is feeding the load with nominal power the result should look like this with the example settings and transformer.





Four characteristics here present the setting variations based into “Average” and “Maximum” restraint calculation modes. (Figures A, B with average mode and C, D max mode).

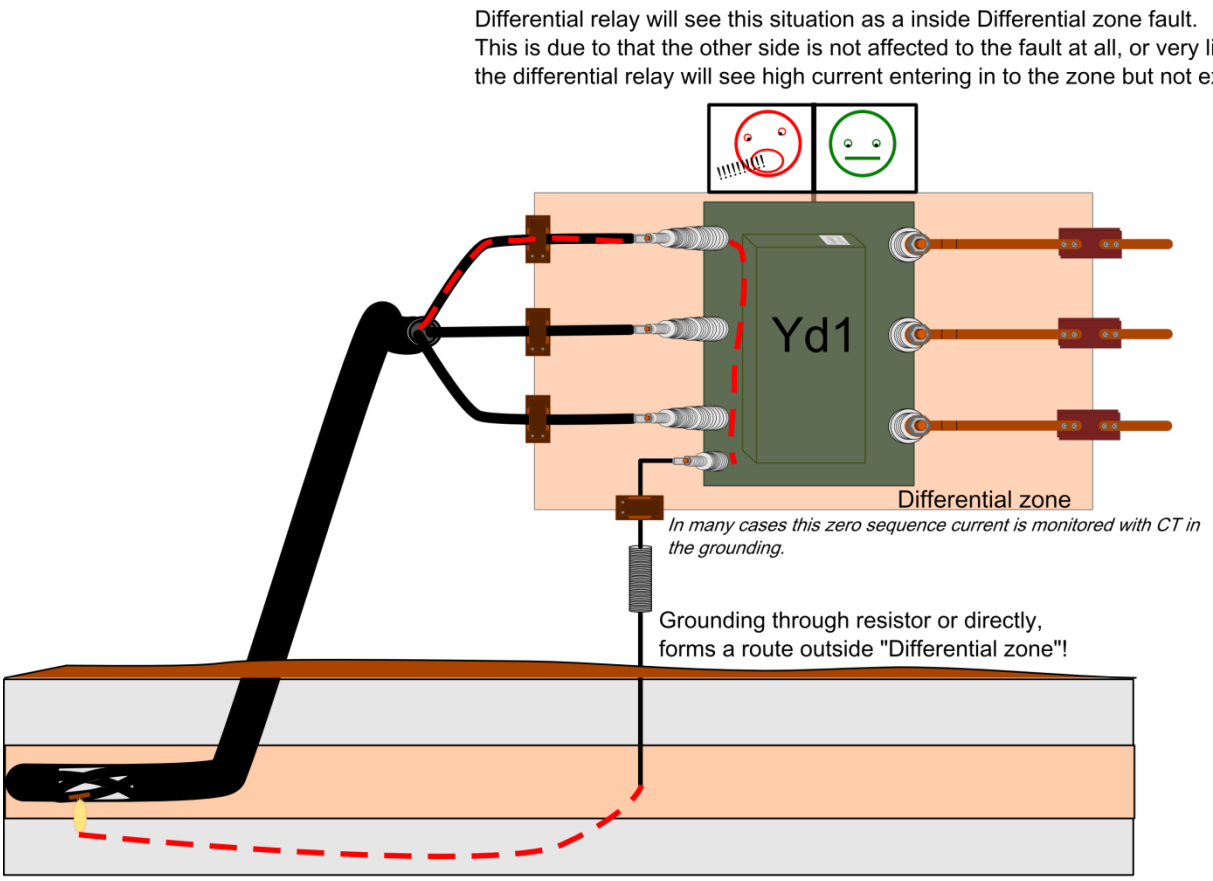
Basically in between these presented restraint calculation modes the characteristics are now set to equally sensitive.

Also the variations of Turnpoint1 setting either to 0.01xIn or 1.0xIn are presented (Figures A, C with Turnpoint 1 set to 1.00 xIn and B, D with Turnpoint 1 set to 0.01 xIn).

Zero sequence compensation for external earth faults

This example did present only one type of transformer and its properties. Very common variation in this kind of transformer is when the star side, no matter HV or LV or both, is grounded thus forming a route outside of the “Differential zone”.

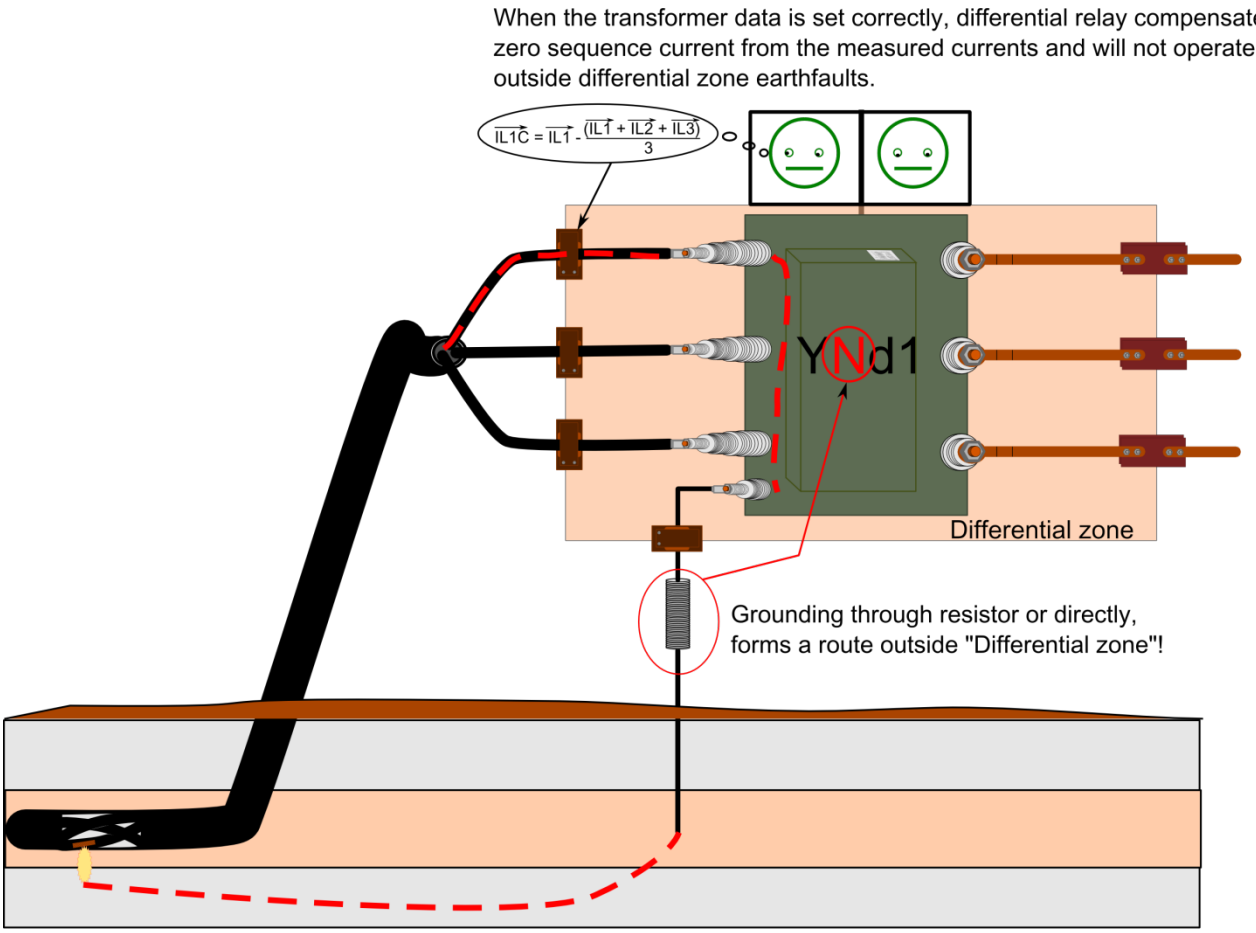
Figure 3.174 Transformer grounding and external fault.



The grounding needs to be known in the differential current calculation since if it is not compensated any low impedance earthfault outside of the differential zone shall cause differential current measured and possible tripping of the differential protection. For this purpose the calculated zero sequence compensation is used. This has to be told to the relay and for that the vector group selection of the transformer setup has either “N” or “n” representing either HV side or LV side grounding.

What this selection actually does is that it deducts the calculated zero sequence current from the per-unitized currents before differential calculation thus negating the outside earth fault effect.

Figure 3.175 Correctly selected transformer setting prevents the differential function operation in out of zone earth faults.



This selection basically does for the “N” or “n” selected side or both of them the zero sequence elimination by applying the before mentioned correction.

$$\overrightarrow{IL1}_{Corr} = \overrightarrow{IL1} - \frac{\overrightarrow{IL1} + \overrightarrow{IL2} + \overrightarrow{IL3}}{3}$$

$$\overrightarrow{IL2}_{Corr} = \overrightarrow{IL2} - \frac{\overrightarrow{IL1} + \overrightarrow{IL2} + \overrightarrow{IL3}}{3}$$

$$\overrightarrow{IL3}_{Corr} = \overrightarrow{IL3} - \frac{\overrightarrow{IL1} + \overrightarrow{IL2} + \overrightarrow{IL3}}{3}$$

Important note!: By enabling the zero sequence compensation by selecting the “N” or “n” in the transformer vector group, simultaneously the sensitivity to single phase one end fault will decrease by 1/3. For this reason restricted earth fault protection should be enabled for the zero sequence compensated side. Restricted earth fault enabling requires that in addition to phase currents measurement also the starpoint current is available and can be connected to the residual current channel of the relay on corresponding (HV/LV) side measurement.

Restricted earthfault

When the transformer grounded side is compensated with before mentioned zero sequence compensation that side will be 1/3 (~33%) more insensitive for inside zone single phase faults. For this reason it is advised that the restricted earthfault stage should be activated in the zero sequence compensated side of the transformer and also because of normal phase differential protection cannot be set to provide maximum sensitivity to inside area single phase (earth) faults due to transformer and application depended properties described in previous chapter it is advised to be enabled in all cases when the wye side starpoint is grounded. This differential stage looks the ingoing calculated residual current and compares it to outgoing starpoint current. If the single phase (earth-fault) occurs outside of the differential zone this function will not operate but if the fault should occur inside the differential zone it will operate quickly, thus this definition this protection is referred as “Restricted Earth Fault (REF)” because it is sensitive to earth faults only inside the protection zone.

In the differential function for transformers two stages of low impedance restricted earth fault protection are available.

Operation characteristics of REF HV and REF LV are similar than Idb> function presented percentage characteristics, even though both sides are independent and freely settable. Differential and biasing currents are calculated as follows per each side.

For HV side:

$$HV_{I0d_Bias_AVG} = \frac{\left|(\overrightarrow{IL1}_{HV} + \overrightarrow{IL2}_{HV} + \overrightarrow{IL3}_{HV}) + \overrightarrow{I0}_{HVMEAS}\right|}{2}$$

$$HV_{I0d_Bias_MAX} = \max\left((\overrightarrow{IL1}_{HV} + \overrightarrow{IL2}_{HV} + \overrightarrow{IL3}_{HV}), \overrightarrow{I0}_{HVMEAS}\right)$$

$$HV_{I0d>_diff_add} = \left|(\overrightarrow{IL1}_{HV} + \overrightarrow{IL2}_{HV} + \overrightarrow{IL3}_{HV}) + \overrightarrow{I0}_{HVMEAS}\right|$$

$$HV_{I0d>_diff_substract} = \left|(\overrightarrow{IL1}_{HV} + \overrightarrow{IL2}_{HV} + \overrightarrow{IL3}_{HV}) - \overrightarrow{I0}_{HVMEAS}\right|$$

For LV side:

$$LV_{I0d_Bias_AVG} = \frac{\left|(\overrightarrow{IL1}_{LV} + \overrightarrow{IL2}_{LV} + \overrightarrow{IL3}_{LV}) + \overrightarrow{I0}_{LVMEAS}\right|}{2}$$

$$LV_{I0d_Bias_MAX} = \max\left((\overrightarrow{IL1}_{LV} + \overrightarrow{IL2}_{LV} + \overrightarrow{IL3}_{LV}), \overrightarrow{I0}_{LVMEAS}\right)$$

$$LV_{I0d>_diff_add} = \left|(\overrightarrow{IL1}_{LV} + \overrightarrow{IL2}_{LV} + \overrightarrow{IL3}_{LV}) + \overrightarrow{I0}_{LVMEAS}\right|$$

$$LV_{I0d>_diff_subtract} = \left|(\overrightarrow{IL1}_{LV} + \overrightarrow{IL2}_{LV} + \overrightarrow{IL3}_{LV}) - \overrightarrow{I0}_{LVMEAS}\right|$$

For both sides REF stages have average and maximum bias current calculation setting option as well as the add or subtract differential current calculation options similarly to the phase differential stages (depend of the installation directions of the CTs and desired sensitivity for bias calculation).

In differential stage the reference current for the REF protection for transformers is always the protected side nominal current (HV, LV), which is calculated in the relay TRF module.

For transformer application the setting of the REF stage, whether it is located in the HV or LV side may be set a lot more sensitive than phase differential. Basically the setting sensitivity should be defined by the fact if there is expected CT saturation or not (Transformer maximum single phase output compared to neutral point CT ratings). The tripping characteristics may be set differently in case if the network is directly grounded or through impedance and the fault current may be expected to saturate CTs in the external fault also.

For this reason there are three sections in the REF function characteristics also, non- biased, slightly biased and heavily biased. For high impedance or close to neutral winding fault the first non biased section should consider the possible measurement errors of the CTs and the desired sensitivity for internal fault close to neutral and the Turnpoint 1 setting up to 2 x CT in. Normally the neutral point CT is with lower primary current rating than phase current CTs so it's primary to maximum current rating should be the guiding factor in the setting calculation. First biased section (Slope 1) should consider the effect of possible saturation in the neutral point CT on normal outside region earth faults and second biased section (Slope 2) heavy full through fault possibly caused saturation in the phase current CTs.

As a basic setting could be considered following:

Pick-up (basic sensitivity): Phase current CT error (Px) typically 5-10%

Turnpoint 1: 2 x neutral current CT nominal primary to transformer nominal current ratio

Slope 1: Calculate maximum single phase through fault overcurrent to nominal ratio and used biasing mode ratio.

Turnpoint2: Set to maximum accuracy limit factor to transformer nominal ratio of the neutral point CT e.g. 5,10 typically. In case if the single phase overcurrent fault is over this value, set Turnpoint 2 to that value.

Slope 2: Set to maximum restraint calculation mode to 100% and average mode to 200%.

Blockings from harmonics (2^{nd} and 5^{th})

In transformer protection harmonics are always present in energisation situations which come from high current in the inductances of the transformer when the coils are energized. Also in the over fluxing / overvoltage situation harmonics are present also in the currents. From these different situations can be divided the cases so that in energisation situation even harmonics are generated, which of the 2^{nd} harmonic is the most commonly used in the inrush blocking and in overvoltage cases odd harmonics are generated which of mostly 5^{th} harmonic is used for blocking (3^{rd} harmonic is also present in wye-windings, it will be though absent in delta-windings so therefore 5^{th} harmonic is commonly used for overfluxing/excitation detection).

In this chapter the blocking refers to Idb> (biased differential) stage which has these 2^{nd} and 5^{th} blockings internally applied. If the Idi> stage (non biased differential) should be blocked, for this reason external blocking should be used.

2^{nd} Harmonic for magnetizing inrush blocking, principle and usage.

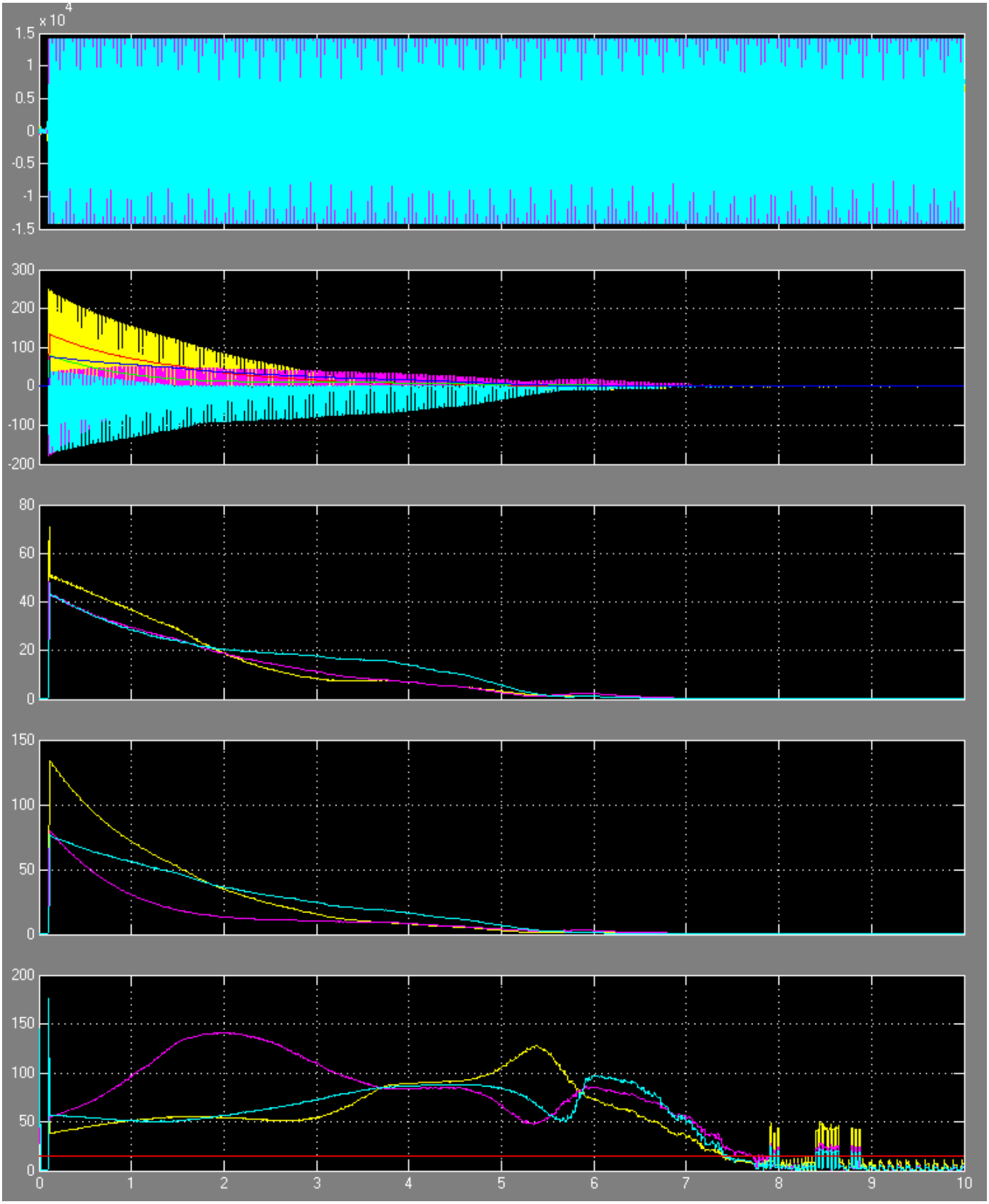
When a power transformer primary side is energized (secondary side open) transformer can be considered as a simple inductance. In normal operation of transformer the flux produced in the transformer core is lagging the fed voltage by radians (90 deg). This means that when the voltage is in zero crossing, the steady state value of the flux will be in its negative or positive maximum value. In energization situation there is no flux available at instant when the winding is energized due to there is no (live) magnetic flux linked to the transformer core before the voltage is switched to the winding (remanence flux may still exist). After a finite time from the energisation the flux will reach its steady state operation and this time will be depend on the transformer properties (size, R/X ratio etc.). In practice this means that the flux in the transformer core will start basically from zero as does the voltage in the winding do when energizing the primary side of transformer, in given time (depending of the transformer properties) the flux shall be 90 degrees behind the winding voltage and the system is in steady state.

This start-up transition in the transformer effects so that the flux in the first half cycle after energization shall be up to 2 times of the nominal flux value. The transformer core generally is saturated just above the steady state value of the flux and because of this the transformer core will be decreasingly saturated during this transition time. During this saturation time

transformer primary draws very high current with heavy amount of even harmonics which of highest is 2nd. This current is generally called “(magnetizing) inrush current in transformer”. Inrush current in transformer may be up to 10 times higher than nominal rated current of transformer. Energizing characteristics of transformer are related on the ratings of the transformer as well as design of the transformer (transformer limbs constructions etc.)

Basically this energization current shall be seen in the differential relay as a differential current since it will flow through the primary side winding only. For this purpose the 2nd harmonic component generated by the saturation of the transformer core can be used to block the biased sensitive differential stage during energization.

Figure 3.176 Transformer energization magnetizing inrush.



In the figure above is presented small transformer energizing behavior, where the first curve from top is the applied voltage, second are phase currents peak and FFT values

(as mentioned in the earlier chapter, the calculated FFT value is about 50% of the peak value), third graph presents the 2nd harmonic absolute values in amperes, fourth graph presents the fundamental (50 Hz) FFT calculated currents in amperes, and fifth graph presents the relative 2nd harmonic components to corresponding fundamental component currents with the 15% setting limit for display what the setting presents in this concept.

As can be seen that the magnetizing inrush with this small transformer (2MVA used in the previous example also) is very short, about 7 seconds, there is still over the nominal measurable current which is seen only in the primary side of the transformer thus would cause clearly tripping of the differential relay if tried to energize without magnetizing inrush blocking. When looking at the currents can be noted that the fundamental component currents (which are used for differential calculations) magnitudes are roughly as follows:

$$IL1peak = 140\,A = 1.2xIn$$

$$IL2peak = 75\,A = 0.65xIn$$

$$IL3peak = 70\,A = 0.60xIn$$

When remembering that in this example the transformer HV (primary) –side nominal current was 115.5A it yields to following:

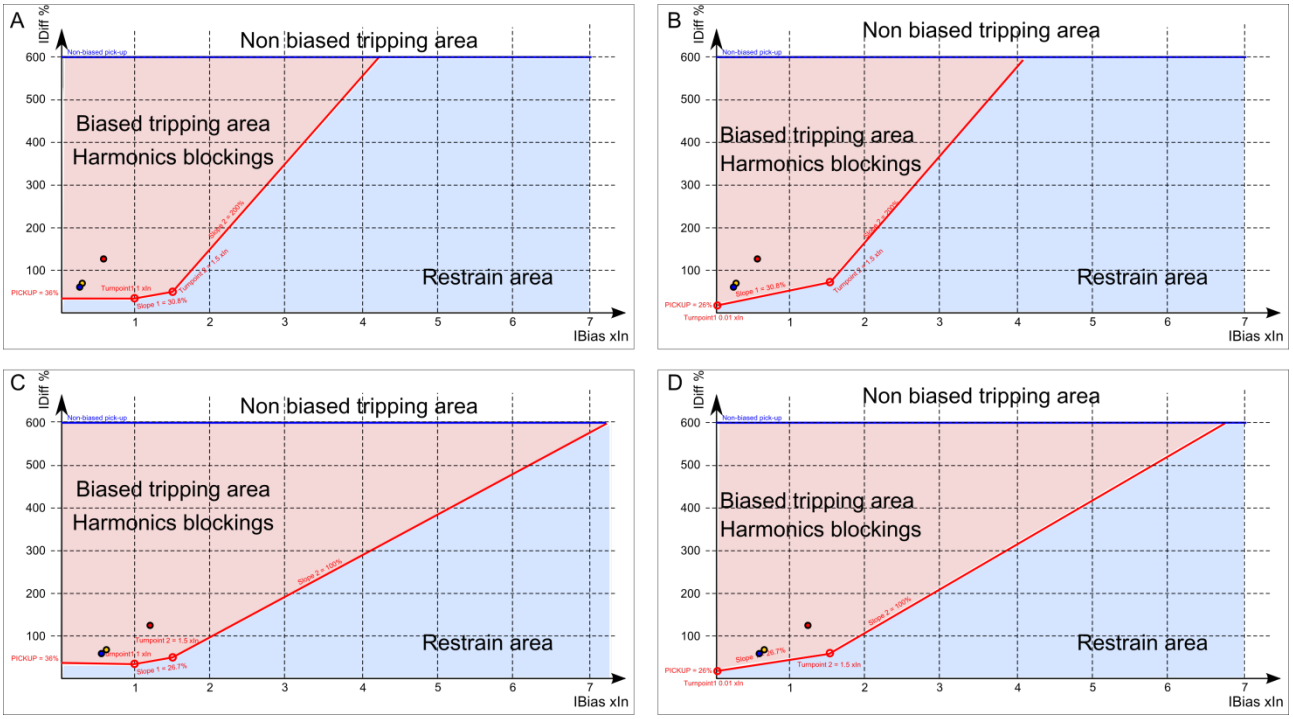
$$IL1_{diff} = 120\%,\ IL1_{biasAVG} = \frac{1.2xIn}{2} = 0.6xIn,\ IL1_{biasMAX} = 1.2xIn$$

$$IL2_{diff} = 65\%,\ IL2_{biasAVG} = \frac{0.65xIn}{2} = 0.33xIn,\ IL2_{biasMAX} = 0.65xIn$$

$$IL3_{diff} = 60\%,\ IL3_{biasAVG} = \frac{0.60xIn}{2} = 0.30xIn,\ IL3_{biasMAX} = 0.60xIn$$

In the set characteristics the differential currents would look like in the graph below.

Figure 3.177 Differential currents in the energization of 2 MVA transformer.



Now this result is still very low considering of the magnetizing inrush current magnitudes but still the differential relay would definitely trip in this case if it would not be prevent from operating by 2nd harmonic blocking. Situation is the same with all of the setting variations calculated.

In following figure is presented principle operation of the harmonic blocking in the transformer differential. When the transformer is energized both, the fundamental frequency component as well as the 2nd harmonic component will increase significantly. In this example the harmonic blocking limit was set to 15% (ratio of 2nd harmonic/fundamental per each phase), which seems more than sufficient for this transformer and the pick-up in the example is set to 30%. Now when the flux in the transformer core starts to catch up, saturation of the core reduces and the current for magnetizing reduces as well, the blocking shall be active until the setting is reached which after the blocking shall release per each phase separately. For this transformer the harmonic blocking limit could have been set to 30% and the energizing would have been successful still since the 2nd harmonic is heavily still present in time the fundamental currents reduce below the pick-up limit of the differential stage.

Figure 3.178 Inrush blocking by using 2nd harmonic related to fundamental frequency component.

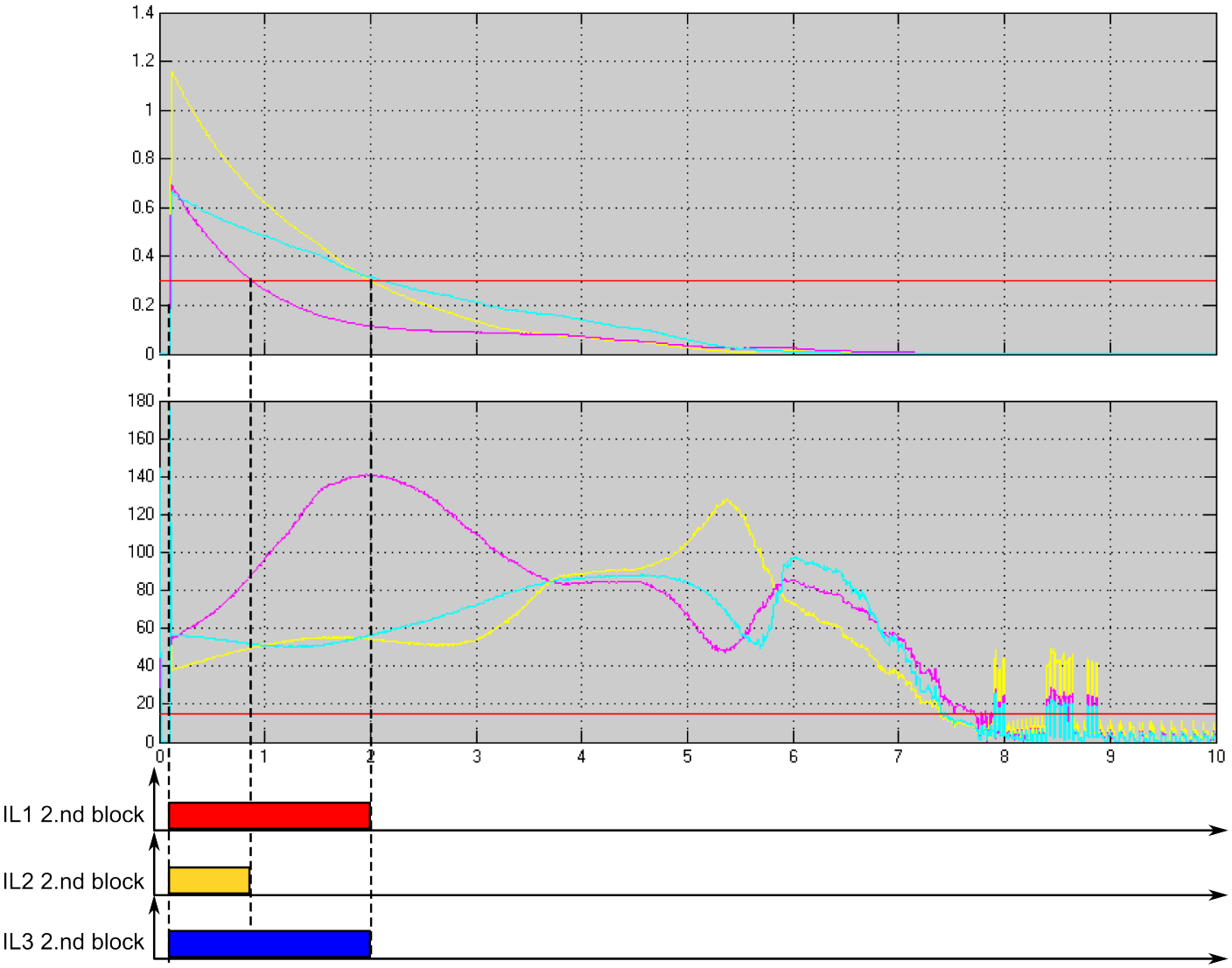
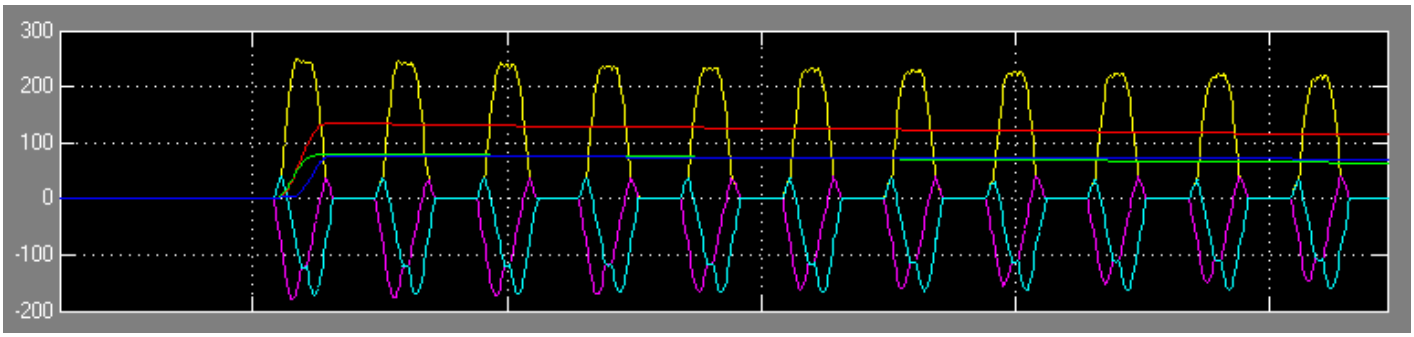


Figure 3.179 Example of transformer magnetizing inrush currents.



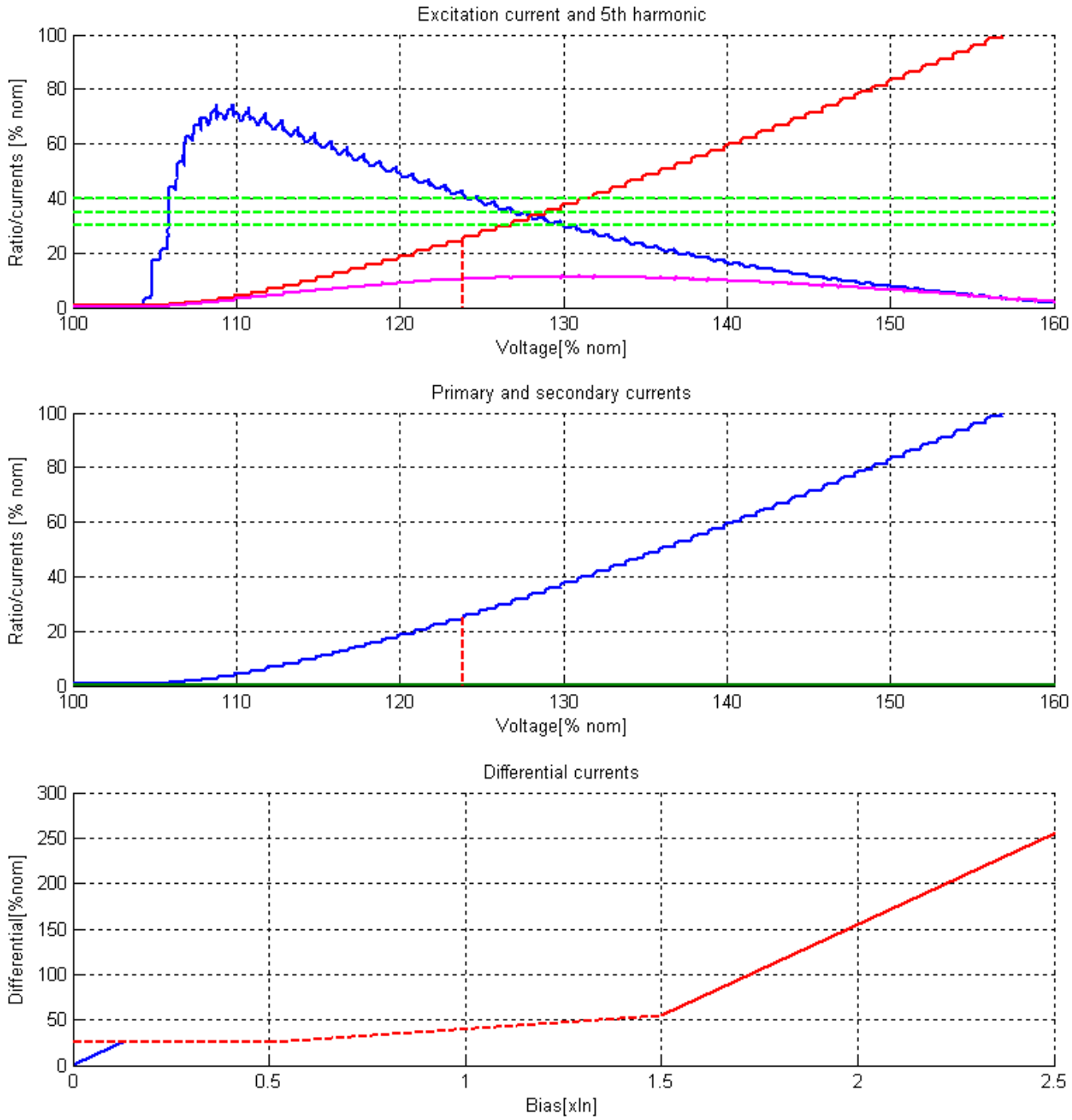
As conservative setting suggestion for standard type transformer could be recommended 2nd harmonic blocking enabled with sensitivity set to around 15-20% harmonic content compared to fundamental frequency. Final tuning for the transformer settings can be made in commissioning if there should be any issues on problematic transformer energisation.

5th Harmonic for over excitation block, principle and usage.

When the transformer primary side voltage increases for some reason (V/f) ratio is higher than designed, transformer will over excite very rapidly. Reasons for this event may be that the LV side fault causes the loading to be thrown off suddenly causing temporary overvoltage or in the network frequency goes down for some reason e.g. overloading or generation

drop. In both of these mentioned cases the differential relay should not trip even the measured currents shall be considerably higher on the primary side than secondary side due to the over excitation in the transformer core.

Figure 3.180 Transformer behaviour in case of overvoltage caused over excitation.

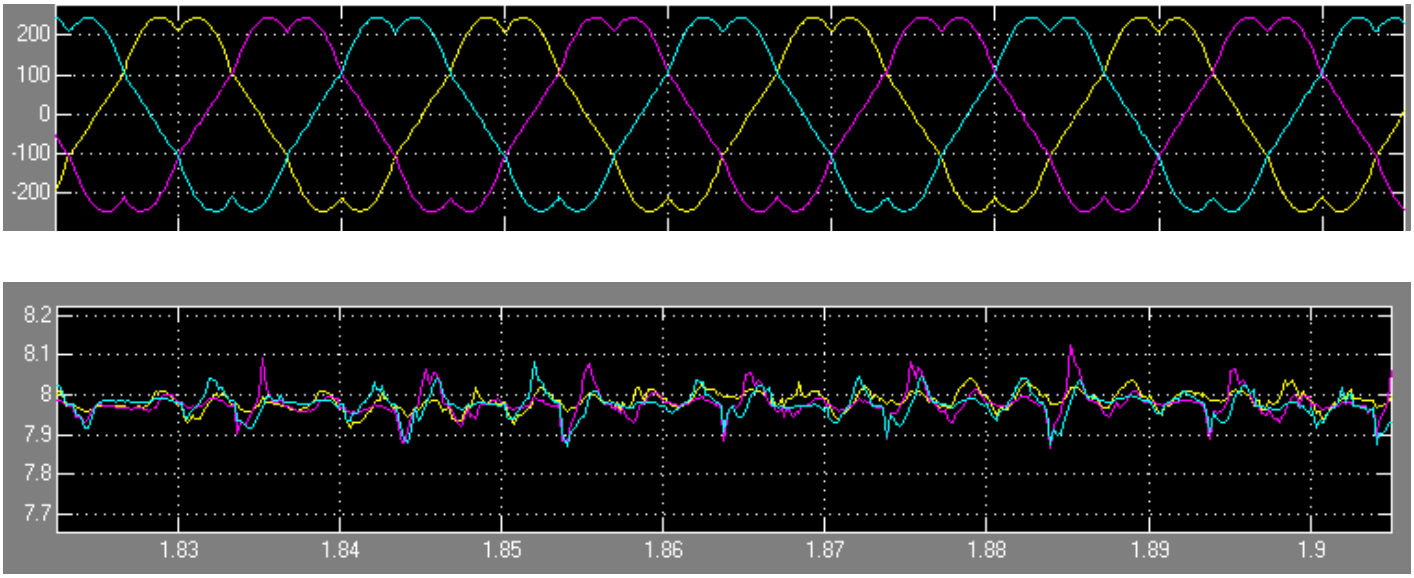


In the figure above is presented one simulated power transformer behavior in case of overvoltage. In the simulation transformer was unloaded on secondary side while the voltage of primary side was increased with a ramp.

In the figure first graph presents the excitation current, its 5th harmonic component and their relation (which is used in the blocking). Also into the graph are plotted possible suggested setting limits for the 5th harmonic detection (30%, 35% and 40%). In the second graph are plotted primary and secondary currents in function of the voltage and in the last graph the differential characteristics and differential/bias currents.

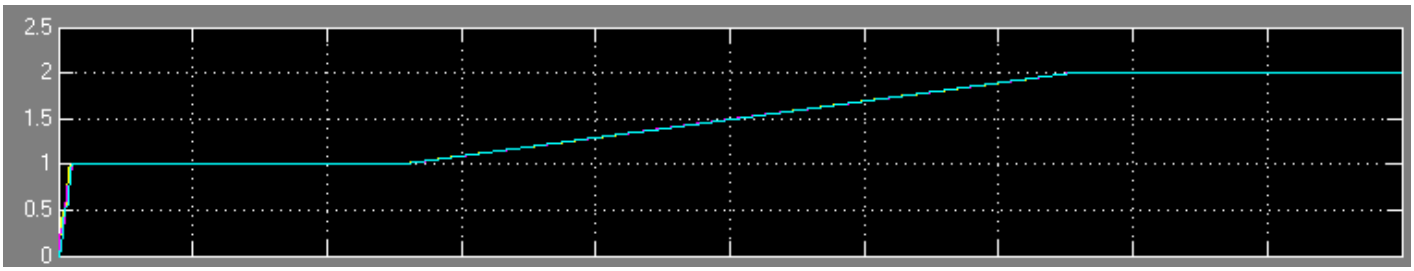
As can be noted from the graphs the 5th harmonic component starts to increase rapidly in comparison to the fundamental in the start situation when the voltage is about 120% of nominal (this is related completely to the transformer properties and its saturation characteristics). This behavior is anyway common to all transformers, when the core starts to saturate there will be heavy amount of 5th harmonic in the magnetizing current. When the overvoltage exceeds certain point in the magnetizing characteristics, 5th harmonic is there still but in the other hand the fundamental component of the current starts to grow very rapidly, which causes that the relation of the 5th harmonic to fundamental will be decreasing rapidly in function of the primary side voltage. Thus the magnetizing current grows it is seen only in the primary side of the transformer and is seen by differential relay as pure differential current. In the last graph is seen the differential pick-up setting reached in situation when the voltage is about 125% of the nominal. This means that in this case the over excitation generated differential current could trip the transformer in this point, however the fifth harmonic component relation ratio to fundamental magnitude is already decreasing in this point and when considering what would happen if the overvoltage would be e.g. 130%, it would mean that there is no blocking available even the differential current would be highly over the setting limit (~40% vs. setting in this case 25%). This behavior still can be considered to be correct for the power transformer since overvoltage like this can cause more serious problems and therefore tripping is desired.

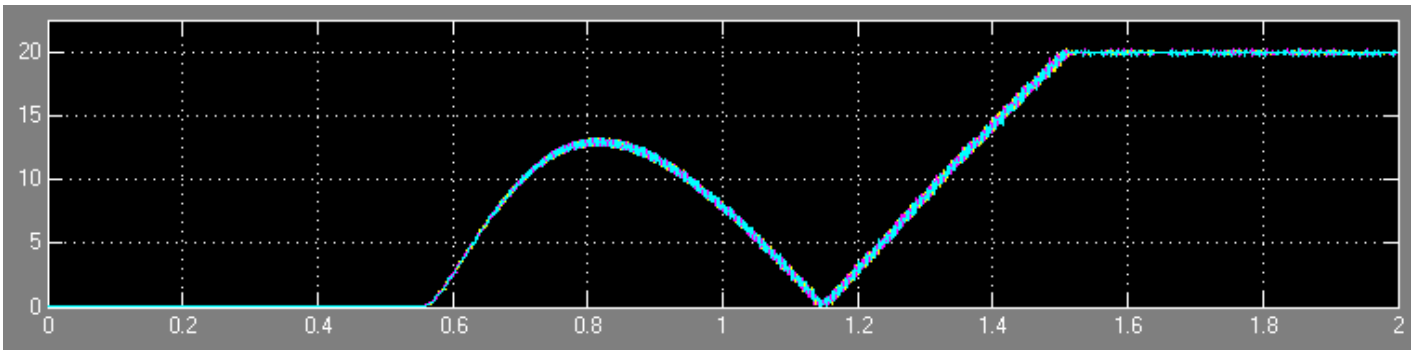
Figure 3.181 Example waveforms of the transformer running with 200% rated voltage with corresponding 5th harmonic to fundamental ratio.

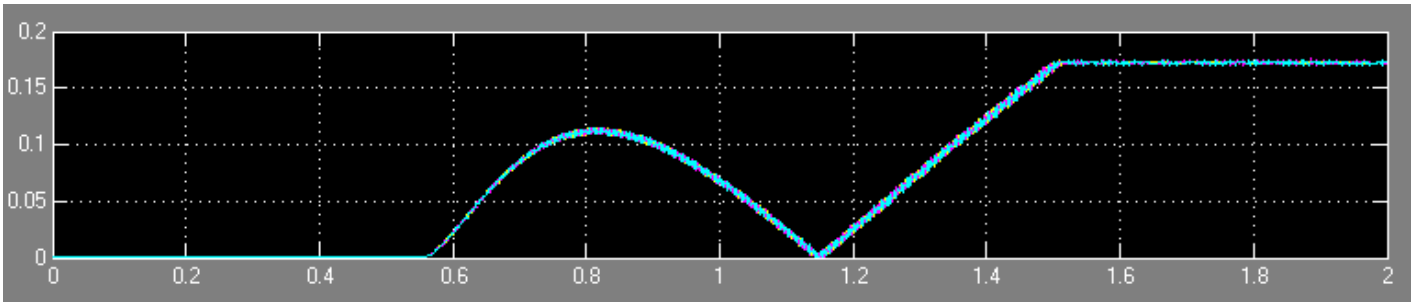


Traditionally the relation of 5th harmonic to fundamental has been used for blocking the differential relay from tripping in overvoltage/over excitation situations. Based into the ratio check this however is not very failsafe way in order that to set it correctly and so that it could be more of use the magnetizing properties and hysteresis of the transformer should be completely known.

Figure 3.182 Per unitized system voltage and magnitude of the 5th harmonic component, absolute and scaled to transformer nominal.





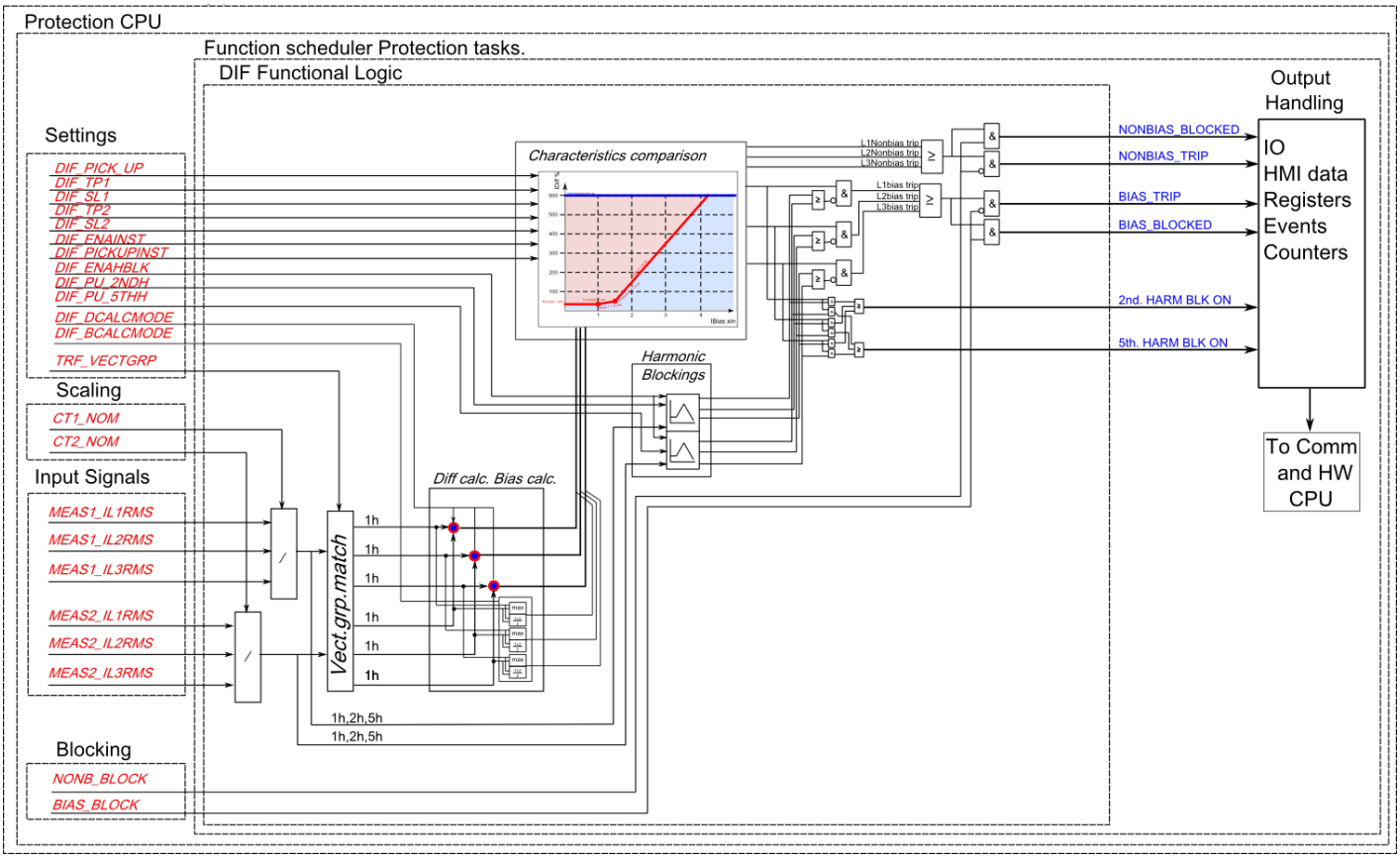


As can be seen in the figure above the 5th harmonic component increases, decreases and then increases again in the function of rising system voltage, in this case about with overvoltage of 160% the 5th harmonic seems to disappear completely. In this kind of behavior the previously mentioned blocking behavior can be used, it automatically blocks with smaller overvoltage (in order if there is any differential current) and releases if the overvoltage is too heavy when the differential current most probably is over the tripping limit.

However the behavior of the blocking is very unpredictable if the exact saturation characteristic of the transformer is not known and (this cannot be estimated without knowing the exact design of the transformer) if there is chance that the over excitation can cause problems (in practice this means that there is no overvoltage relay available) this blocking can be enabled with setting of 30-40% with disturbance recorder enabled. If there should happen anything related to tripping due to over excitation, settings may be adjusted based into the data captured by disturbance recorder.

Differential function details

Figure 3.183 Simplified function block diagram of the DIF function.



Differential function outputs the trip and blocked signals from the biased and non biased functions as well as the 2nd and 5th harmonic blocks activation signals. These signals can be used in the protection application.

Settings and signals

Settings of the differential function (DIF) are a combination of transformer monitor and differential stage function settings. In following table are shown the functions used with the DIF function including the per unitizing and transformer general settings used for pre calculation.

Table 3.215 Settings related to DIF function pre calculation.

Name	Range	Step	Default	Funcs.	Description
Transformer nominal MVA	0.1...500.0MVA	0.1MVA	1.0MVA	All	Nominal MVA of transformer. This value is used to calculate nominal currents of HV, and LV side.
HV side nominal voltage	0.1...500.0kV	0.1kV	110.0kV	All	HV side nominal voltage of the transformer. This value is used to calculate nominal currents of HV side.
LV side nominal voltage	0.1...500.0kV	0.1kV	110.0kV	All	LV side nominal voltage of the transformer. This value is used to calculate nominal currents of LV side.
Transformer Zk%	0.01...25.00%	0.01%	3.00%	Info	Transformer short circuit impedance in %. Used for calculation of the short circuit currents
Transformer nom. freq	10...75Hz	1Hz	50Hz	Info	Transformer nominal frequency. Used for calculation of transformer nominal short circuit inductance.
Transf. Vect. group	0:Manual 1:Yy0 2:Yyn0 3:YNy0	-	1:Yy0	TRF, DIFF	Selection of the transformer vector group. Selection values from 1 to 26 are predefined so that just by selecting correct vector group the scaling and vector matching is applied in the relay automatically.

Name	Range	Step	Default	Funcs.	Description
	4:YNyn0 5:Yy6 6:Yyn6 7:YNy6 8:YNyn6 9:Yd1 10:YNd1 11:Yd7 12:YNd7 13:Yd11 14:YNd11 15:Yd5 16:YNd5 17:Dy1 18:Dyn1 19:Dy7 20:Dyn7 21:Dy11 22:Dyn11 23:Dy5 24:Dyn5 25:Dd0 26:Dd6				In the predefinitions it is assumed that the HV side is connected to CT1 module and LV side is in CT2 module. If the protected transformer vector group is not found in the predefined list, manual set can be applied by selecting 0: Manual set.
HV side Star or Zigzag / Delta	0:Star/Zigzag 1:Delta	-	0:Star/ Zigzag	TRF, DIFF	Selection of the HV side connection, star or zigzag or delta. Selection is visible only if vector group is set to “0:Manual set”

Table 3.216 Settings related to DIF function pre calculation. (continued).

Name	Range	Step	Default	Funcs.	Description
HV side grounded	0:Not grounded 1:Grounded	-	0:Not grounded	TRF, DIFF	Selection whether the zero sequence compensation should be applied into HV side currents calculation. Selection is visible only if vector group is set to “0:Manual set”
HV side lead or lag LV	0:Lead 1:Lag	-	0:Lead	TRF, DIFF	Selection for HV side leads or lags LV side. Selection is visible only if vector group is set to “0:Manual set”
LV side Star or Zigzag / Delta	0:Star/Zigzag 1:Delta	-	0:Star/ Zigzag	TRF, DIFF	Selection of the LV side connection, star or zigzag or delta. Selection is visible only if vector group is set to “0:Manual set”
LV side grounded	0:Not grounded 1:Grounded	-	0:Not grounded	TRF, DIFF	Selection whether the zero sequence compensation should be applied into LV side currents calculation. Selection is visible only if vector group is set to “0:Manual set”
LV side lead or lag HV	0:Lead 1:Lag	-	0:Lead	TRF, DIFF	Selection for LV side leads or lags LV side. Selection is visible only if vector group is set to “0:Manual set”
HV-LV side phase angle	0.0...360.00deg	0.1deg	0.0deg	TRF, DIFF	Angle correction factor for HV LV sides, looked from HV side. e.g. if transformer is Dy1 then set here 30 degrees. Selection is visible only if vector group is set to “0:Manual set”
HV-LV side mag correction	0.0...100.0xIn	0.1xIn	0.0xIn	TRF, DIFF	Magnitude correction for HV-LV side currents per unitizing if the currents are not directly matched via calculation of the nominal values. Selection is visible only if vector group is set to “0:Manual set”

Name	Range	Step	Default	Funcs.	Description
Check online HV-LV configuration	0:- 1:Check	-	0:-	TRF, DIFF	Check online on energized trafo the configuration success. (Trafo needs to have current flowing on both sides as well as there should not be faults seen in order this to work). Selection is visible only if vector group is set to “0:Manual set”
Enable I0d> (REF) HV side	0:Disabled 1:Enabled	-	0: Disabled	TRF,DIFF	HV side restricted earth fault stage enable/disable selection.
HV side Starpoint meas,	0:I01 1:I02	-	0:I01	TRF,DIFF	Selection of the starpoint measurement channel for the HV side restricted earth fault protection. Setting is visible only if “Enable I0d> (REF) HV side” is set to “1: Enabled”

Table 3.217 Settings related to DIF function pre calculation. (continued).

Name	Range	Step	Default	Funcs.	Description
Enable I0d> (REF) LV side	0:Disabled 1:Enabled	-	0: Disabled	TRF,DIFF	LV side restricted earth fault stage enable/disable selection.
LV side Starpoint meas,	0:I01 1:I02	-	0:I01	TRF,DIFF	Selection of the starpoint measurement channel for the LV side restricted earth fault protection. Setting is visible only if “Enable I0d> (REF) LV side” is set to “1: Enabled”

Table 3.218 DIF function operating characteristics settings.

Name	Range	Step	Default	Description
Differential calculation mode	0:Add 1:Subtract	-	1:Subtract	Calculation mode of the differential current. Depends of the installation direction of the CT:s and the desired current directions. If both sides current flow same direction differential current is subtracted, if opposite then added.
Bias calculation mode	0:Average 1:Maximum	-	0:Average	Calculation mode of biasing current. With average mode the operation may be set more sensitive while maximum mode the bias will be always higher thus giving more stable operation.
Idb> Pickup	0.01...100.00%	0.01%	10.00%	Base sensitivity for the differential characteristics
Turnpoint 1	0.01...50.00xIn	0.01xIn	1.00xIn	Turnpoint 1 for the differential characteristics
Slope 1	0.01...250.00%	0.01%	10.00%	Slope1 of the differential characteristics
Turnpoint2	0.01...50.00xIn	0.01xIn	3.00xIn	Turnpoint 2 for the differential characteristics
Slope 2	0.01...250.00%	0.01%	200.00%	Slope2 of the differential characteristics
Enable harmonic blocking	0:No harm.block 1:2nd harm block 2:5th harm block 3:2nd and 5th harm block	-	1:2nd harm block	Selection of the internal blockings to be used for detection of transformer normal but differential current causing operations.
2nd harm block pickup	0.01...50.00%	0.01%	15.00%	Pick-up detection relation (fundamental to harmonic ratio) for 2nd harmonic blocking stage. This setting is visible only if the “Enable harmonic blocking” setting is set either to 1 or 3 mode.
5th harm block pickup	0.01...50.00%	0.01%	35.00%	Pick-up detection relation (fundamental to harmonic ratio) for 5th harmonic blocking stage. This setting is visible only if the “Enable harmonic blocking” setting is set either to 2 or 3 mode.

Name	Range	Step	Default	Description
Enable Idi> stage	0:Disabled 1:Enabled	-	1:Enabled	Selection of the non biased and non blocked differential stage enabled or disabled.
Idi> No bias Pickup	200.00... 1500.00%	0.01%	600.00%	Pick-up setting for the non biased/non blocked differential stage. This setting is visible only if “Enable Idi>” stage is set to 1.
HV I0d> Pickup	0.01...100.00%	0.01%	10.00%	Base sensitivity for the HV side restricted earthfault differential characteristics Setting is visible only if “Enable I0d> (REF) HV side” is set to “1: Enabled”
HV I0d> Turnpoint 1	0.01...50.00xIn	0.01xIn	1.00xIn	Turnpoint 1 for the HV side restricted earthfault differential characteristics Setting is visible only if “Enable I0d> (REF) HV side” is set to “1: Enabled”
HV I0d> Slope 1	0.01...250.00%	0.01%	10.00%	Slope1 of the HV side restricted earthfault differential characteristics Setting is visible only if “Enable I0d> (REF) HV side” is set to “1: Enabled”
HV I0d> Turnpoint2	0.01...50.00xIn	0.01xIn	3.00xIn	Turnpoint 2 for the HV side restricted earthfault differential characteristics Setting is visible only if “Enable I0d> (REF) HV side” is set to “1: Enabled”
HV I0d> Slope 2	0.01...250.00%	0.01%	200.00%	Slope2 of the HV side restricted earthfault differential characteristics. Setting is visible only if “Enable I0d> (REF) HV side” is set to “1: Enabled”
LV I0d> Pickup	0.01...100.00%	0.01%	10.00%	Base sensitivity for the LV side restricted earthfault differential characteristics. Setting is visible only if “Enable I0d> (REF) LV side” is set to “1: Enabled”
LV I0d> Turnpoint 1	0.01...50.00xIn	0.01xIn	1.00xIn	Turnpoint 1 for the LV side restricted earthfault differential characteristics. Setting is visible only if “Enable I0d> (REF) LV side” is set to “1: Enabled”
LV I0d> Slope 1	0.01...250.00%	0.01%	10.00%	Slope1 of the LV side restricted earthfault differential characteristics. Setting is visible only if “Enable I0d> (REF) LV side” is set to “1: Enabled”
LV I0d> Turnpoint2	0.01...50.00xIn	0.01xIn	3.00xIn	Turnpoint 2 for the LV side restricted earthfault differential characteristics. Setting is visible only if “Enable I0d> (REF) LV side” is set to “1: Enabled”
LV I0d> Slope 2	0.01...250.00%	0.01%	200.00%	Slope2 of the LV side restricted earthfault differential characteristics. Setting is visible only if “Enable I0d> (REF) LV side” is set to “1: Enabled”

Table 3.219 Calculations of the DIF function.

Name	Description
L1Bias	Calculated phase L1 Bias current
L2Bias	Calculated phase L2 Bias current
L3Bias	Calculated phase L3 Bias current
L1Diff	Calculated phase L1 Differential current
L2Diff	Calculated phase L2 Differential current
L3Diff	Calculated phase L3 Differential current
L1Char	Calculated phase L1 Max differential current allowed with current bias level
L2Char	Calculated phase L2 Max differential current allowed with current bias level
L3Char	Calculated phase L3 Max differential current allowed with current bias level
HV I0d> Bias current	Calculated HV side restricted earth fault Bias current

Name	Description
HV I0d> Diff current	Calculated HV side restricted earth fault Differential current
HV I0d> Char current	Calculated HV side restricted earth fault differential current allowed with current bias level
LV I0d> Bias current	Calculated LV side restricted earth fault Bias current
LV I0d> Diff current	Calculated LV side restricted earth fault Differential current
LV I0d> Char current	Calculated LV side restricted earth fault differential current allowed with current bias level

Table 3.220 Output signals of the TRF function

Name	Description
Idb> Bias Trip	Trip output signal from the biased differential stage
Idi> Nobias Trip	Trip output signal from the non-biased/non-blocked differential stage
Idb> Bias Blocked	Blocked output from the biased differential stage (external blocking)
Idi> Bias Blocked	Blocked output from the non-biased/non-blocked differential stage (external blocking)
Idb> 2^{nd} harm block on	Output of 2^{nd} harmonic activation signal
Idb> 5^{th} harm block on	Output of 5^{th} harmonic activation signal
HV I0d> Trip	Trip output signal from the biased restricted earth fault differential stage HV side
HV I0d> Trip	Blocked output signal from the biased restricted earth fault differential stage HV side
LV I0d> Trip	Trip output signal from the biased restricted earth fault differential stage LV side
LV I0d> Trip	Blocked output signal from the biased restricted earth fault differential stage LV side

Events and registers

DIF function generates events from internal status changes. From changes of the tripping events also data register is available.

Table 3.221 Event codes of DIF function.

Event Number	Event channel	Event block name	Event Code	Description
4544	71	DIF1	0	Idb> Trip On
4545	71	DIF1	1	Idb> Trip Off
4546	71	DIF1	2	Idb> Blocked (ext) On
4547	71	DIF1	3	Idb> Blocked (ext) Off
4548	71	DIF1	4	Idi> Trip On
4549	71	DIF1	5	Idi> Trip Off
4550	71	DIF1	6	Idi> Blocked (ext) On
4551	71	DIF1	7	Idi> Blocked (ext) Off
4552	71	DIF1	8	2.nd Harmonic Block On
4553	71	DIF1	9	2.nd Harmonic Block Off
4554	71	DIF1	10	5.th Harmonic Block On
4555	71	DIF1	11	5.th Harmonic Block Off
4556	71	DIF1	12	L1 2.nd harm On
4557	71	DIF1	13	L1 2.nd harm Off
4558	71	DIF1	14	L2 2.nd harm On
4559	71	DIF1	15	L2 2.nd harm Off

Event Number	Event channel	Event block name	Event Code	Description
4560	71	DIF1	16	L3 2.nd harm On
4561	71	DIF1	17	L3 2.nd harm Off
4562	71	DIF1	18	L1 5.th harm On
4563	71	DIF1	19	L1 5.th harm Off
4564	71	DIF1	20	L2 5.th harm On
4565	71	DIF1	21	L2 5.th harm Off
4566	71	DIF1	22	L3 5.th harm On
4567	71	DIF1	23	L3 5.th harm Off
4568	71	DIF1	24	HV I0d> Block On
4569	71	DIF1	25	HV I0d> Block Off
4570	71	DIF1	26	HV I0d> Trip On
4571	71	DIF1	27	HV I0d> Trip Off
4572	71	DIF1	28	LV I0d> Block On
4573	71	DIF1	29	LV I0d> Block Off
4574	71	DIF1	30	LV I0d> Trip On
4575	71	DIF1	31	LV I0d> Trip Off

Table below is presents the structure of DIF function register content. This information is available in 12 last recorded events.

Table 3.222 Register content

Date & Time	Event code	L1 Bias current	L1 Diff current	L1 Char current	L2 Bias current	L2 Diff current	L2 Char current
dd.mm.yyyy hh:mm:ss.mss	4544-4575 Descr.	Registered L1 Bias current	Registered L1 Diff current	Registered L1 max diff current with bias	Registered L2 Bias current	Registered L2 Diff current	Registered L2 max diff current with bias

L3 Bias current	L3 Diff current	L3 Char current	HV I0d> Bias current	HV I0d> Differential current	HV I0d> Characteristics current
Registered L3 Bias current	Registered L3 Diff current	Registered L3 max diff current with bias	Registered HV side REF Bias current	Registered HV side REF Diff current	Registered HV side REF max diff current with bias

LV I0d> Bias current	LV I0d> Differential current	LV I0d> Characteristics current	SG in use	Ftype
Registered LV side REF Bias current	Registered LV side REF Diff current	Registered LV side REF max diff current with bias	Used setting group	Detected fault type (faulty phases)

3.10.5 Underimpedance protection Z< (21)

See **Protections, Generator protections, Underimpedance protection Z< (21)**.

3.10.6 Automatic voltage regulator AVR (90)

Automatic voltage regulator (AVR) is used for secondary voltage control in transformers which have on-load tap changer (LTC). Voltage regulator raises or lowers the secondary voltage based onto measurements of the bus voltage. Actual

controlling takes place in LTC which either increases or decreases the secondary winding thus causes increase or decrease of the transformer output voltage.

Transformer secondary voltage / bus voltage may vary based onto the load change, load power factor changes, transmission system variations, R and X of the load changes and LTC changes. From these mentioned quantities the LTC changes. Aim of using automatic voltage regulator is to maintain stable secondary voltage so that distribution voltage does not rise dangerously high or fall unusably low.

For the acceptable voltage range utilities have to follow regional or governmental regulations. For example, in Finland regulation (SFS-EN 50160) requires that distribution voltage phase to ground is 230V. Voltage quality measurement is done with 10-minute average, within this measurement 95% of the measured voltages must be ±10% of nominal voltage and all measured voltages must be +10% ... -15% of the nominal voltage. This voltage is normally gotten from 20/0.4 kV distribution transformers on the medium voltage overhead line (rural areas) and cable networks (urban areas) so the 20kV medium voltage is the place where the voltage has to be controlled for all distribution transformers behind the feeding transformer by controlling the LTC. This control model is commonly called “Bus regulation”.

Other uses for voltage control are for example reactive power control and optimization in the transmission lines.

AVR features and configuration

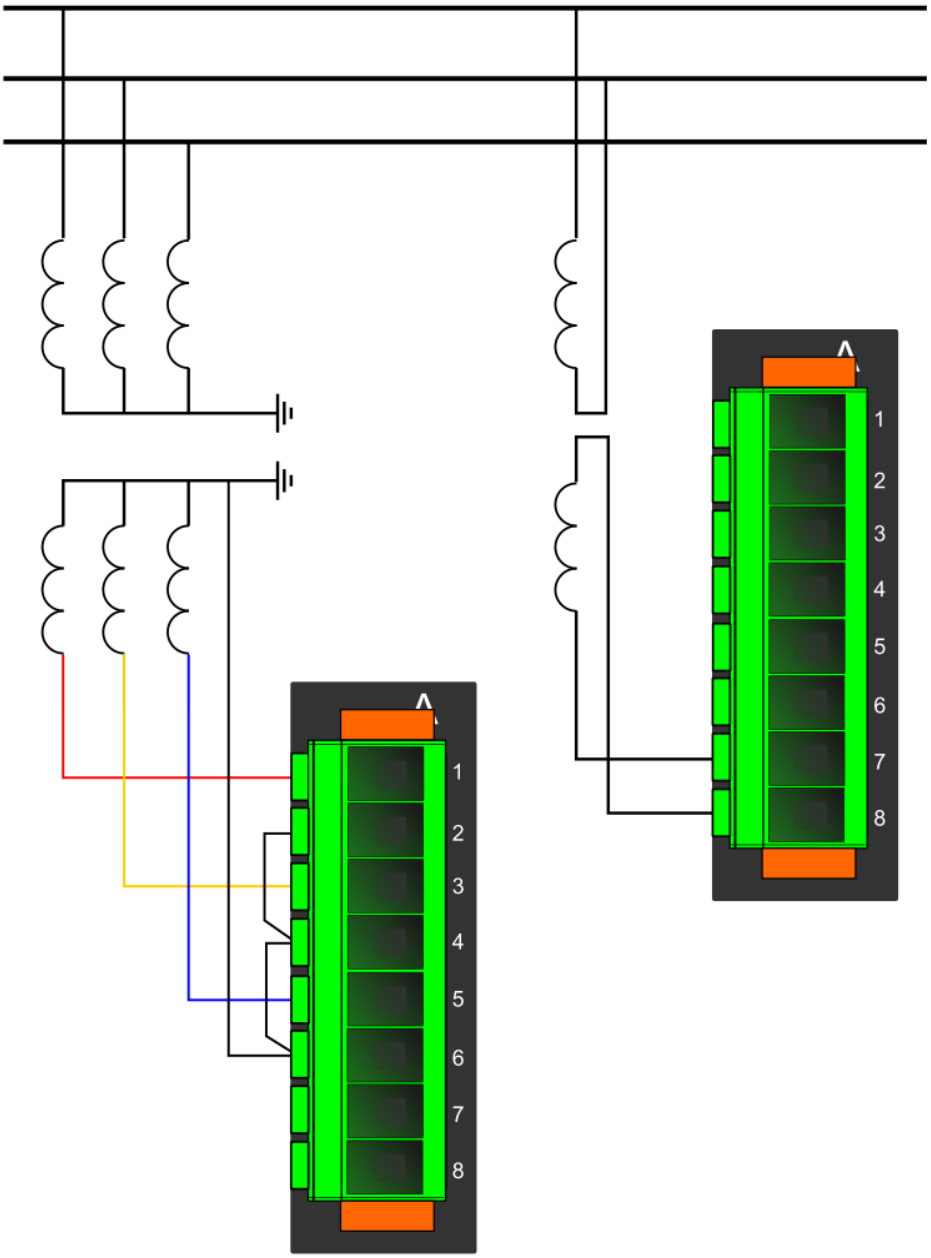
AVR features separate definite and inverse operating time voltage raise and lower windows, instant overvoltage lower, undervoltage blocking and inbuilt overcurrent blocking functions. Target voltage as well as operating settings for the voltage windows can be changed via setting group changes. Tap changer location is monitored with mA, RTD or digital input channel voltage measurement. Tap changer position can be controlled with automatic control and manual control. AVR monitors bus phase to phase voltage. Operation of the AVR can be blocked by external commands by blocking either control algorithm completely or blocking the control outputs only.

Configuring of the AVR is presented in following examples.

General settings

General settings include the measurement reference voltage selection. In this part the measured phase to phase voltage has to be selected as well as the measurement input in case if U4 input is used for voltage measurements.

Figure 3.184 Two of the voltage measurement connection options.



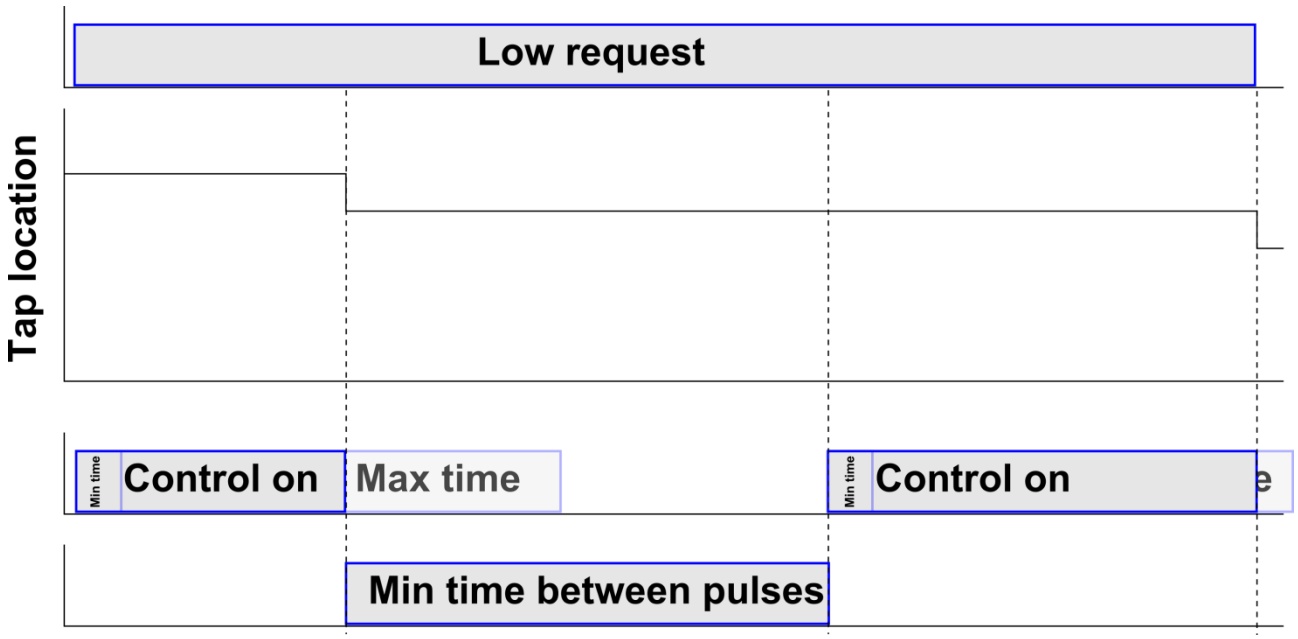
If the relay has full voltage connection with complete phase to phase or phase to ground voltages (left side connection example 3LN+U4 (also 3LL + U4 and 2LL+U3+U4 modes) AVR measurement voltage can be selected directly to U12, U23 or U31. In case only one voltage is available for AVR then it should be connected to U4 input and the AVR needs to be set to measure from U4 channel and the connected voltage (U12, U23 or U31).

General settings menu also includes on-line measurements and calculations from the AVR function as well as the location of the tap changer. Information about the settings and AVR status is found in this part.

Control settings

Control settings include the operating mode selection (Auto / Manual) and the control pulse length max and minimum settings for the used output contacts. Instant operation the minimum wait time between pulses is also set here.

Figure 3.185 Control pulse timing settings.



Control pulses minimum and maximum times are user set. If during the control pulse tap changes and the voltage changes as well to controlled direction the command is terminated. If the maximum set control time has passed the control signal is terminated. In case of instant low request the minimum time between pulses is used after the control pulse is terminated to prevent new control pulse output during this time.

Tap settings

The properties of the used tap changer are set in Tap settings. Number of tap changer positions and middle position as well as the position indication message is configured here.

Example:

Transformer has tap changer with 18 positions of which position 9 presents middle position. Tap changer location is indicated by mA signal 4...20 mA to the relay. Each tap position has 1.67% effect to the transformer output voltage. The highest mA value is expected when tap is in the highest position.

Tap changer properties are set to the AVR:

Setting	**Value**
Tap position indication	mA input
Tap steps totally	18 steps
Tap center position	9 step
Tap step effect	1.67 %

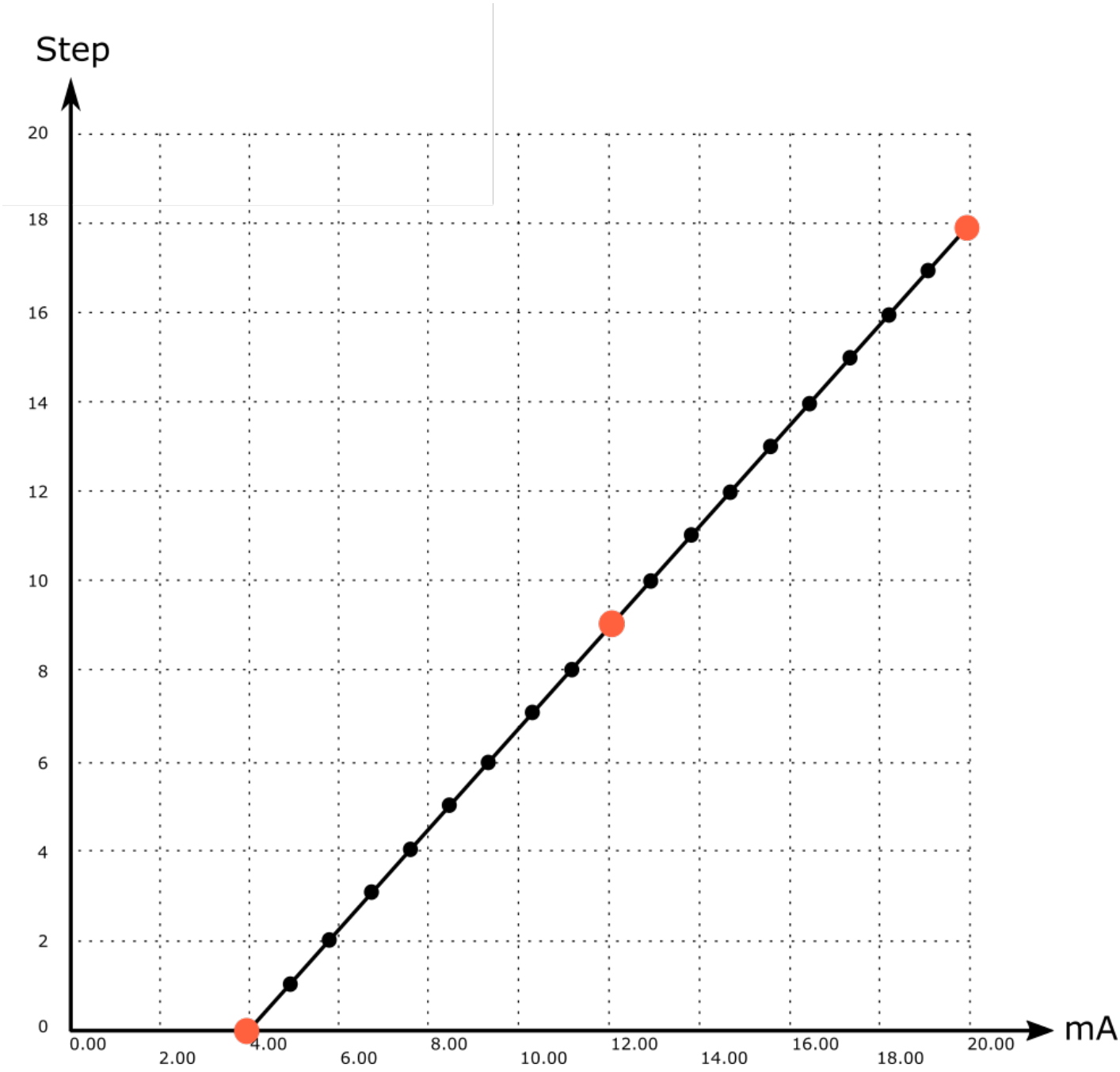
Setting	Value
mA input low range	4 mA
mA input high range	20 mA
Tap position indication	Max.mA.max.Pos

AVR function calculates based to given values:

Calculation	Value
Tap step voltage effect	334 Vpri
Tap maximum decrease	-15.03%
Tap maximum increase	15.03%
Tap control band	30.06%
Tap step in mA	0.889mA
mA input now	measured mA input value

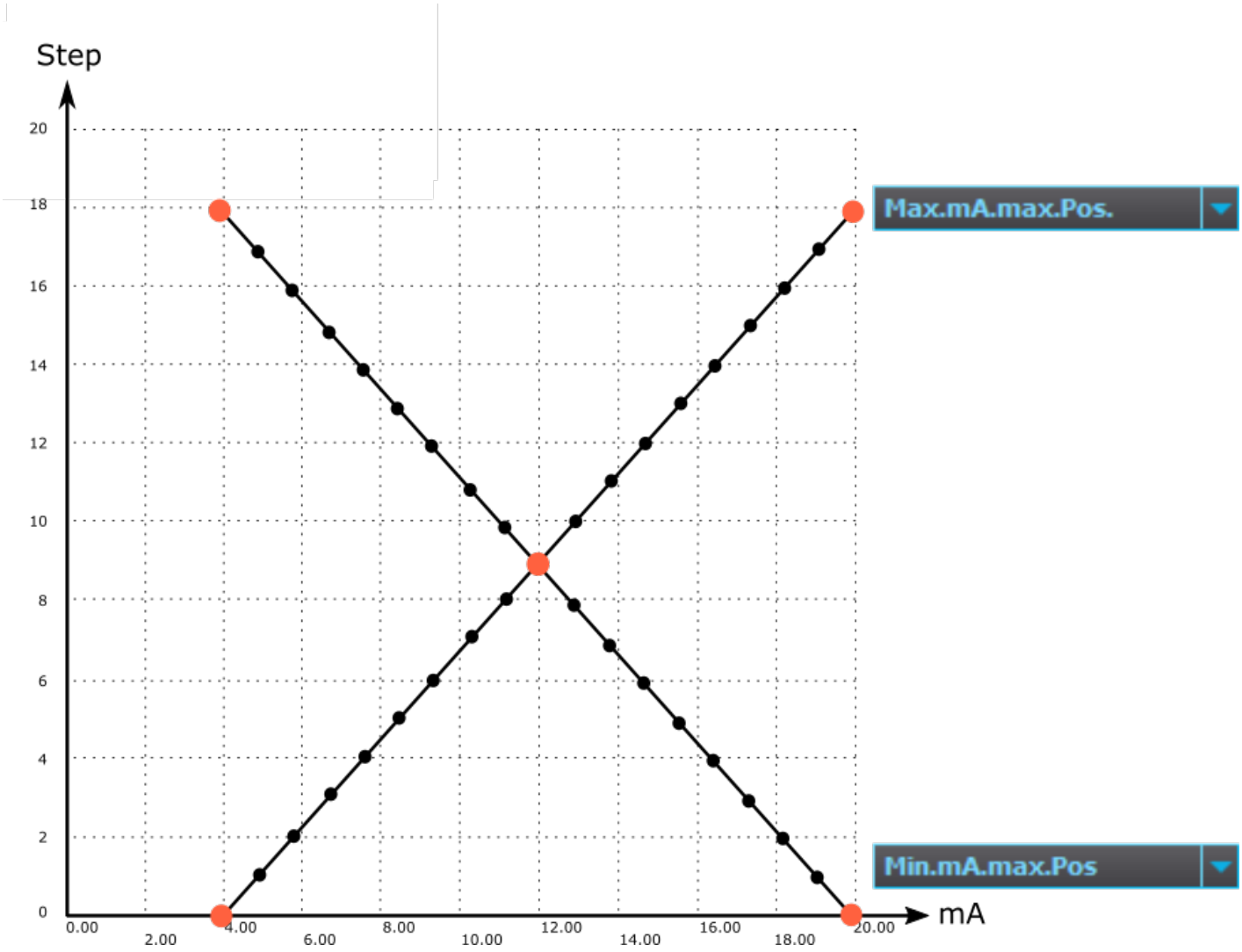
These basic settings define the control area where AVR must operate.

Figure 3.186 Tap position indication according to the settings in the example.



Some tap changers might work “inversely” meaning maximum mA measurement means the tap changer is in the lowest position. If this is the case this can be switched with “Tap position indication” parameter.

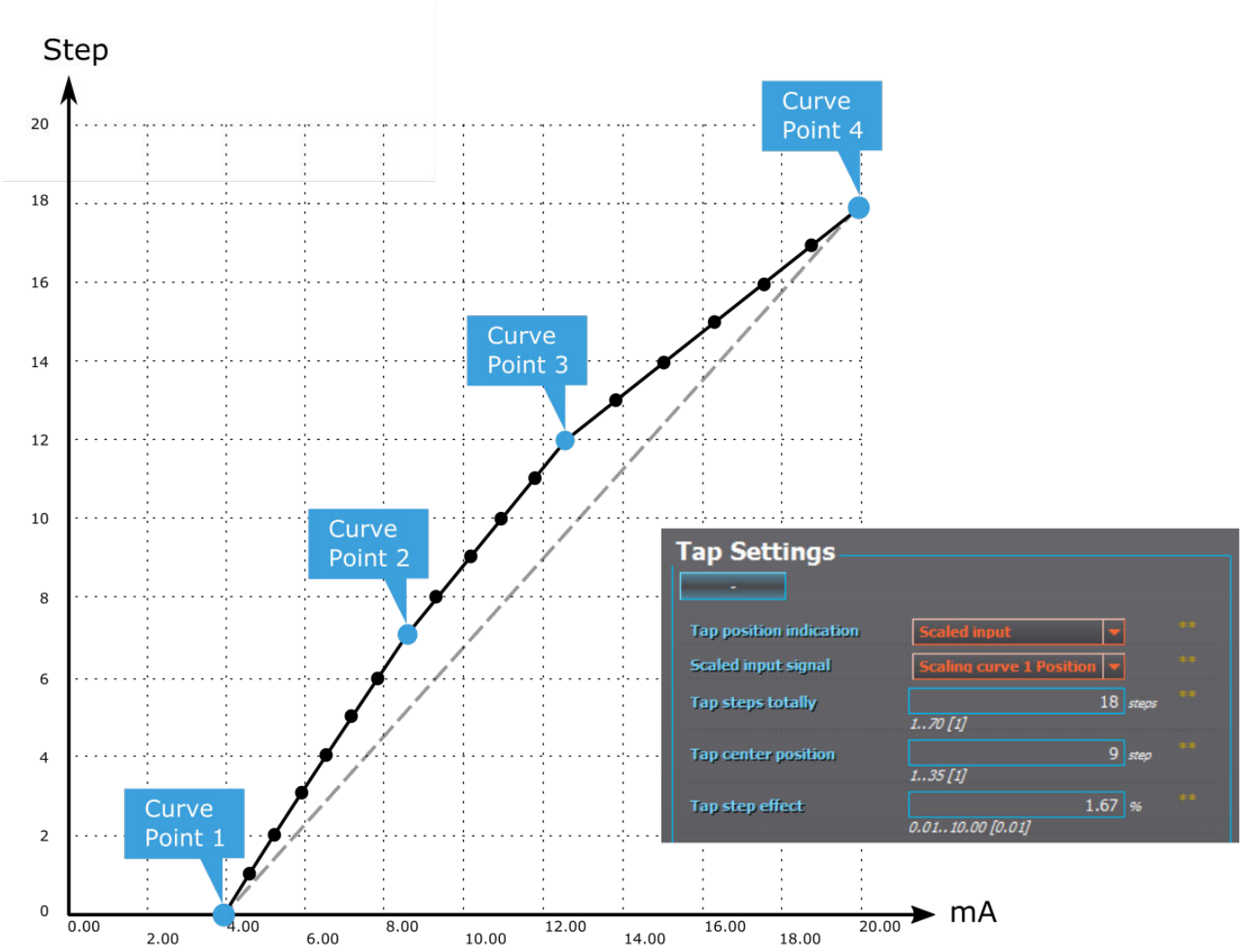
Figure 3.187 Tap position indication can be switched.

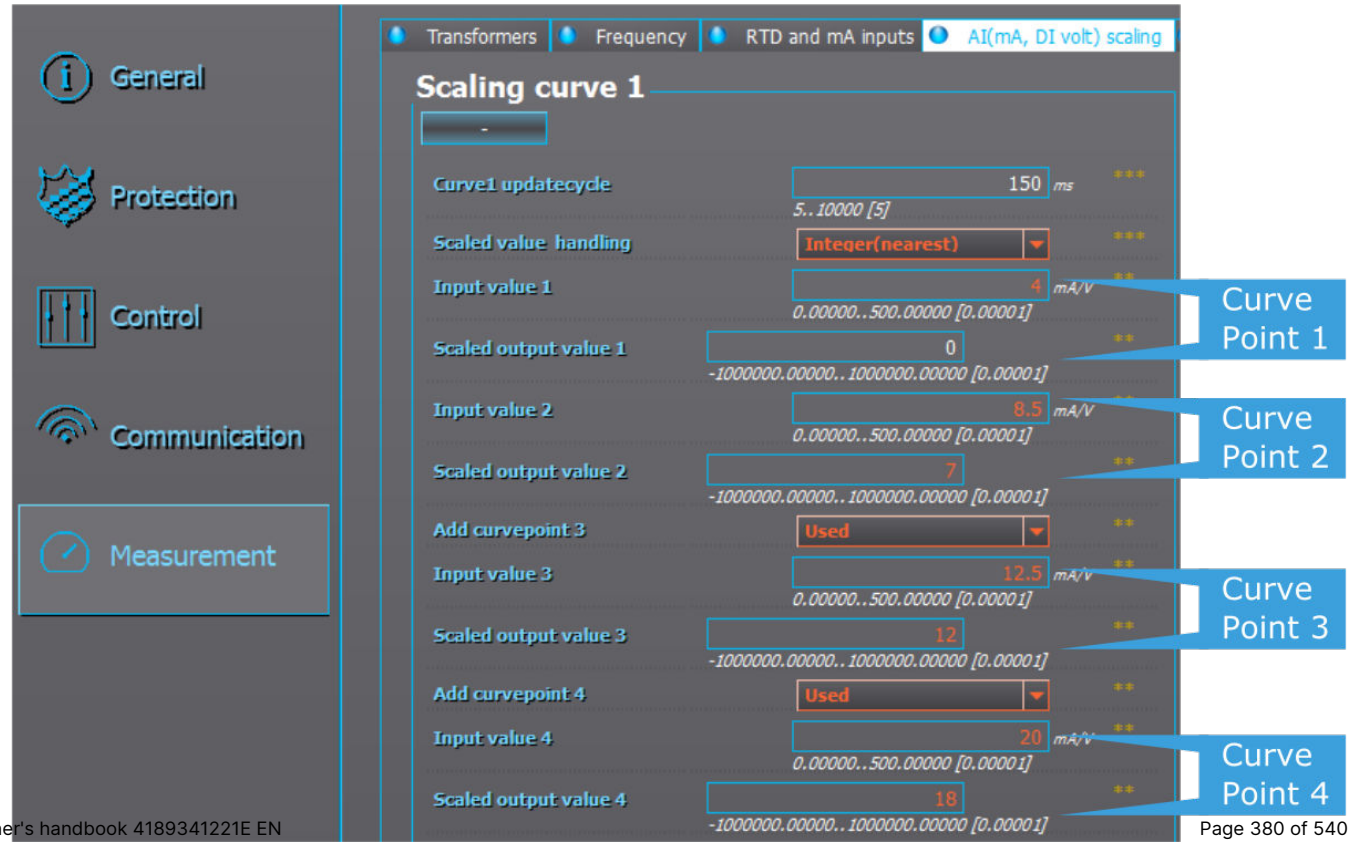


Correcting non-linear mA tap position indication with current scaling

When setting up the tap changer settings it is ideal that the mA difference between each step would be identical. Most of the time this is not the case and in some cases this non-linear ramp-up can cause the voltage regulator function to assume the tap position has changed two steps or zero steps when the tap changer has actually been controlled for one step. This can be corrected by scaling the tap position output value gotten from mA inputs. Below is an example where tap changer has 18 positions and the mA/position curve has been corrected at two points between the min and max positions.

Figure 3.188 Example settings when Scaled curve is used





Tap position with external mA input

Alternative for using RTD&mA card is to use external mA unit ADAM-4016 unit which connects to RS-485 port.

Tap position with BCD coded binary inputs

Sometimes tap position indication is done by using multiple binary inputs. With BCD coded binary inputs any one decimal numeral can be represented by a five-bit pattern. To use BCD coded inputs set the binary inputs used set *Tap position indication* at the function *Info* page to *BCD coded inputs*. Binary inputs are then defined in voltage regulator menu *IO → Input signal control*. It is possible to set up to five binary inputs for BCD coding. Up to 31 positions can be indicated by using BCD coding.

Decimal	5	4	3	2	1	BCD bit
digit	16	8	4	2	1	BCD code
0	0	0	0	0	0	
1	0	0	0	0	1	
2	0	0	0	1	0	
3	0	0	0	1	1	
4	0	0	1	0	0	
5	0	0	1	0	1	
6	0	0	1	1	0	
7	0	0	1	1	1	
8	0	1	0	0	0	
9	0	1	0	0	1	
10	0	1	0	1	0	
11	0	1	0	1	1	
12	0	1	1	0	0	
13	0	1	1	0	1	
14	0	1	1	1	0	
15	0	1	1	1	1	
16	1	0	0	0	0	
17	1	0	0	0	1	
18	1	0	0	1	0	
19	1	0	0	1	1	
20	1	0	1	0	0	
21	1	0	1	0	1	
22	1	0	1	1	0	
23	1	0	1	1	1	
24	1	1	0	0	0	
25	1	1	0	0	1	
26	1	1	0	1	0	
27	1	1	0	1	1	
28	1	1	1	0	0	
29	1	1	1	0	1	
30	1	1	1	1	0	
31	1	1	1	1	1	

Tap position measured from resistance

Instead of using mA measurement RTD resistance is an applicable option. To use RTD measurement the position indication needs to be scaled in menu *Measurement → AI(mA, DI volt) scaling*.

Figure 3.189 Example scaling for tap position indication with RTD measurement

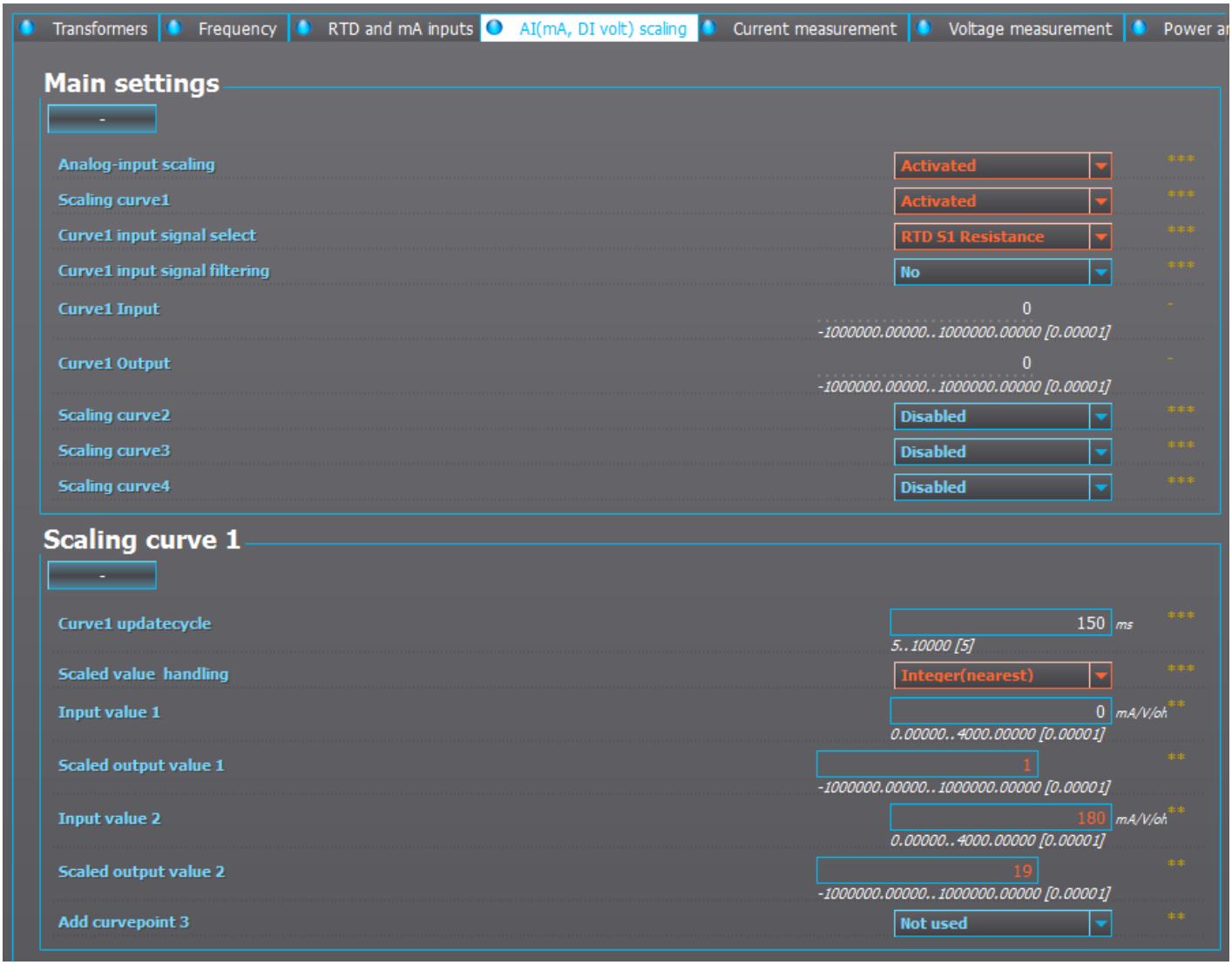
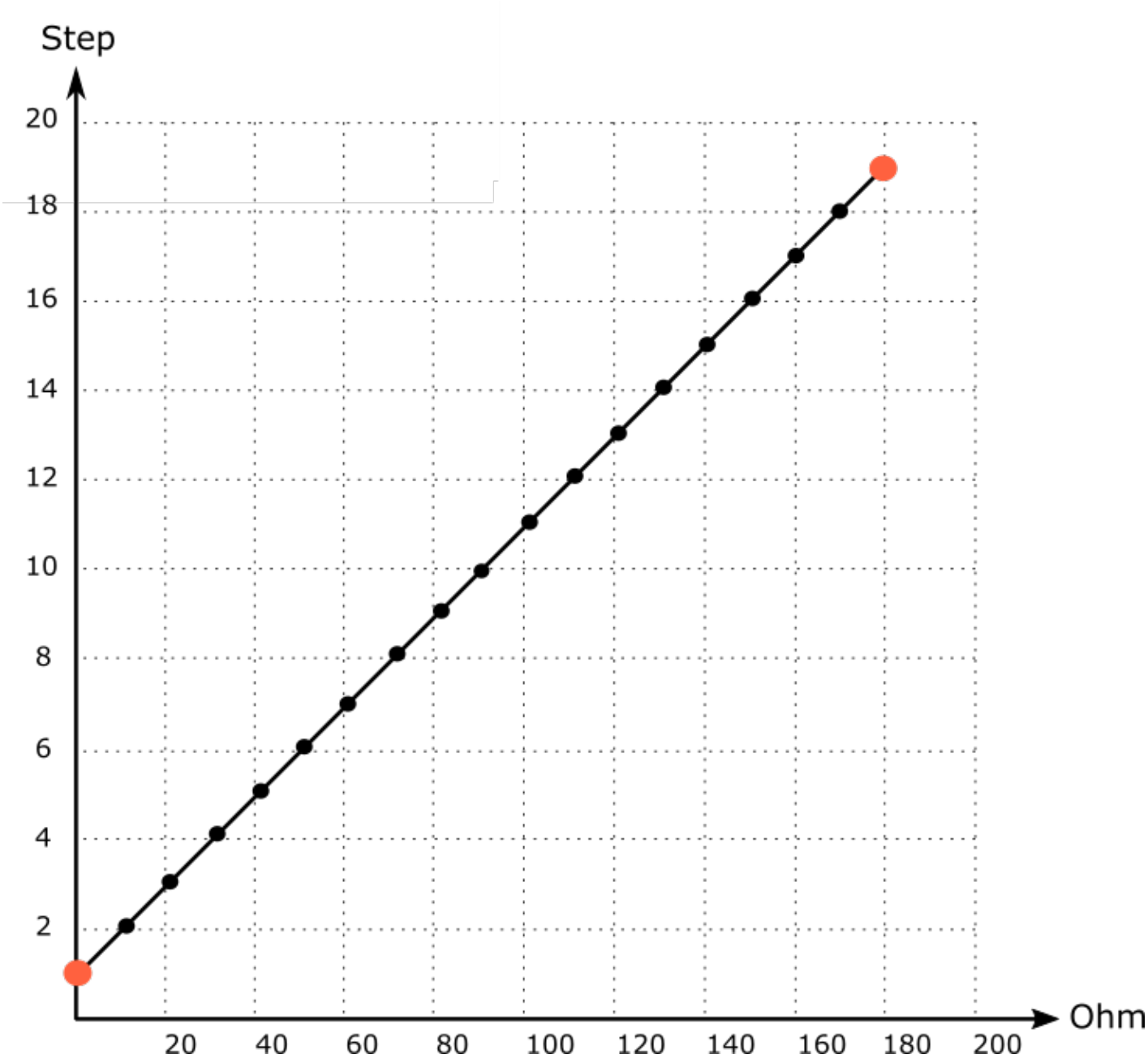


Figure 3.190 Result of the example RTD scaling configuration



In the example figure RTD card sensor 1 is used for tap position indication. With these settings measured resistance 0-180 Ohm is transferred to tap position 1-19. To use this scaling set *Tap position indication* to *Scaled input* in voltage regulator control function page.

Tap position measured from digital input voltage

If none of the above possibilities (RTD, mA or BCD coding) are available it is also possible to use a digital input channel to measure the voltage over the tap changer through a resistor and use this to indicate the tap changer position.

For setup use the same procedure as in RTD measurement option as described previously but instead select the desired digital input as the tap position source.

Voltage regulation settings

Settings presented in this section can be changed on-line by changing the setting group.

The target voltage and the control window where the voltage should be kept needs to be set for the voltage regulation AVR in percentage of nominal value. On parameterization of the voltage window should be considered between regulating sensitivity and also minimizing of the control operations. Unnecessarily tight voltage window may cause excessive control operations which cause the network voltage fluctuation. Calm network and control operations on only necessary cases should be the target. Correctly set voltage window saves the actual tap changer mechanics and keeps the network voltage stable on normal network events.

Few basic rules apply to the parameterization of the first voltage window. First rule is that the window never should be set under one tap step effect in percentage and the window should not be over the allowed voltage variation to loads.

Minimum voltage window size can be calculated as follows:

$$U >/<_{window} = 1.2 \times tap\ step\ effect\ \%$$

This gives 20% more of total band for regulating and with this setting is made sure that the voltage is inside the voltage window after tap change operation. Regulating sensitivity can be increased by setting smaller window but it is not advised.

To set the window to the AVR the calculated U>/<$_{window}$ is divided by two and set to the U> setting (+UTGT) and U< setting (-UTGT) parameters. If both of the window settings are set equally AVR has same sensitivity for over and undervoltage situations. Voltage windows as well as all other setting parameters are in relation of the set target voltage UTGT. If target voltage is changed this given window will follow new target voltage with same parameters.

Figure 3.191 Set window is too tight in comparison to the tap effect. Voltage regulator cannot reach the target window and constantly rises and lowers the voltage. Eventually stabile voltage may be found but next tap change request will cause similar fluctuation.

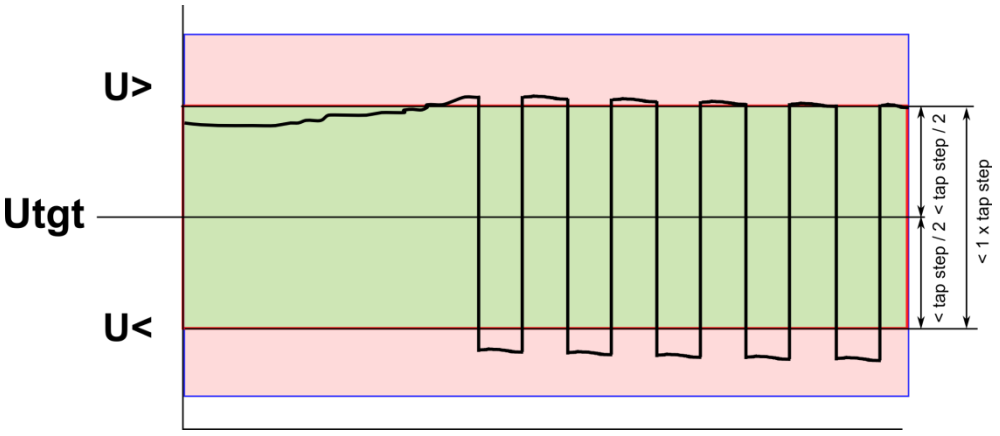


Figure 3.192 Set window is still too tight in comparison to the tap effect. Voltage regulator reaches the set target window with one tap change. However, the voltage after tap change is very near to opposite limit. If voltage changes

back to original value tap change is needed again. This may cause excessive amount of tap operations and the network voltage quality is not significantly improved.

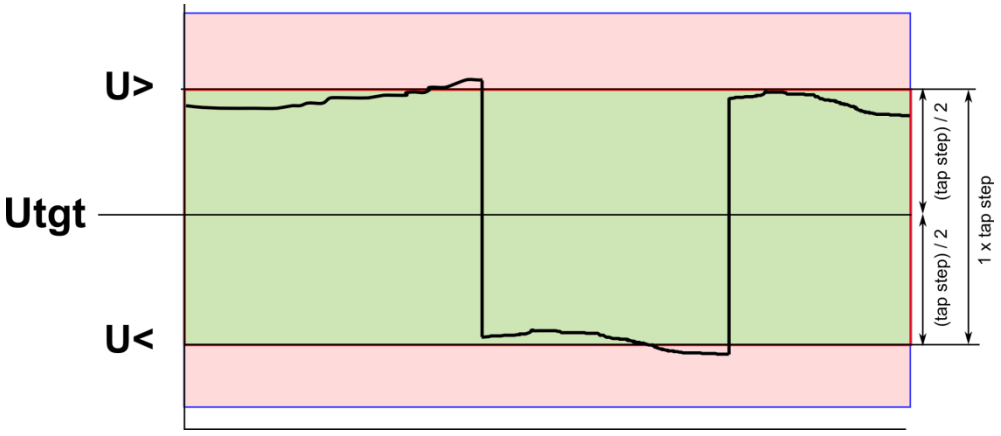
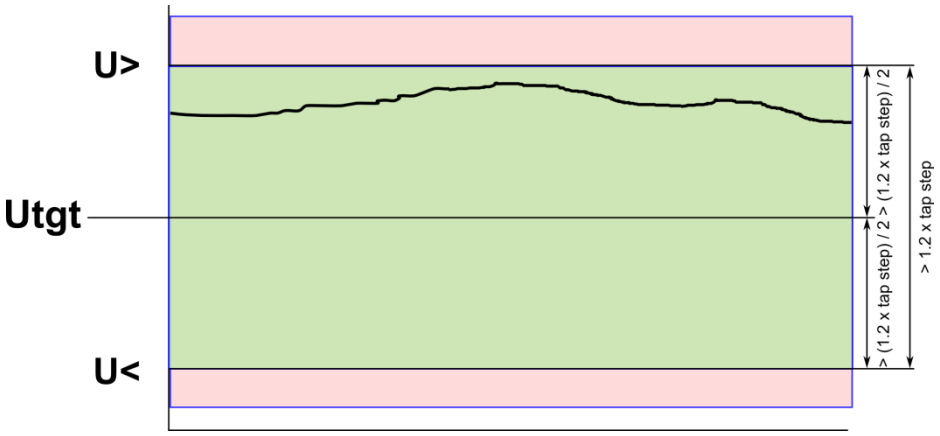


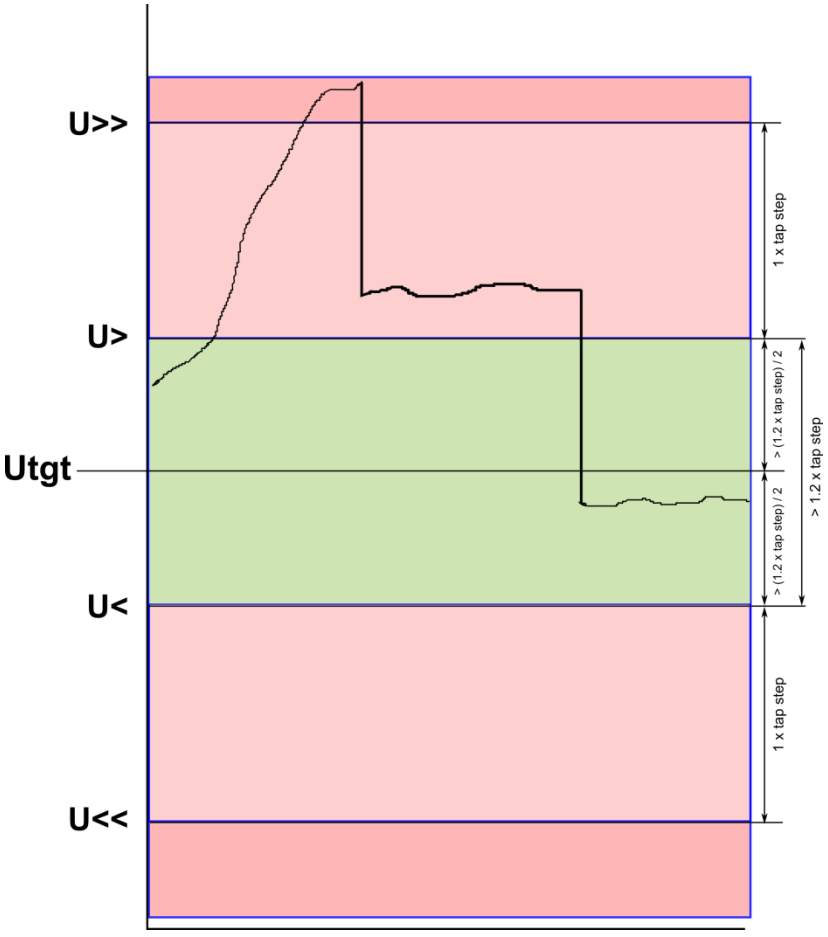
Figure 3.193 Setting recommendation. Set window is 20% bigger than tap step effect. This sensitivity is recommended for stabile and calm operation. This ensures that after tap changing the voltage is not too near of the opposite voltage window border. If more sensitivity is wanted, voltage window below 5% bigger than tap step effect is not recommended.



In the AVR applications first window (U>/$<_{window}$) is normally used for slower operation with definite set operating time on small deviations. Typically this operating time may be 30...120 seconds. Operating time starts to count when the measured voltage exceeds either U> or U< setting limit. If this situation continues until the set operating time tap change operation is applied. If measured voltage returns to target voltage window operating time counter is reset. In the target voltage window 3% hysteresis is applied for the U> and U< pick-up reset.

To define the second voltage window and settings for fast operation the setting limit should be considered so that it is not used before one tap change cannot bring the voltage inside the set first voltage window.

Figure 3.194 First voltage window is 20% bigger than tap step effect. Second window is increased by two tap steps from the first window.

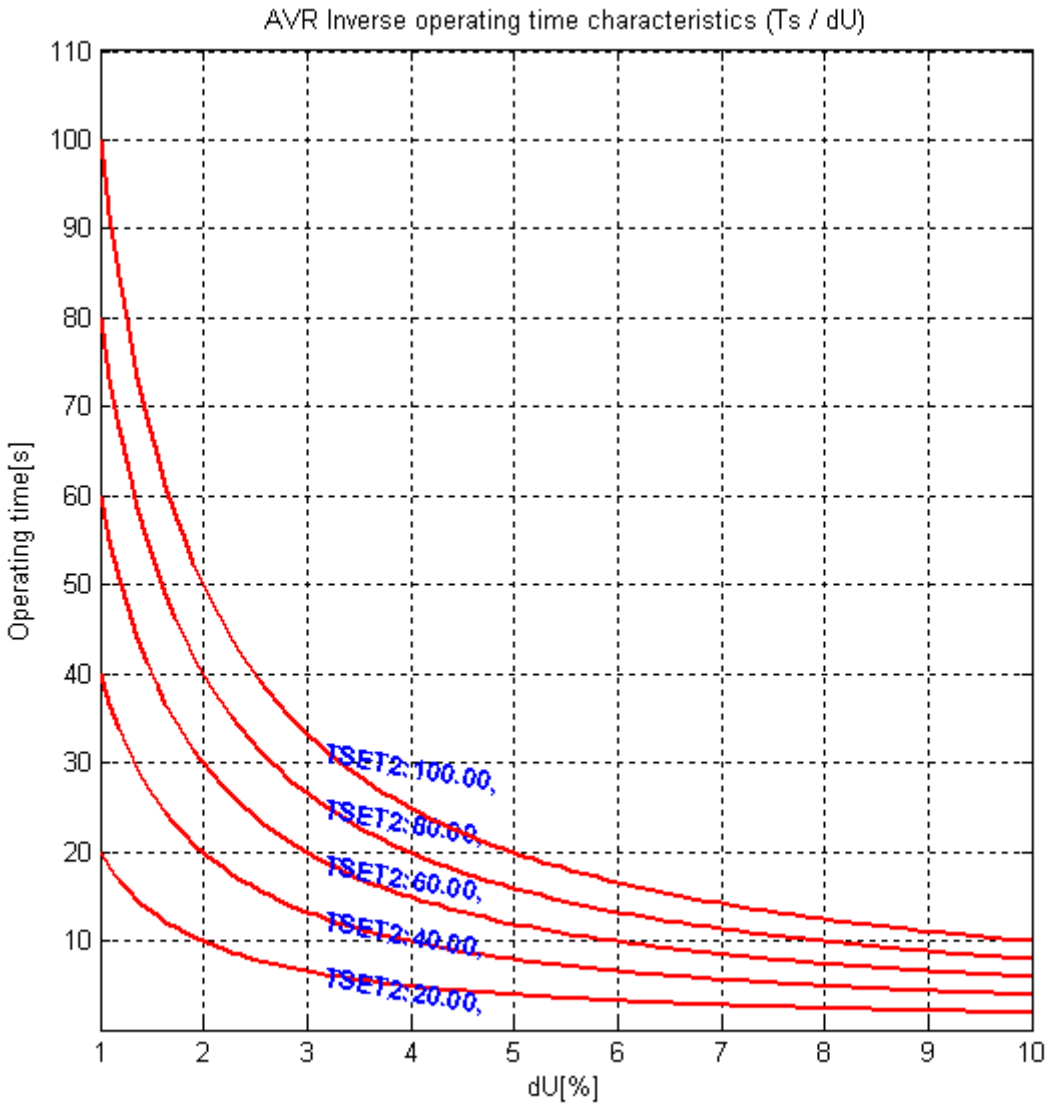


Operating time for the second fast window (is recommended have in inverse mode though it can also be set to definite operating mode. This means that if the measured voltage exceeds the threshold a lot the operating time will be faster and if the measured voltage exceeds the threshold less the operating time will be slower.

AVR inverse operating time follows equation:

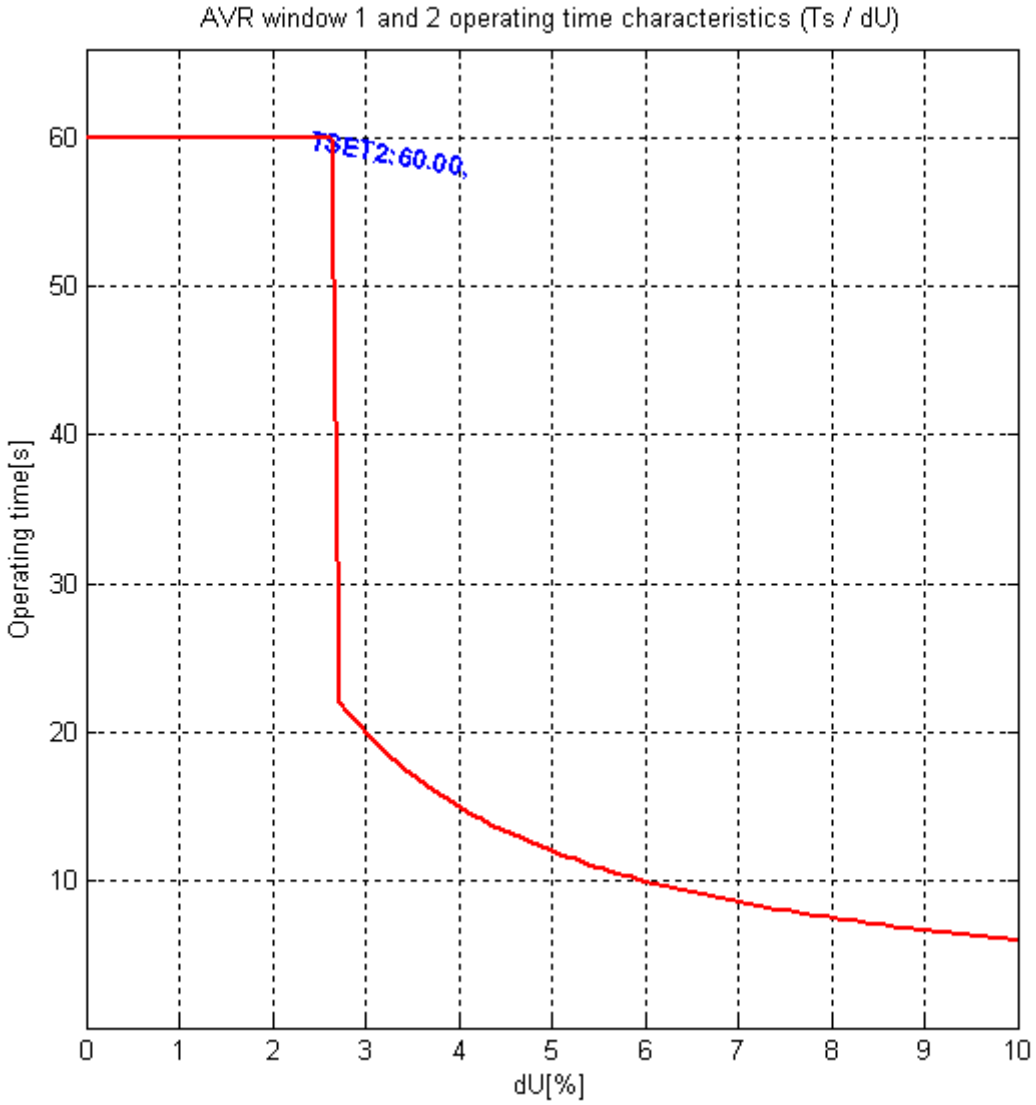
$$Operating\ time = \frac{U \gg\ll Time\ delay}{|\Delta U\%|}$$

Figure 3.195 Inverse operating time characteristics for second (U>/<$_{window}$) .



Inverse operating time controls voltage back to the set target window faster if the deviation is bigger and slower when deviation is smaller.

Figure 3.196 Combined operating time characteristics of voltage windows in function of voltage deviation to the set target voltage.



From the operating characteristics it can be seen that the faster inverse operation until the U>>/<< window threshold setting which after U>/< window threshold gives definite operating time.

Settings for this example are:

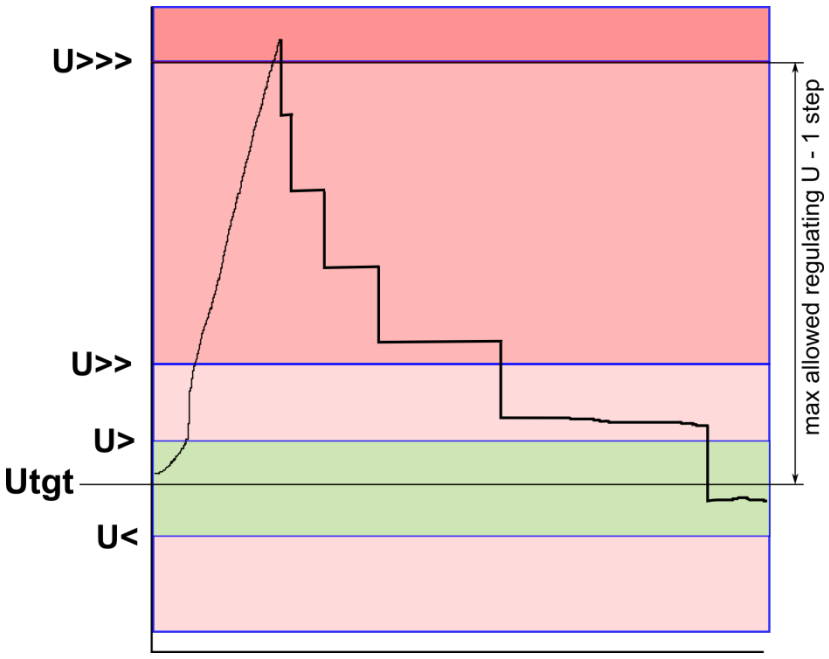
U>/< pick-up = (1.2 * TAPEFF) / 2 = (1.2 * 1.67%) / 2 = 1%, Operating time 60 seconds.

U>>/<< pick-up = U>/< pick-up + TAPEFF = 1 % + 1.67% = 2.67%, Operating time 60 seconds.

For very high overvoltage AVR has an instant low function which lowers the voltage without any given set time delay except the given minimum time between control pulses.

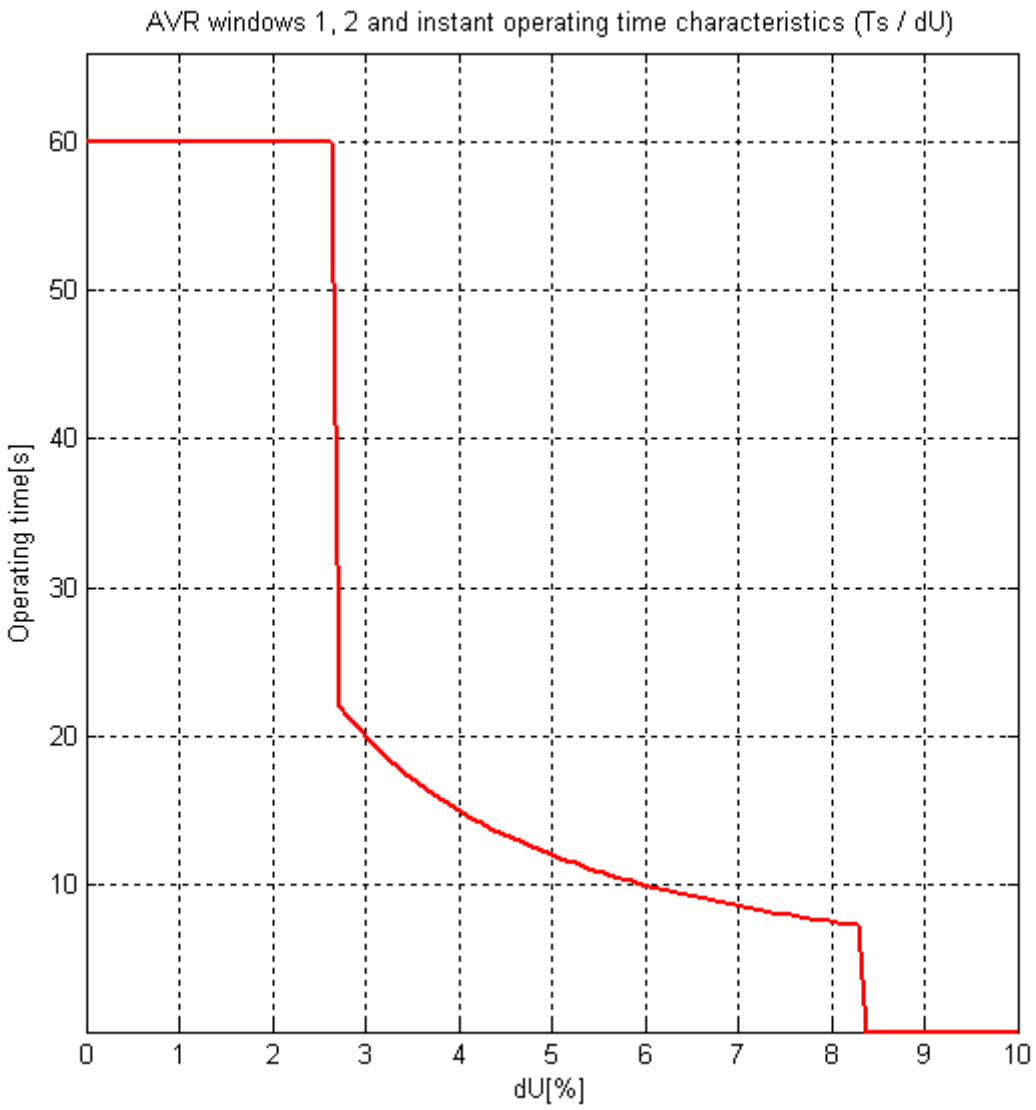
This function is used in the AVR until the measured voltage is below the set instant low threshold level. After the set instant low threshold level is reached corresponding window time characteristics calculate the consecutive time delays until the desired target window is reached.

Figure 3.197 Instant low command utilized in addition to two time delayed windows.



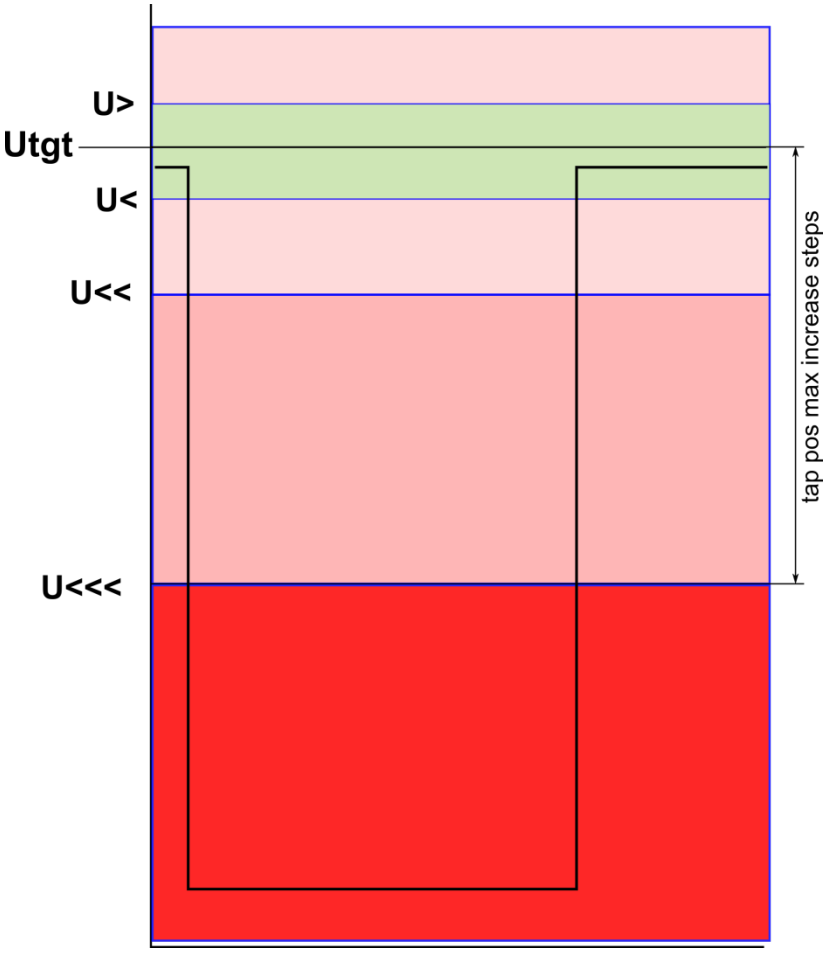
Pick up setting recommendation for the instant low function is maximum allowed overvoltage subtracted with tap effect. By this way there should not be situation where the voltage is allowed pass longer time over the maximum allowed voltage. For example if the maximum allowed overvoltage is 10% by local standards and tap effect for the transformer is 1.67% instant low function pick-up should be set 10% - 1.67% = 8.33%.

Figure 3.198 Instant low setting effect to time characteristics.



AVRs low voltage blocking prevents the operation of the tap changer control in case of heavy short circuit faults in the feeding network side as well as the drifting of the tap to maximum voltage increase position during power off situations.

Figure 3.199 Low voltage blocking prevents the tap changer operations to avoid the control to maximum position when the feeding voltage returns to nominal level.



Setting suggestion for the low voltage blocking is the maximum tap increase positions effect. For example if the tap changer has +/- 9 x 1.67% control range, undervoltage blocking should be set to 9 x 1.67% = 15 %

Last part of the AVR configuration is to make sure that load side overcurrent/short circuit fault does not cause tap change operation due to load side voltage drop. If the operation of AVR is not blocked during the short circuit fault when the transformer is under heavy overcurrent, tap changer controls the voltage up to compensate the voltage drop causing most probably damage to the tap changer equipment. Internal overcurrent blocking can be used to achieve this (if the phase currents are measured with the AVR) or pick-up signal from the external overcurrent relay or transformer protection relay may be used either with goose or wired signal to the AVR digital input.

Measured input values

AVR measures phase to phase voltages for voltage controlling. Optionally phase currents can be measured for overcurrent blocking.

Table 3.223 Measurement magnitudes used by the AVR function.

Signal	Description	Time base
U12 System	Phase to phase system voltage U12	5 ms
U23 System	Phase to phase system voltage U23	5 ms
U31 System	Phase to phase system voltage U31	5 ms
IL1	Phase current IL1	5 ms
IL2	Phase current IL2	5 ms
IL3	Phase current IL3	5 ms

General settings

General settings define the basic control voltage measurement configuration settings as well as give overall information about AVR condition and status.

Table 3.224 Measurement magnitudes used by the AVR function.

Signal	Description	Time base
U12 System	Phase to phase system voltage U12	5 ms
U23 System	Phase to phase system voltage U23	5 ms
U31 System	Phase to phase system voltage U31	5 ms
IL1	Phase current IL1	5 ms
IL2	Phase current IL2	5 ms
IL3	Phase current IL3	5 ms

General settings

General settings define the basic control voltage measurement configuration settings as well as give overall information about AVR condition and status.

Table 3.225 General settings parameters.

Name	Description	Range	Step	Default
Voltage measurement	Selection of the measured system voltage from the U1, U2 and U3 inputs.	0: U12 1: U23 2: U31 3: U4 input	-	0:U12
U4 measure (visible only if Voltage measurement is set to 3:U4 Input)	Selection of the measured system voltage from the U4 input.	0: U12 1: U23 2: U31	-	0:U12

Table 3.226 General settings indications and measurements.

Name	Description	Range	Step	Default
Avr settings condition (bitmask)	Internal information about settings. If the value differs from 0 settings are not correct.	1b: U>> set too low 2b: U< set too high 3b: U> set higher than U>> 4b: U< set lower than U<< 5b: U>>> set too low 6b: U<<< set too high 7b: VT selection not ok	-	0 (settings are ok)
Avr operational condition (bitmask)	Internal information about AVR current status	1b: Raise command on 2b: Lower command on 3b: Operation blocked 4b: Output control blocked 5b: U<<< block on 6b: I> block on 7b: Tap on highlimit 8b: Tap on lowlimit 9b: Operation blocked 10b: U>/< pick-up on 11b: U>>/<< pick-up on 12b: Control wait time on	-	0 (Nothing happens)

Name	Description	Range	Step	Default
		13b: Manual control mode on		
AVR timer active	In case if AVR is counting time the timer is shown here	0:- 1:Fine tune Decrease 2:Fine tune Increase 3:Low set Decrease 4:High set Degrease 5:Instant Decrease 6:Low set Increase 7:High set Increase	-	0:no timers active.
Time left to operation	Counter left time before action	0.000...1800.000s	0.005s	0s
Voltage now	Measured reference voltage in comparison to nominal	0.000...140.000%Un	0.01%Un	0%Un
Voltage difference to set target	Measured reference voltage difference to set target voltage	0.000...140.000%Un	0.01%Un	100%Un
Voltage set now to	Based into tap changer location displays primary voltage deviation.	-50000...50000Vpri	0.01V	0.00V
U>>> (instant) setting	Set instant stage compared to nominal 100% level	0.000...140.000%	0.01%	110%
U>> setting	Set second window high limit compared to nominal 100% level	0.000...140.000%	0.01%	105%
U> setting	Set first window high limit compared to nominal 100% level	0.000...140.000%	0.01%	100.88%
U< setting	Set first window low limit compared to nominal 100% level	0.000...140.000%	0.01%	99.12%
U<< setting	Set second window low limit compared to nominal 100% level	0.000...140.000%	0.01%	95%
U<<< setting	Set undervoltage block limit	0.000...140.000%	0.01%	85%
Voltage meas condition	Display of measured voltage selection. Check value that selected voltage input is correct.	0:U12 1:U23 2:U31 3:U4 Input	-	0:U12
Tap location (- 0 +)	Tap location in the tap changer in relation to middle point.	-30...30	1	0
Absolute tap location	Tap location in the tap changer in relation to whole range 0...max tap steps.	0...50	1	0
Tap changer on high border	Indication if the tap changer has reached maximum voltage high position	0:No 1:Yes	-	0:No
Tap changer on low border	Indication if the tap changer has reached minimum voltage low position	0:No 1:Yes	-	0:No

Control settings

Control settings define the control model and manual raise and lower commands from the HMI. Control outputs timing control is here as well.

Table 3.227 Control settings parameters.

Name	Description	Range	Step	Default
Control mode	Selection of control mode	0: Auto	-	0:Auto

Name	Description	Range	Step	Default
		1: Manual		
Manual tap increase	Increase tap by 1 step to higher voltage	0:- 1:Increase	-	0:-
Manual tap decrease	Decrease tap by 1 step to lower voltage	0:- 1:Decrease	-	0:-
Control pulselength max	Maximum time the tap control (up or down) output contact can be closed	0.000...1800.000s	0.005s	2.000s
Control pulselength min	Minimum time the tap control (up or down) output contact should be closed.	0.000...1800.000s	0.005s	2.000s
Min time between pulses	Minimum time in between of separate consecutive control commands	0.000...1800.000s	0.005s	0.500s

Tab settings

In tap settings the tap changer equipment properties and connection for position indication to AVR are set.

Table 3.228 Tap settings parameters.

Name	Description	Range	Step	Default
Tap position indication	Selection of tap position indication message.	0: Select 1: mA input 7 2: mA input 8 3: mA External input (ADAM) 4: Scaled input 5: BCD coded inputs	-	0: Select
Tap steps totally	Number of tap steps from minimum to maximum	1...70	1	18
Tap center location	Position of nominal non regulated tap location	1...35	1	9
Tap step effect	Effect of one tap step in percentage of nominal voltage	0.01...10.00%	0.01%	1.67%
Tap position indication	Defines if mA minimum or maximum value is the highest tap position.	1:Max.mA.max.Pos.2:Min.mA.max.Pos	-	1:Max.mA.max.Pos
mA input low range	mA input measurement presenting the minimum tap position. Setting is visible if any of the mA position indication modes are selected.	0.000...4.000mA	0.001mA	4.000mA
mA input high range	mA input measurement presenting the maximum tap position. Setting is visible if any of the mA position indication modes are selected.	0.010...20.000mA	0.001mA	4.000mA

Table 3.229 Tap settings indications and measurements

Name	Description	Range	Step	Default
Tap step voltage effect	One tap step effect to primary voltage	0.00...5000.00Vpri	0.01Vpri	0 Vpri
Tap maximum decrease	Maximum voltage decrease from nominal position in percentage	-140.00...0.00%	0.01%	0.00%
Tap maximum increase	Maximum voltage increase from nominal position in percentage	0.00...140.00%	0.01%	0.00%

Name	Description	Range	Step	Default
Tap controlband	Tap changer control band where the secondary voltage may be varied	0.00...140.00%	0.01%	0.00%
Tap step in mA	One tap step effect change to mA measurement	0.000...20.000mA	0.001mA	0mA
mA input now	mA input measurement value at the moment	0.000...20.000mA	0.001mA	0mA

Statistics

Counters of the AVR common operations and statuses.

Table 3.230 Counters of AVR function

Name	Description	Range
AVR rised voltage	How many times AVR has increased the bus voltage	One tap control operation increases cumulative sum by 1
AVR reduced voltage	How many times AVR has decreased the bus voltage	One tap control operation increases cumulative sum by 1
AVR control blocked	How many times AVR operation has been blocked by external command	One blocking operation increases cumulative sum by 1
AVR undervoltage blocked	How many times AVR operation has been blocked by detected undervoltage condition	One blocking operation increases cumulative sum by 1
AVR overcurrent blocked	How many times AVR operation has been blocked by detected overcurrent condition	One blocking operation increases cumulative sum by 1

Operational regulating settings

These settings define the AVR regulating behavior.

Table 3.231 Operational regulating settings.

Name	Description	Range	Step	Default
Target voltage (UTGT)	Optimal regulating target voltage in comparison to nominal voltage	70.00...140.00%	0.01%	100.00%
U>/< window in use	Low set definite time voltage window in use or not	0:Not in use 1:In use	-	0:Not in use
U> setting (+UTGT) (visible if U>/< window in use)	High voltage limit for the low set voltage window	0.10...30.00%	0.01%	0.88%
U< setting (-UTGT) (visible if U>/< window in use)	Low voltage limit for the low set voltage window	0.10...30.00%	0.01%	0.88%
U>/< time delay (DT) (visible if U>/< window in use)	Operating time delay for low set voltage window threshold deviation (up/down) before regulating command	0.000...1800.000s	0.005s	60.000s
U>>/<< window in use	High set definite/inverse time voltage window in use or not	0:Not in use 1:In use	-	0:Not in use
U>> setting (+UTGT) (visible if U>>/<< window in use)	High voltage limit for the high set voltage window	0.10...30.00%	0.01%	2.67%
U<< setting (-UTGT) (visible if U>>/<< window in use)	Low voltage limit for the high set voltage window	0.10...30.00%	0.01%	2.67%
U>>/<< time delay mode (visible if U>>/<< window in use)	Inverse or definite time mode for the second high set voltage window	0: Definite 1: Integral	-	1:Integral
U>>/<< time delay (DT/Multiplier) (visible if U>>/<< window in use)	Operating time delay for high set voltage window threshold deviation. This value	0.000...1800.000s	0.005s	60.000s

Name	Description	Range	Step	Default
	directly if time delay mode is 0:Definite. If integral mode then this is the inverse operating time multiplier			
U>>> instant in use	Selection whether the instant low function is used	0: Not in use 1: In use	-	0:Not in use
U>>> setting (+UTGT) (visible if U>>> instant in use)	Overvoltage threshold for U>>> instant low stage	0.10...30.00%	0.01%	8.33%
U<<< block setting (-UTGT)	Undervoltage blocking threshold	5.00...60.00%	0.01%	15.00%
Internal OC blocking	Selection whether internal overcurrent detection blocks the AVR operation	0: Not in use 1: In use	-	0: Not in use
Internal OC pick-up >	Pick-up threshold for internal overcurrent blocking.	0.00...40.00xIn	0.01xIn	2.00xIn

Function external blocking

Operation of the AVR can be blocked either by internal or external input commands. If the operation is wanted to be done externally, binary input or goose messages can be used for blocking the operation. AVR function provides two separate inputs for blocking which of the first one when controlled to active blocks the control algorithm operation and output contacts (for application use) while the second one blocks only the output contacts but control algorithm is still operational (for commissioning the settings).

Table 3.232 AVR blocking inputs

Name	Description
AVR Block op and outs	Application block for the AVR function. Should be used for all external blockings of the AVR operation. Blocks both the output contacts and the algorithm from operating.
AVR block control outs	Commissioning block for the actual controlling of the output contacts. Blocks only the output contacts from the AVR function.

Output signals

Following output signals available in the AVR function.

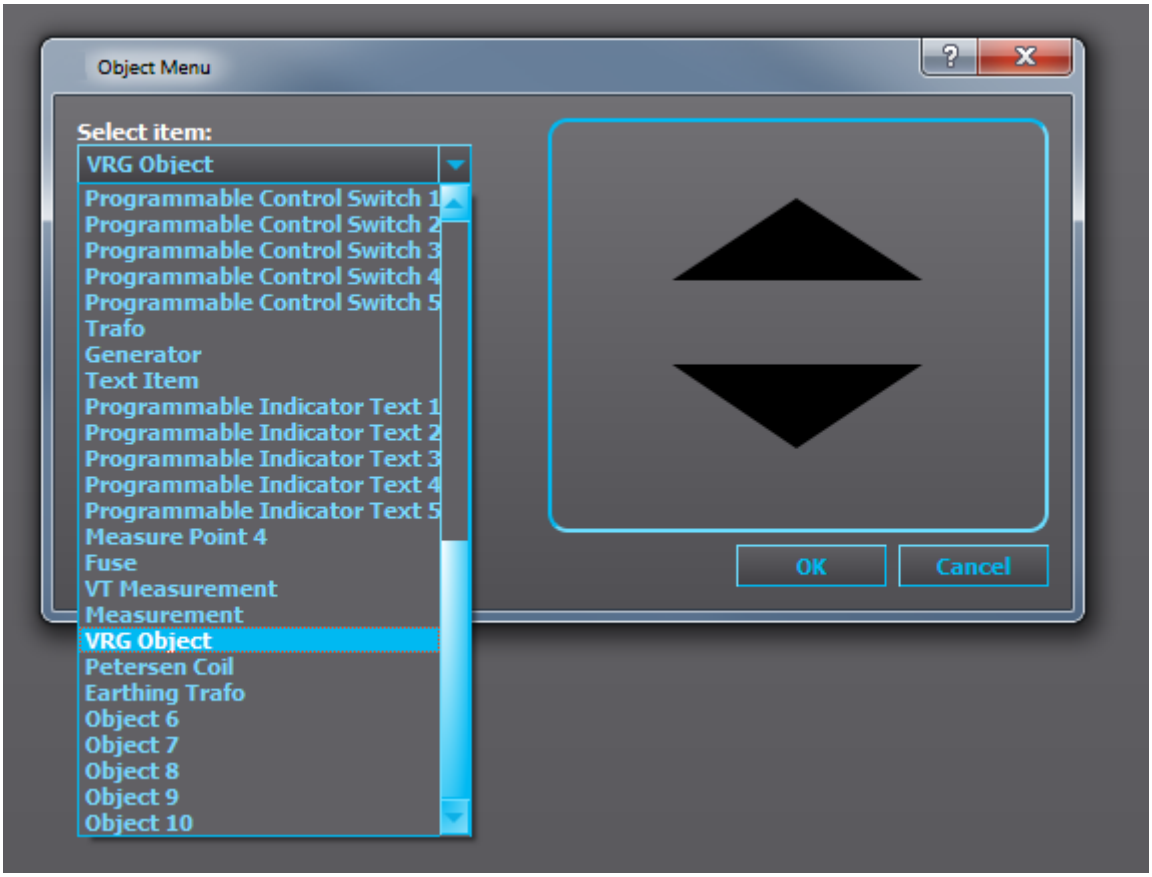
Table 3.233 AVR output signals

Name	Description
AVR raise tap CMD	Output command to raise tap one step
AVR lower tap CMD	Output command to lower tap one step
AVR in manual control	Indicates that the automatic voltage regulation mode is overridden by manual control
AVR U>/< started	Indicates that the first voltage window threshold has been exceeded and the AVR is counting time to tap change operation.
AVR U>>/<< started	Indicates that the second voltage window threshold has been exceeded and the AVR is counting time to tap change operation.
AVR outputs blocked	Indicates that the output contact control is blocked and the actual output signals and events are not given to the tap changer
AVR operation blocked	Indicates that the AVR algorithms and measurements are blocked
AVR control wait on	Indicates that the AVR consecutive controls time delay is activated and on. Further output commands are suppressed until this signal releases.
AVR U< block active	Internal undervoltage blocking of the tap change operation is active
AVR I> block active	Internal overcurrent blocking of the tap change operation is active

Name	Description
AVR tap in highlimit	Indicates that further voltage raise commands cannot be given since the tap changer is on high limit
AVR tap in lowlimit	Indicates that further voltage lower commands cannot be given since the tap changer is on low limit

Controlling the voltage regulator from the mimic in manual mode

To control the tap position up and down from the mimic view it is possible to add “VRG Object” into the mimic. This object has and internal connection to the voltage regulator function. When voltage regulator has been set to manual mode tap position can be controlled up and down with this object, where button “0” will control tap position down and “1” will control tap position up.



To switch the voltage regulator to manual/automatic mode a signal for this must be determined. In the voltage regulator *IO → Input signal control* menu signal *AVR to Manual control* determines this. The signal can be a digital input, logical signal or programmable control switch signal. If this kind of external signal is used it is better to control that external signal to switch between the two modes (Auto/Manual) from SCADA instead of the voltage regulators internal signal Auto/Man. Controlling the internal auto/man signal from SCADA when there is also external signal switching between auto/man mode can lead conflicts between the two controls.

Controlling voltage regulator remotely with IEC61850 in manual mode

To control automatic voltage regulator manually in manual mode VRG must be added to a dataset. If VRG is added to a dataset it is possible to control voltage regulator with *VRG AVCO/TapChg/Oper. 0=Stop, 1=Higher, 2=Lower.*

Events and registers

The AVR function generates events and registers from the status changes of internal pick-ups and other control events.

12 last registers are available in the function where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values.

Table 3.234 Events codes of the AVR function.

Event Number	Event channel	Event block name	Event Code	Description
7360	115	VRG1	0	Tap Raise command On
7361	115	VRG1	1	Tap Raise command Off
7362	115	VRG1	2	Tap Lower command On
7363	115	VRG1	3	Tap Lower command Off
7364	115	VRG1	4	Block operation On
7365	115	VRG1	5	Block Operation Off
7366	115	VRG1	6	Block Output commands On
7367	115	VRG1	7	Block Output commands Off
7368	115	VRG1	8	Low voltage blocking On
7369	115	VRG1	9	Low voltage blocking Off
7370	115	VRG1	10	Overcurrent blocking On
7371	115	VRG1	11	Overcurrent blocking Off
7372	115	VRG1	12	Tap on highlimit On
7373	115	VRG1	13	Tap on highlimit Off
7374	115	VRG1	14	Tap on lowlimit On
7375	115	VRG1	15	Tap on lowlimit Off
7376	115	VRG1	16	Operation blocked On
7377	115	VRG1	17	Operation blocked Off
7378	115	VRG1	18	U>/< Start On
7379	115	VRG1	19	U>/< Start Off
7380	115	VRG1	20	U>>/<< Start On
7381	115	VRG1	21	U>>/<< Start Off
7382	115	VRG1	22	Control wait time On
7383	115	VRG1	23	Control wait time Off
7384	115	VRG1	24	Manual control On
7385	115	VRG1	25	Automatic control On
7386	115	VRG1	26	Tap raise requested On
7387	115	VRG1	27	Tap raise requested Off
7388	115	VRG1	28	Tap lower requested On
7389	115	VRG1	29	Tap lower requested Off

4. Other functions

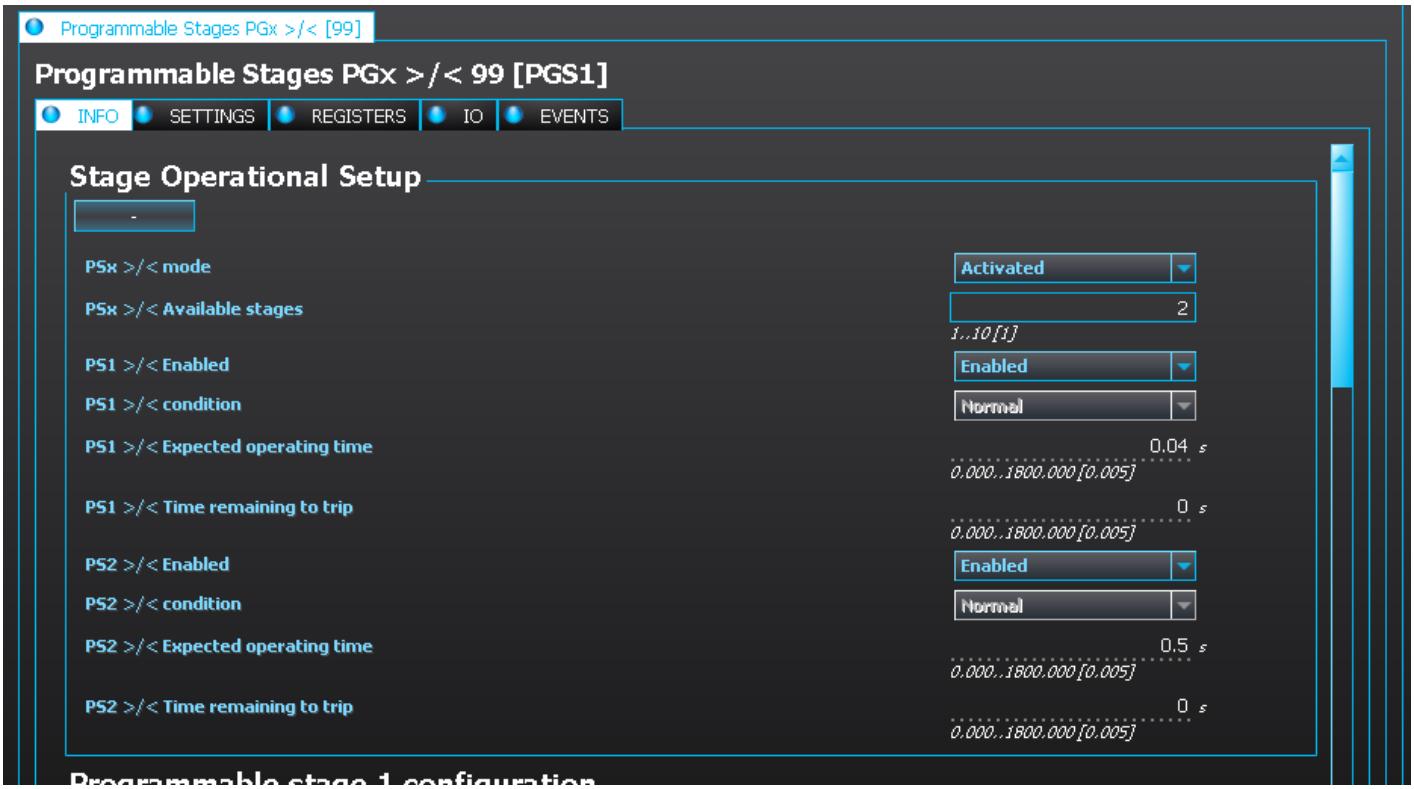
4.1 General functions

4.1.1 Programmable stage PGx >/< (99)

The programmable stage (PGS) is a stage that can be programmed by the user to create more advanced applications either as an individual stage or together with programmable logic. The relay has ten programmable stages, of which each can be set to compare from one to three analog measurements. The programmable stages have over-, under- and rate-of-change available with definite time delay to trip from pick-up included.

Programmable stage cycle time is 5ms. The pick-up delay depends on the used analog signal and its refresh rate, being typically under a cycle in 50Hz system.

The amount of used programmable stages are set in the INFO-tab. When PGx >/< has been set as “Activated”, the amount of programmable stages can be set anywhere between 1 to 10 depending on the need of the application. In the example below the amount of programmable stages have been set to 2, which results in PS1 and PS2 appearing. The inactive stages are hidden until they are activated.



It should be noted that setting the available stages will not set those stages active but the available stages also need to be enabled individually with PSx>/< Enable parameter. The active stages shows its current state, expected operating time and also the time remaining to trip under the activation parameter. If the stage is not active “PSx>/< condition” will merely display “Disabled”.

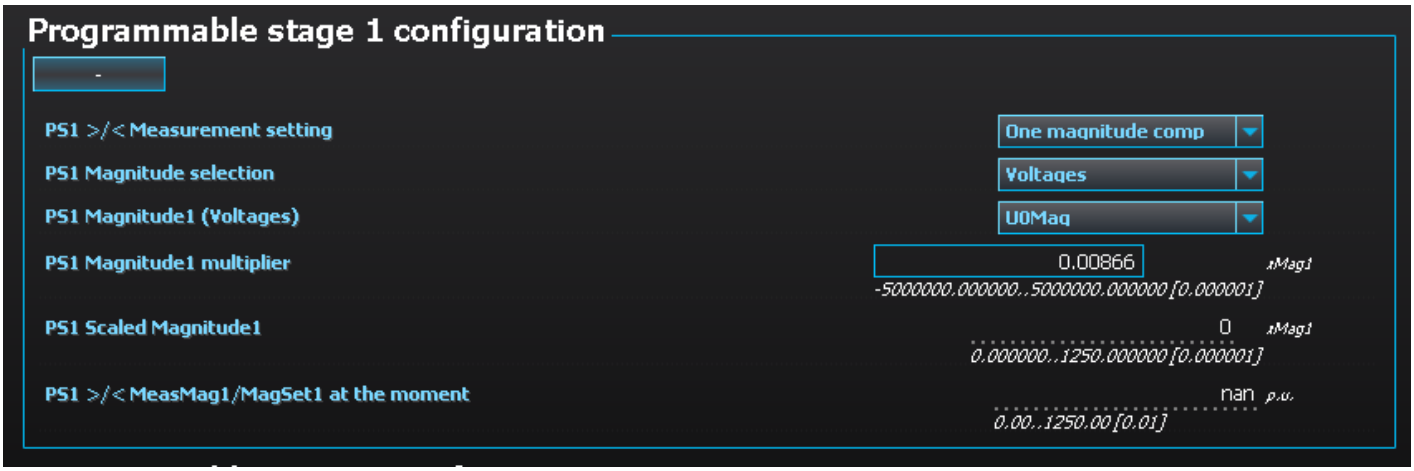
Setting up programmable stage

Programmable stages can be set to follow one, two or three analog measurements with *PSx>/< Measurement settings* parameter. A measurement signal must be chosen for the comparator and possibly set a scaling for the signal. Below is an example of a scaling in which primary neutral voltage has been scaled to percentage value so that it would be easier to handle setting up the comparator.

The scaling factor was calculated by taking the inverse value of 20kV system:

$$k = \frac{1}{\frac{20000V}{\sqrt{3}}} = 0.00866$$

With this multiplier in full earth fault neutral voltage would be 11547 volts primary which is now multiplied with 0.00866 multiplier inverses to 100%. This way pre-processed signal is easier to set, but it is also possible to just use scaling factor of 1.0 and set the desired pick-up limit as primary voltage. In the same way any chosen measurement value can be scaled to desired form.

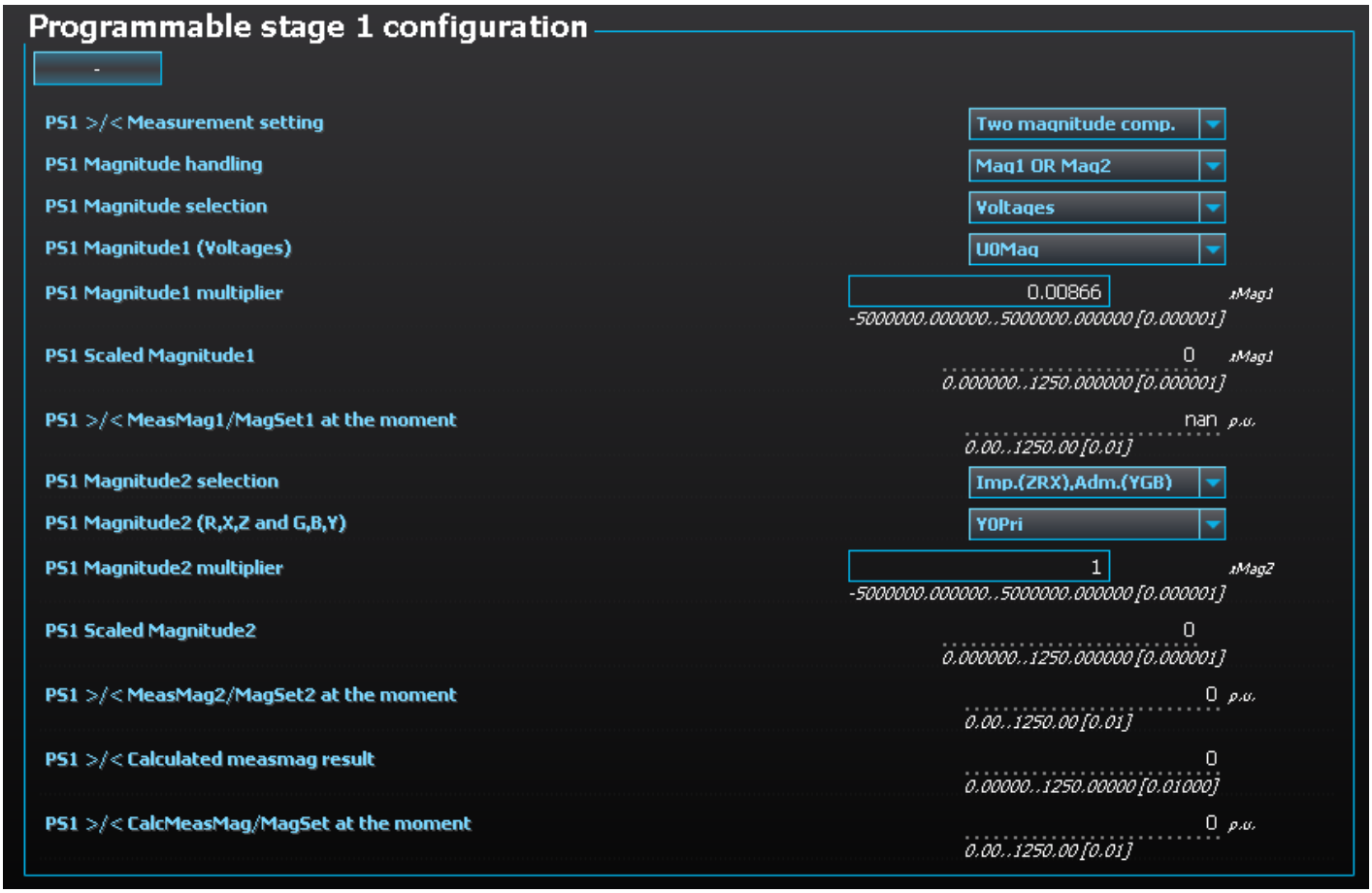


In case two or three signals are chosen to compare additional signal settings appear. In the menu you choose how signals are pre-processed for comparison. Available modes for the signal comparison are below.

Mode	**Description**
0:Mag1 x Mag2	Signal1 x Signal2 multiply. The comparison uses the product of Signal1 x Signal2 calculation
1:Mag1 / Mag2	Signal1 / Signal2 division. The comparison uses the product of Signal1 / Signal2
2:Max(Mag1,Mag2)	Bigger value of the chosen signals is used in the comparison.
3:Min(Mag1,Mag2)	Smaller value of the chosen signals is used in the comparison.
4:Mag1 OR Mag2	Either of the chosen signals have to fulfill the pick-up condition. Both signals have their own pick-up setting.
5:Mag1 AND Mag2	Both chosen signals have to fulfill the pick-up condition. Both signals have their own pick-up setting.

Mode	Description
6:Mag1 – Mag2	Signal1 – Signal2 subtraction. The comparison uses the product of Signal1 – Signal2 calculation.

In the example below analog comparison has been set with two signals. The stage will trip if either of the measured signals fulfills the comparison condition.

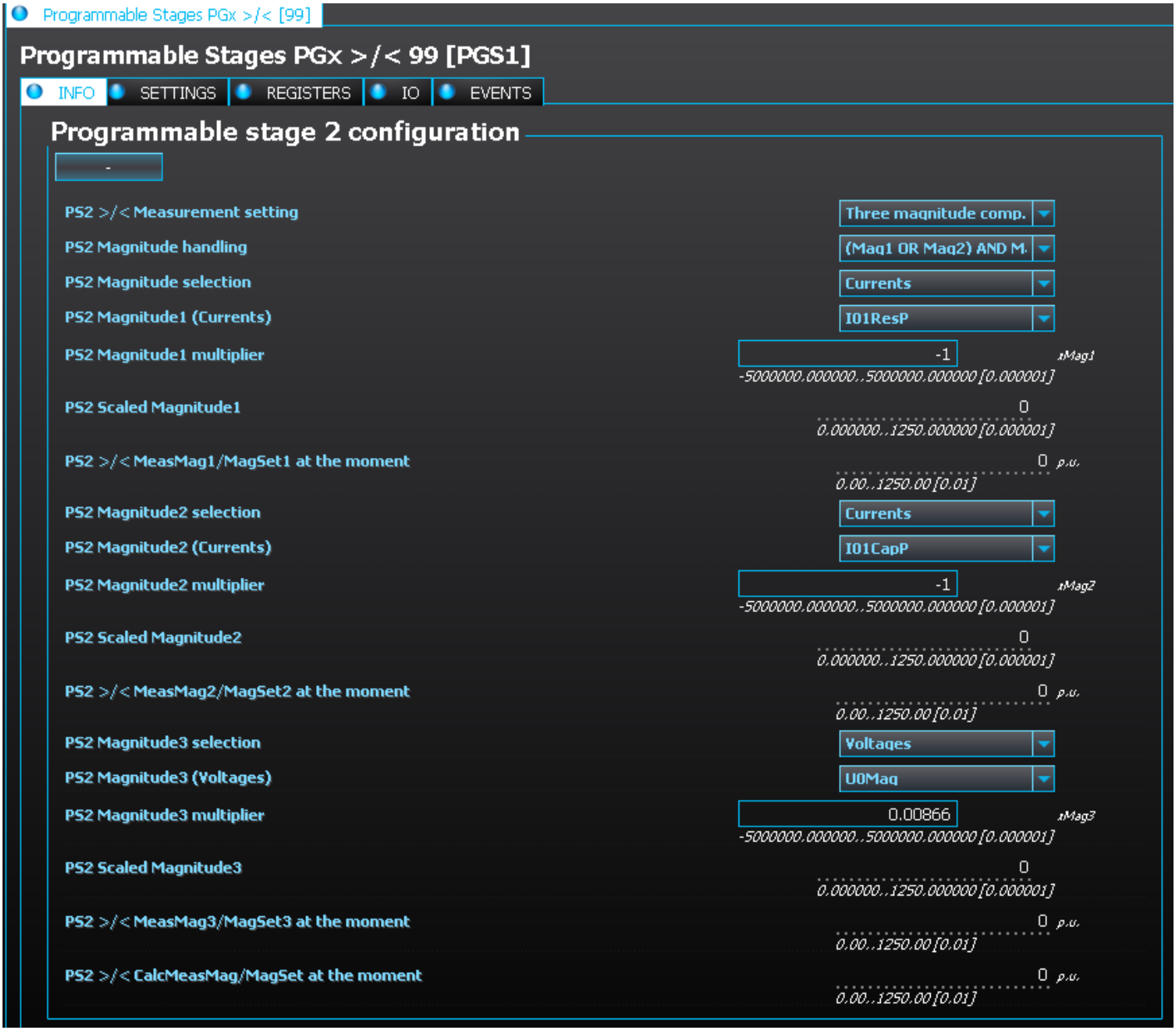


In the same way, it is possible to set up comparison of three values.

Mode	Description
0:Mag1 x Mag2 x Mag3	Signal1 x Signal2 x Signal3 multiply. The comparison uses the product of Signal1 x Signal2 calculation
1:Max(Mag1,Mag2,Mag3);	Biggest value of the chosen signals is used in the comparison.
2:Min(Mag1,Mag2,Mag3)	Smallest value of the chosen signals is used in the comparison.

Mode	Description
3:Mag1 OR Mag2 OR Mag3	Any of the signals need to fulfill the pick-up condition. Each signal has their own pick-up setting.
4:Mag1 AND Mag2 AND Mag3	All of the signals need to fulfill the pick-up condition. Each signal has their own pick-up setting.
5:(Mag1 OR Mag2) AND Mag3	Signal 1 OR Signal 2 AND Signal 3 has to fulfill the pick-up condition. Each signal has their own pick-up setting.

In the example below three measurements are used. Signal 1 or Signal 2 must be fulfilled along with Signal 3 to trip the stage.



The settings for different comparison setting are in setting groups which means by changing the setting group each signal parameter can be changed by a signal.

When setting the comparators you first choose the comparator mode. The following modes are available:

Mode	Description
0:Over >	Greater than. If the measured signal is higher than the set pick-up level, the comparison condition is fulfilled.
1:Over(abs) >	Bigger than (absolute). If the absolute value of the measured signal is higher than the set pick-up level, the comparison condition is fulfilled.
2:Under <	Less than. If the measured signal is less than the set pick-up level, the comparison condition is fulfilled. A blocking limit can also be set. This means the comparison is not active when measured value is under the set blocking limit.
3:Under(abs) <	Less than (absolute). If the absolute value of the measured signal is less than the set pick-up level, the comparison condition is fulfilled. A blocking limit can also be set. This means the comparison is not active when measured value is under the set blocking limit.
4:Delta set(%) +/- >	Relative change over time. If the measured signal changes more than the set relative pick-up value in 20ms, the comparison condition is fulfilled. The condition is dependent on direction.
5:Delta abs(%) >	Relative change over time (absolute). If the measured signal changes more than the set relative pick-up value in 20ms to either direction, the comparison condition is fulfilled. The condition is not dependent on direction.
6:Delta +/- measval	Change over time. If the measured signal changes more than the set pick-up value in 20ms, the comparison condition is fulfilled. The condition is dependent on direction.
7:Delta abs measval	Change over time (absolute). If the measured signal changes more than the set pick-up value in 20ms to either direction, the comparison condition is fulfilled. The condition is not dependent on direction.

Pick-up level is set for each comparison individually. When setting up pick-up level the used modes and the desired action need to be taken into consideration. The pick-up limit can be set as either positive or negative.

Each pick-up level has a separate hysteresis/deadband setting which is 3% by default.

Each stage has a user settable operating and releasing time delay.

Analog signals

Analog signals have been divided into categories to help find the desired value.

IL1	**Description**
IL1ff(p.u.)	IL1 Fundamental frequency in per unit value
IL1 2nd h.	IL1 2nd harmonic in per unit value
IL1 3rd h.	IL1 3rd harmonic in per unit value
IL1 4th h.	IL1 4th harmonic in per unit value
IL1 5th h.	IL1 5th harmonic in per unit value
IL1 7th h.	IL1 7th harmonic in per unit value
IL1 9th h.	IL1 9th harmonic in per unit value
IL1 11th h.	IL1 11th harmonic in per unit value
IL1 13th h.	IL1 13th harmonic in per unit value
IL1 15th h.	IL1 15th harmonic in per unit value
IL1 17th h.	IL1 17th harmonic in per unit value
IL1 19th h.	IL1 19th harmonic in per unit value
IL2	Description
IL2ff(p.u.)	IL2 Fundamental frequency in per unit value
IL2 2th h.	IL2 2nd harmonic in per unit value
IL2 3th h.	IL2 3th harmonic in per unit value

IL1	**Description**
IL2 4th h.	IL2 4th harmonic in per unit value
IL2 5th h.	IL2 5th harmonic in per unit value
IL2 7th h.	IL2 7th harmonic in per unit value
IL2 9th h.	IL2 9th harmonic in per unit value
IL2 11th h.	IL2 11th harmonic in per unit value
IL2 13th h.	IL2 13th harmonic in per unit value
IL2 15th h.	IL2 15th harmonic in per unit value
IL2 17th h.	IL2 17th harmonic in per unit value
IL2 19th h.	IL2 19th harmonic in per unit value
IL3	Description
IL3ff(p.u.)	IL3 Fundamental frequency in per unit value
IL3 2.h	IL3 2nd harmonic in per unit value
IL3 3.h	IL3 3rd harmonic in per unit value
IL3 4th h.	IL3 4th harmonic in per unit value
IL3 5th h.	IL3 5th harmonic in per unit value
IL3 7th h.	IL3 7th harmonic in per unit value

IL1	**Description**
IL3 9th h.	IL3 9th harmonic in per unit value
IL3 11th h.	IL3 11th harmonic in per unit value
IL3 13th h.	IL3 13th harmonic in per unit value
IL3 15th h.	IL3 15th harmonic in per unit value
IL3 17th h.	IL3 17th harmonic in per unit value
IL3 19th h.	IL3 19th harmonic in per unit value
I01	Description
I01ff(p.u.)	I01 Fundamental frequency in per unit value
I01 2nd h.	I01 2nd harmonic in per unit value
I01 3rd h.	I01 3rd harmonic in per unit value
I01 4th h.	I01 4th harmonic in per unit value
I01 5th h.	I01 5th harmonic in per unit value
I01 7th h.	I01 7th harmonic in per unit value
I01 9th h.	I01 9th harmonic in per unit value
I01 11th h.	I01 11th harmonic in per unit value
I01 13th h.	I01 13th harmonic in per unit value

IL1	**Description**
I01 15th h.	I01 15th harmonic in per unit value
I01 17th h.	I01 17th harmonic in per unit value
I01 19th h.	I01 19th harmonic in per unit value
IL02	Description
I02ff(p.u.)	I02 Fundamental frequency in per unit value
I02 2.h	I02 2nd harmonic in per unit value
I02 3.h	I02 3nd harmonic in per unit value
I02 4th h.	I02 4th harmonic in per unit value
I02 5th h.	I02 5th harmonic in per unit value
I02 7th h.	I02 7th harmonic in per unit value
I02 9th h.	I02 9th harmonic in per unit value
I02 11th h.	I02 11th harmonic in per unit value
I02 13th h.	I02 13th harmonic in per unit value
I02 15th h.	I02 15th harmonic in per unit value
I02 17th h.	I02 17th harmonic in per unit value
I02 19th h.	I02 19th harmonic in per unit value

IL1	Description
TRMS	Description
IL1 TRMS	IL1 True RMS in per unit value
IL2 TRMS	IL2 True RMS in per unit value
IL3 TRMS	IL3 True RMS in per unit value
I01 TRMS	I01 True RMS in per unit value
I02 TRMS	I02 True RMS in per unit value
Calculated	Description
I0Z Mag	Current zero sequence in per unit value
I0CALC Mag	Calculated I0 in per unit value
I1 Mag	Positive sequence current in per unit value
I2 Mag	Negative sequence current in per unit value
IL1 Ang	IL1 angle of current fundamental frequency component
IL2 Ang	IL2 angle of current fundamental frequency component
IL3 Ang	IL3 angle of current fundamental frequency component
I01 Ang	I01 angle of current fundamental frequency component
I02 Ang	I02 angle of current fundamental frequency component

IL1	Description
I0CALC Ang	Angle of calculated residual current
I1 Ang	Angle of positive sequence current
I2 Ang	Angle of negative sequence current
I01ResP	I01 current resistive component primary current.
I01CapP	I01 current capacitive component primary current.
I01ResS	I01 current resistive component secondary current.
I01CapS	I01 current capacitive component secondary current.
I02ResP	I02 current resistive component primary current.
I02CapP	I02 current capacitive component primary current.

Phase-phase voltages	Description
UL12Mag	UL12 Primary voltage V
UL23Mag	UL23 Primary voltage V
UL31Mag	UL31 Primary voltage V
Phase-Neutral voltages	Description
UL1Mag	UL1 Primary voltage V

Phase-phase voltages	**Description**
UL2Mag	UL2 Primary voltage V
UL3Mag	UL3 Primary voltage V
U0Mag	U0 Primary voltage V
Angles	Description
UL12Ang	UL12 angle
UL23Ang	UL23 angle
UL31Ang	UL31 angle
UL1Ang	UL1 angle
UL2Ang	UL2 angle
UL3Ang	UL3 angle
U0Ang	U0 angle
Calculated	Description
U0CalcMag	Calculated residual voltage V
U1 pos.seq.V Mag	Positive sequence voltage V
U2 neg.seq.V Mag	Negative sequence voltage V
U0CalcAng	Calculated residual voltage angle

Phase-phase voltages	Description
U1 pos.seq.V Ang	Positive sequence voltage angle
U2 neg.seq.V Ang	Negative sequence voltage angle

Powers category	Description
S3PH	3 Phase apparent power S kVA
P3PH	3 Phase active power P kW
Q3PH	3 Phase reactive power Q kvar
tanfi3PH	3 Phase active power direction
cosfi3PH	3 Phase reactive power direction
SL1	Apparent power L1 S kVA
PL1	Active power L1 P kW
QL1	Reactive power L1 Q kVar
tanfiL1	Phase active power direction L1
cosfiL1	Phase reactive power direction L1
SL2	Apparent power L2 S kVA
PL2	Active power L2 P kW

Powers category	Description
QL2	Reactive power L2 Q kVar
tanfiL2	Phase active power direction L2
cosfiL2	Phase reactive power direction L2
SL3	Apparent power L3 S kVA
PL3	Active power L3 P kW
QL3	Reactive power L3 Q kVar
tanfiL3	Phase active power direction L3
cosfiL3	Phase reactive power direction L3

Imp.(ZRX),Adm.(YGB) category	Description
RL12Pri	Resistance R L12 primary ohm
XL12Pri	Reactance X L12 primary ohm
RL23Pri	Resistance R L23 primary ohm
XL23Pri	Reactance X L23 primary ohm
RL31Pri	Resistance R L31 primary ohm
XL31Pri	Reactance X L31 primary ohm

Imp.(ZRX),Adm.(YGB) category	Description
RL12Sec	Resistance R L12 secondary ohm
XL12Sec	Reactance X L12 secondary ohm
RL23Sec	Resistance R L23 secondary ohm
XL23Sec	Reactance X L23 secondary ohm
RL31Sec	Resistance R L31 secondary ohm
XL31Sec	Reactance X L31 secondary ohm
Z12Pri	Impedance Z L12 primary ohm
Z23Pri	Impedance Z L23 primary ohm
Z31Pri	Impedance Z L31 primary ohm
Z12Sec	Impedance Z L12 secondary ohm
Z23Sec	Impedance Z L23 secondary ohm
Z31Sec	Impedance Z L31 secondary ohm
Z12Angle	Impedance Z L12 angle
Z23Angle	Impedance Z L23 angle
Z31Angle	Impedance Z L31 angle
RL1Pri	Resistance R L1 primary ohm

Imp.(ZRX),Adm.(YGB) category	Description
XL1Pri	Reactance X L1 primary ohm
RL2Pri	Resistance R L2 primary ohm
XL2Pri	Reactance X L2 primary ohm
RL3Pri	Resistance R L3 primary ohm
XL3Pri	Reactance X L3 primary ohm
RL1Sec	Resistance R L1 secondary ohm
XL1Sec	Reactance X L1 secondary ohm
RL2Sec	Resistance R L2 secondary ohm
XL2Sec	Reactance X L2 secondary ohm
RL3Sec	Resistance R L3 secondary ohm
XL3Sec	Reactance X L3 secondary ohm
Z1Pri	Impedance Z L1 primary ohm
Z2Pri	Impedance Z L2 primary ohm
Z3Pri	Impedance Z L3 primary ohm
Z1Sec	Impedance Z L1 secondary ohm
Z2Sec	Impedance Z L2 secondary ohm

Imp.(ZRX),Adm.(YGB) category	Description
Z3Sec	Impedance Z L3 secondary ohm
Z1Angle	Impedance Z L1 angle
Z2Angle	Impedance Z L2 angle
Z3Angle	Impedance Z L3 angle
RSeqPri	Positive Resistance R primary ohm
XSeqPri	Positive Reactance X primary ohm
RSeqSec	Positive Resistance R secondary ohm
XSeqSec	Positive Reactance X secondary ohm
ZSeqPri	Positive Impedance Z primary ohm
ZSeqSec	Positive Impedance Z secondary ohm
ZSeqAngle	Positive Impedance Z angle
GL1Pri	Conductance G L1 primary mS
BL1Pri	Susceptance B L1 primary mS
GL2Pri	Conductance G L2 primary mS
BL2Pri	Susceptance B L2 primary mS
GL3Pri	Conductance G L3 primary mS

Imp.(ZRX),Adm.(YGB) category	Description
BL3Pri	Susceptance B L3 primary mS
GL1Sec	Conductance G L1 secondary mS
BL1Sec	Susceptance B L1 secondary mS
GL2Sec	Conductance G L2 secondary mS
BL2Sec	Susceptance B L2 secondary mS
GL3Sec	Conductance G L3 secondary mS
BL3Sec	Susceptance B L3 secondary mS
YL1PriMag	Admittance Y L1 primary mS
YL2PriMag	Admittance Y L2 primary mS
YL3PriMag	Admittance Y L3 primary mS
YL1SecMag	Admittance Y L1 secondary mS
YL2SecMag	Admittance Y L2 secondary mS
YL3SecMag	Admittance Y L3 secondary mS
YL1Angle	Admittance Y L1 angle
YL2Angle	Admittance Y L2 angle
YL3Angle	Admittance Y L3 angle

Imp.(ZRX),Adm.(YGB) category	Description
G0Pri	Conductance G0 primary mS
B0Pri	Susceptance B0 primary mS
G0Sec	Conductance G0 secondary mS
B0Sec	Susceptance B0 secondary mS
Y0Pri	Admittance Y0 primary mS
Y0Sec	Admittance Y0 secondary mS
Y0Angle	Admittance Y0 angle

Imp.(ZRX),Adm.(YGB) category	Description
System f.	System frequency
Ref f1	Reference frequency 1
Ref f2	Reference frequency 2
M Thermal T	Motor thermal temperature
F Thermal T	Feeder thermal temperature
T Thermal T	Transformer thermal temperature
RTD meas 1...16	RTD measurement channels 1...16

Imp.(ZRX),Adm.(YGB) category	Description
Ext RTD meas 1...8	External RTD measurement channels 1...8 (ADAM)
mA input 7,8,15,16	mA input channels 7,8,15,16
ASC 1...4	Analog scaled curves 1...4

Outputs of the function are Start Trip and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. Programmable stage utilize total of eight separate setting groups which can be selected from one common source.

The function can be operating on instant or time delayed mode. In time delayed mode the operation can be selected for definite time.

Inputs for the function are the operating mode selections, setting parameters and measured and pre-processed magnitudes and binary input signals. Function outputs START, TRIP and BLOCKED signals which can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the three output signal. In instant operating mode the function outputs START and TRIP events simultaneously with equivalent time stamp. Time stamp resolution is 1ms. Function provides also cumulative counters for START, TRIP and BLOCKED events.

Pick-up characteristics

Pick-up of the PGS function is controlled by *Pick-up setting Mag* setting parameter, which defines the maximum/minimum allowed measured magnitude before action from the function. The function constantly calculates the ratio in between the set and measured magnitude. Reset hysteresis is user settable (3% by default) in the function and is always related to the *Pick-up setting Mag* value.

Table 4.1 Pick-up characteristics setting

Name	Description	Range	Step	Default
PS# Pick-up setting Mag#/calc >/<	Pick-up magnitude	-5000000.0000...5000000.0000	0.0001	0.01
PS# Setting hysteresis Mag#	Setting hysteresis	0.0000...50.0000%	0.0001%	3%
Definite operating time delay	Delay setting	0.000...1800.000s	0.005s	0.04s
Release time delays	Pick-up release delay	0.000...1800.000s	0.005s	0.06s

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Resetting characteristics can be set according to the application. Default setting is delayed with 60 ms and the time calculation is held during the release time.

When using the release delay option where the operating time counter is calculating the operating time during the release time, function will not trip if the input signal is not activated again during the release time counting.

Function blocking

In the blocking element the block signal is checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup voltage values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Events and registers

The PGS function generates events and registers from the status changes of start, trip and blocked. To main event buffer is possible to select status “On” or “Off” messages. The PGS function offers four independent instances which events are segregated for each instance operation.

In the function is available 12 last registers where the triggering event of the function (start, trip or blocked) is recorded with time stamp and process data values.

Table 4.2 Event codes of the PGS function instance 1 – 10.

Event Number	Event channel	Event block name	Event Code	Description
8576	134	PGS1	0	PS1 >/< Start ON
8577	134	PGS1	1	PS1 >/< Start OFF
8578	134	PGS1	2	PS1 >/< Trip ON
8579	134	PGS1	3	PS1 >/< Trip OFF
8580	134	PGS1	4	PS1 >/< Block ON
8581	134	PGS1	5	PS1 >/< Block OFF
8582	134	PGS1	6	PS2 >/< Start ON
8583	134	PGS1	7	PS2 >/< Start OFF
8584	134	PGS1	8	PS2 >/< Trip ON
8585	134	PGS1	9	PS2 >/< Trip OFF
8586	134	PGS1	10	PS2 >/< Block ON
8587	134	PGS1	11	PS2 >/< Block OFF
8588	134	PGS1	12	PS3 >/< Start ON
8589	134	PGS1	13	PS3 >/< Start OFF
8590	134	PGS1	14	PS3 >/< Trip ON
8591	134	PGS1	15	PS3 >/< Trip OFF
8592	134	PGS1	16	PS3 >/< Block ON
8593	134	PGS1	17	PS3 >/< Block OFF
8594	134	PGS1	18	PS4 >/< Start ON
8595	134	PGS1	19	PS4 >/< Start OFF
8596	134	PGS1	20	PS4 >/< Trip ON
8597	134	PGS1	21	PS4 >/< Trip OFF
8598	134	PGS1	22	PS4 >/< Block ON
8599	134	PGS1	23	PS4 >/< Block OFF

Event Number	Event channel	Event block name	Event Code	Description
8600	134	PGS1	24	PS5 >/< Start ON
8601	134	PGS1	25	PS5 >/< Start OFF
8602	134	PGS1	26	PS5 >/< Trip ON
8603	134	PGS1	27	PS5 >/< Trip OFF
8604	134	PGS1	28	PS5 >/< Block ON
8605	134	PGS1	29	PS5 >/< Block OFF
8606	134	PGS1	30	reserved
8607	134	PGS1	31	reserved
8608	134	PGS1	32	PS6 >/< Start ON
8609	134	PGS1	33	PS6 >/< Start OFF
8610	134	PGS1	34	PS6 >/< Trip ON
8611	134	PGS1	35	PS6 >/< Trip OFF
8612	134	PGS1	36	PS6 >/< Block ON
8613	134	PGS1	37	PS6 >/< Block OFF
8614	134	PGS1	38	PS7 >/< Start ON
8615	134	PGS1	39	PS7 >/< Start OFF
8616	134	PGS1	40	PS7 >/< Trip ON
8617	134	PGS1	41	PS7 >/< Trip OFF
8618	134	PGS1	42	PS7 >/< Block ON
8619	134	PGS1	43	PS7 >/< Block OFF
8620	134	PGS1	44	PS8 >/< Start ON
8621	134	PGS1	45	PS8 >/< Start OFF
8622	134	PGS1	46	PS8 >/< Trip ON
8623	134	PGS1	47	PS8 >/< Trip OFF
8624	134	PGS1	48	PS8 >/< Block ON
8625	134	PGS1	49	PS8 >/< Block OFF
8626	134	PGS1	50	PS9 >/< Start ON
8627	134	PGS1	51	PS9 >/< Start OFF
8628	134	PGS1	52	PS9 >/< Trip ON
8629	134	PGS1	53	PS9 >/< Trip OFF
8630	134	PGS1	54	PS9 >/< Block ON
8631	134	PGS1	55	PS9 >/< Block OFF
8632	134	PGS1	56	PS10 >/< Start ON
8633	134	PGS1	57	PS10 >/< Start OFF
8634	134	PGS1	58	PS10 >/< Trip ON
8635	134	PGS1	59	PS10 >/< Trip OFF
8636	134	PGS1	60	PS10 >/< Block ON
8637	134	PGS1	61	PS10 >/< Block OFF

In the register of the PGS function start, trip or blocked “On” event process data is recorded. In the table below is presented the structure of OV function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 4.3 Register content.

Date & Time	Event code	>/< Mag#	Mag#/Set#	Trip time remaining	Used SG
dd.mm.yyyy hh:mm:ss.mss	8576-8637 Descr.	Magnitude # value	Measured magnitude/ Pick-up setting	0ms -1800s	1 - 8

4.2 Control functions

4.2.1 Synchrocheck function ΔV/Δa/Δf (25)

To ensure safe closing of the circuit breaker between two systems it is important to check the synchronization. Closing the circuit breaker while the systems are in asynchronous state can cause several problems like current surges which damage the interconnecting elements. Synchrocheck has three stages SYN1, SYN2 and SYN3. SYN1 supervises the synchronization condition between U4 channel and the selected input voltage. SYN2 supervises the synchronization condition between U3 channel and the selected input voltage. SYN3 supervises the synchronization condition between U3 and U4 channels.

Figure 4.1 Example connection of synchrocheck function in 3LN+U4 mode when the SYN1 stage is in use and UL1 is the reference voltage.

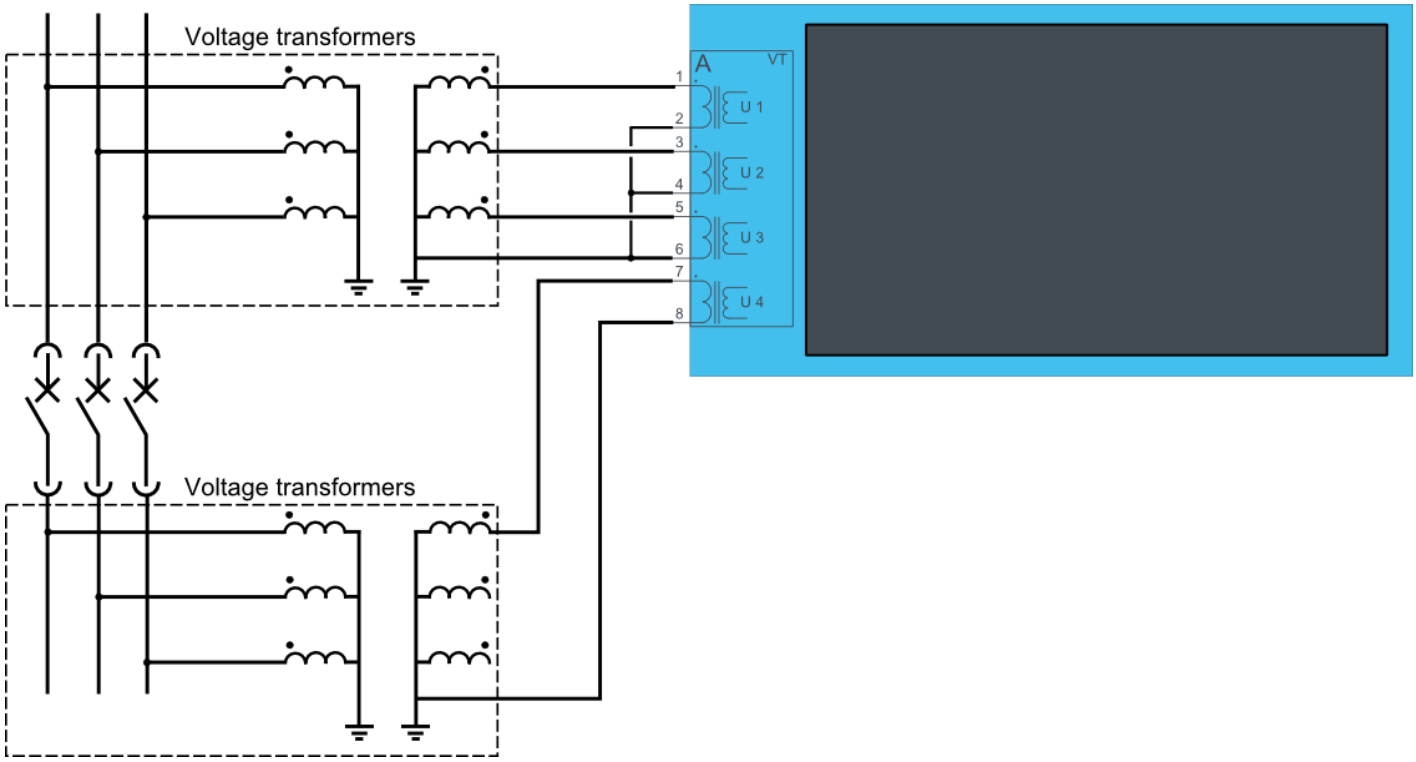


Figure 4.2 Example connection of synchrocheck function in 2LL+U3+U0 mode when the SYN2 stage is in use and UL12 is the reference voltage.

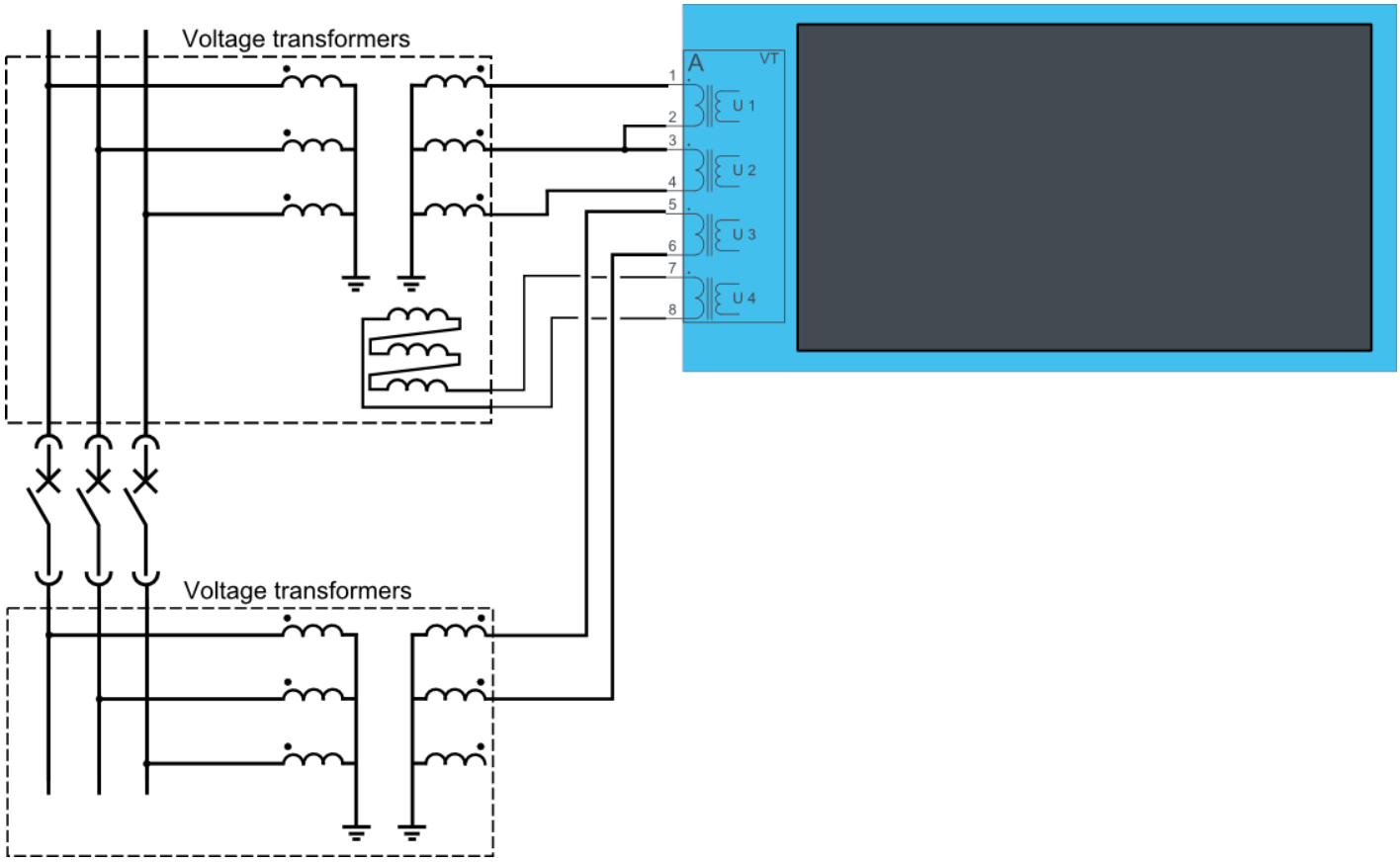


Figure 4.3 Example connection of synchrocheck function in 2LL+U3+U4 mode when the SYN3 stage is in use and UL12 is the reference voltage.

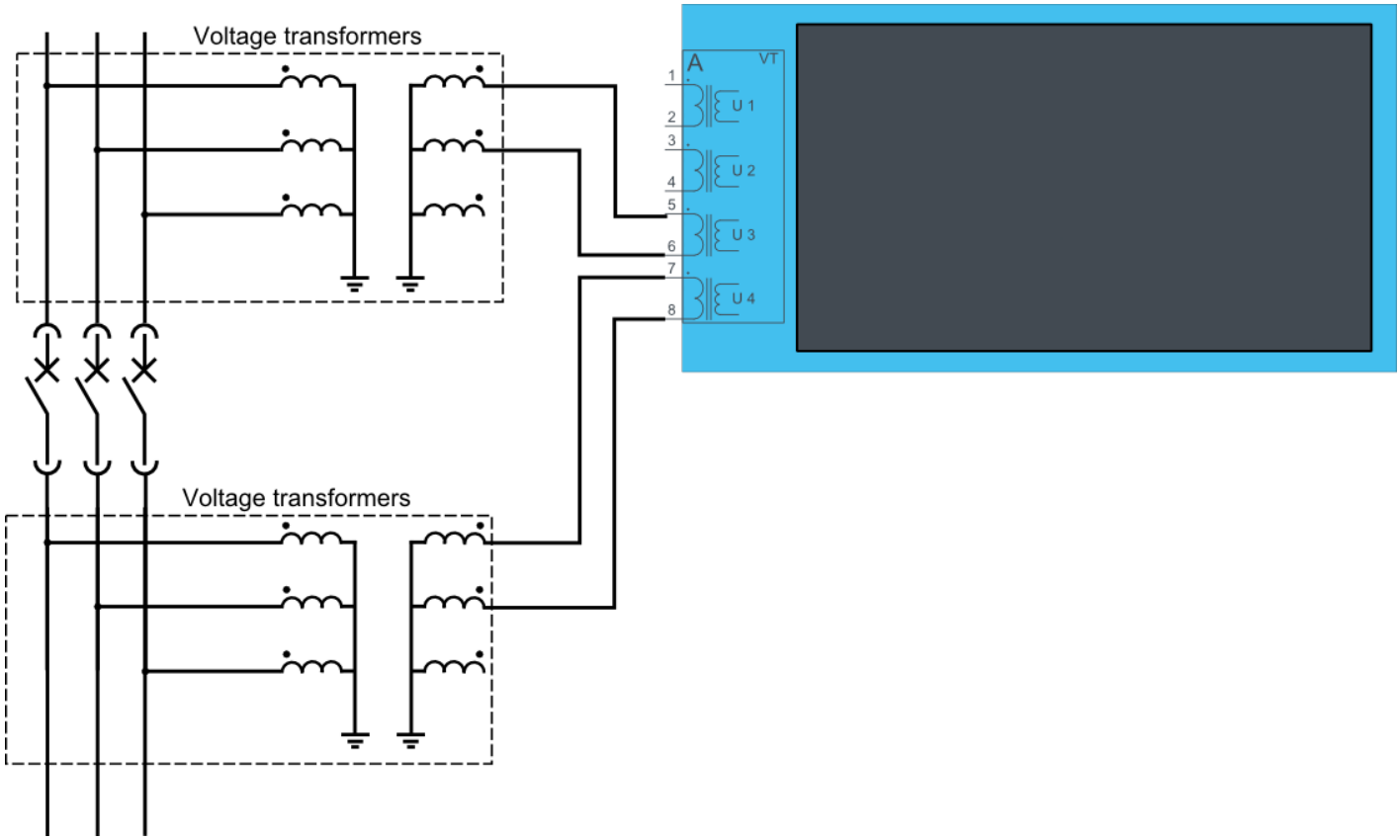


Figure 4.4 Example application of synchrocheck over one breaker in 3LL and 3LN VT connection situations.

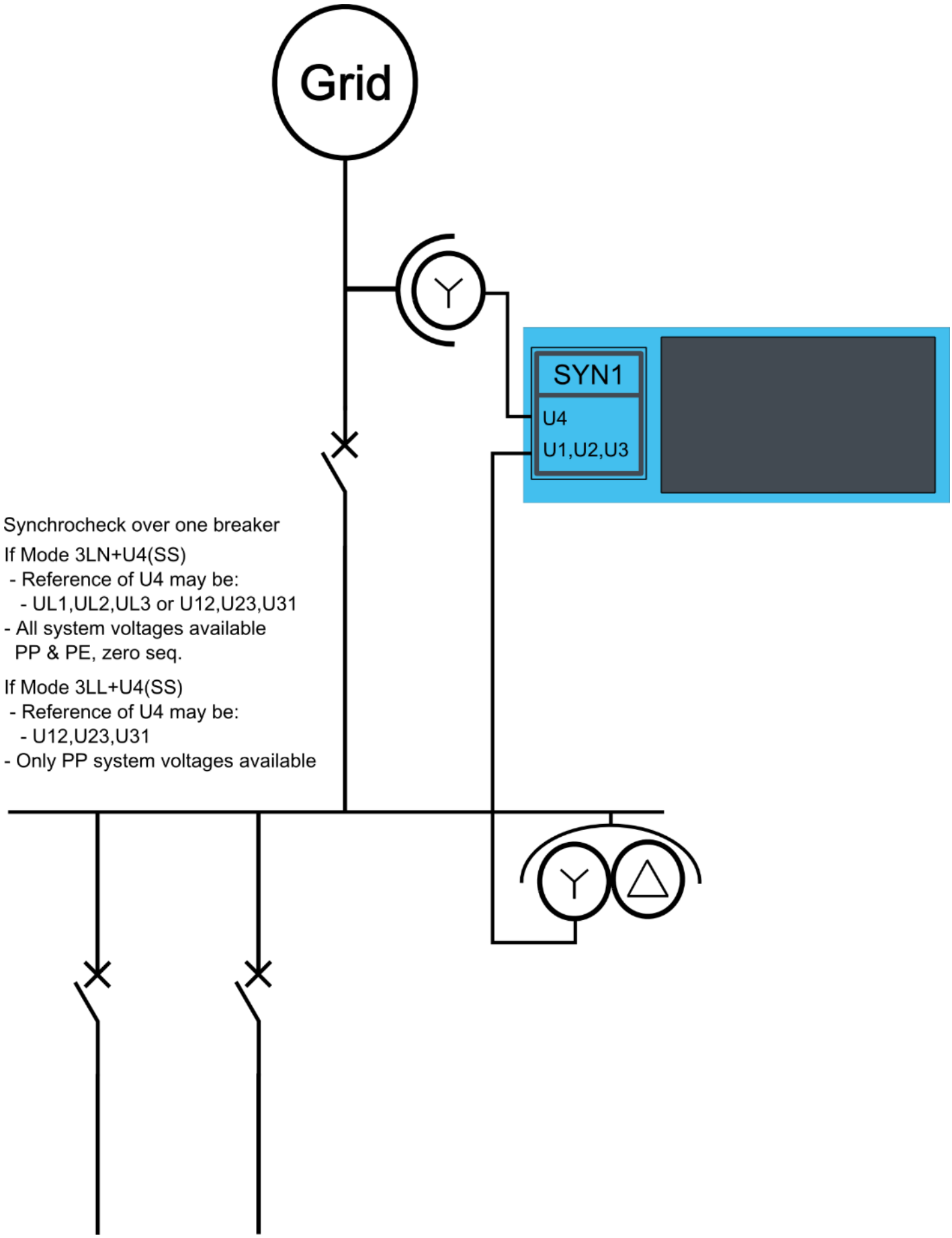


Figure 4.5 Example application of synchrocheck over one breaker with 2LL VT connection.

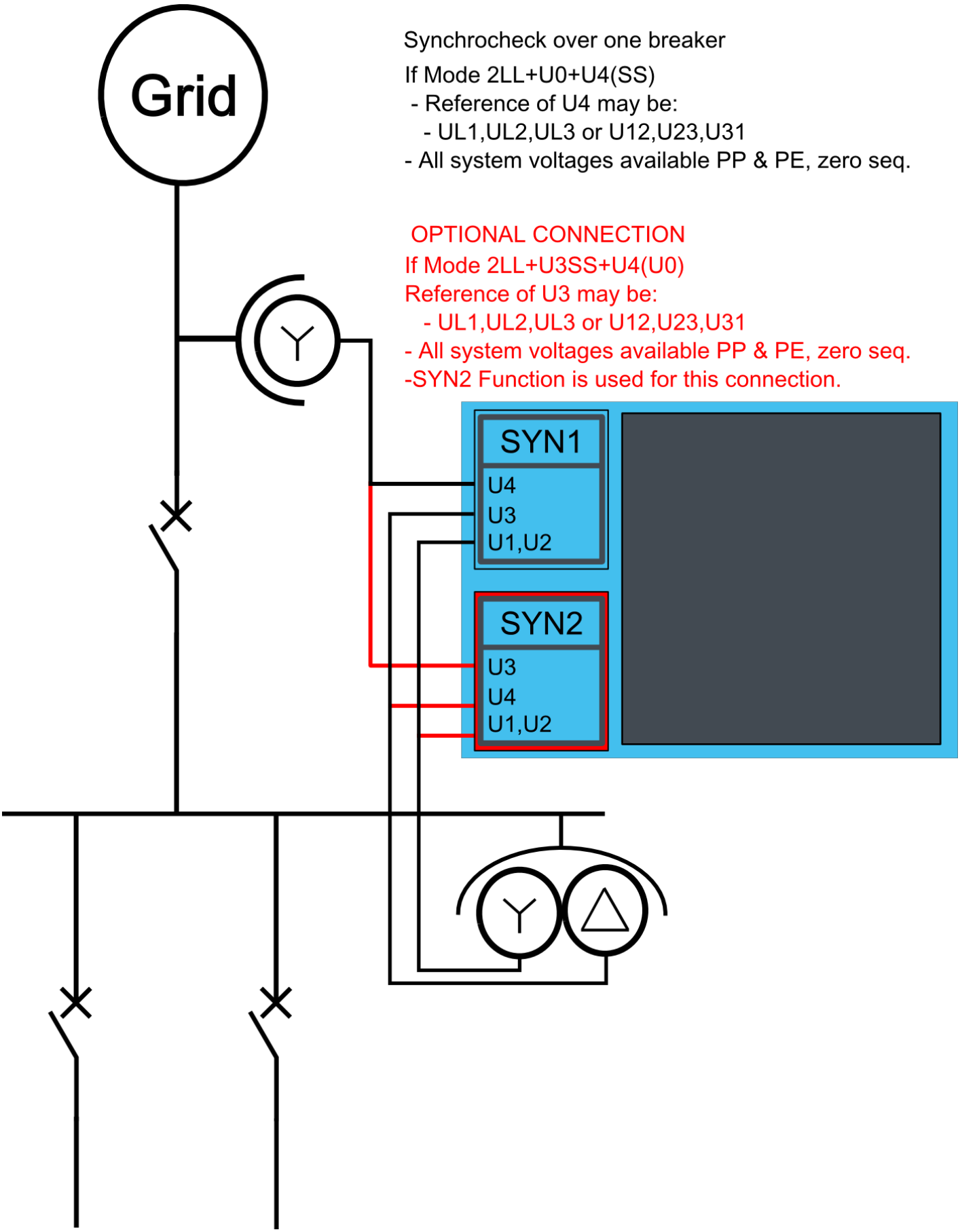


Figure 4.6 Example application of synchrocheck over two breakers in 2LL+U3+U4 mode. Reference of the U3 or U4 voltages may be U12, U23 or U31.

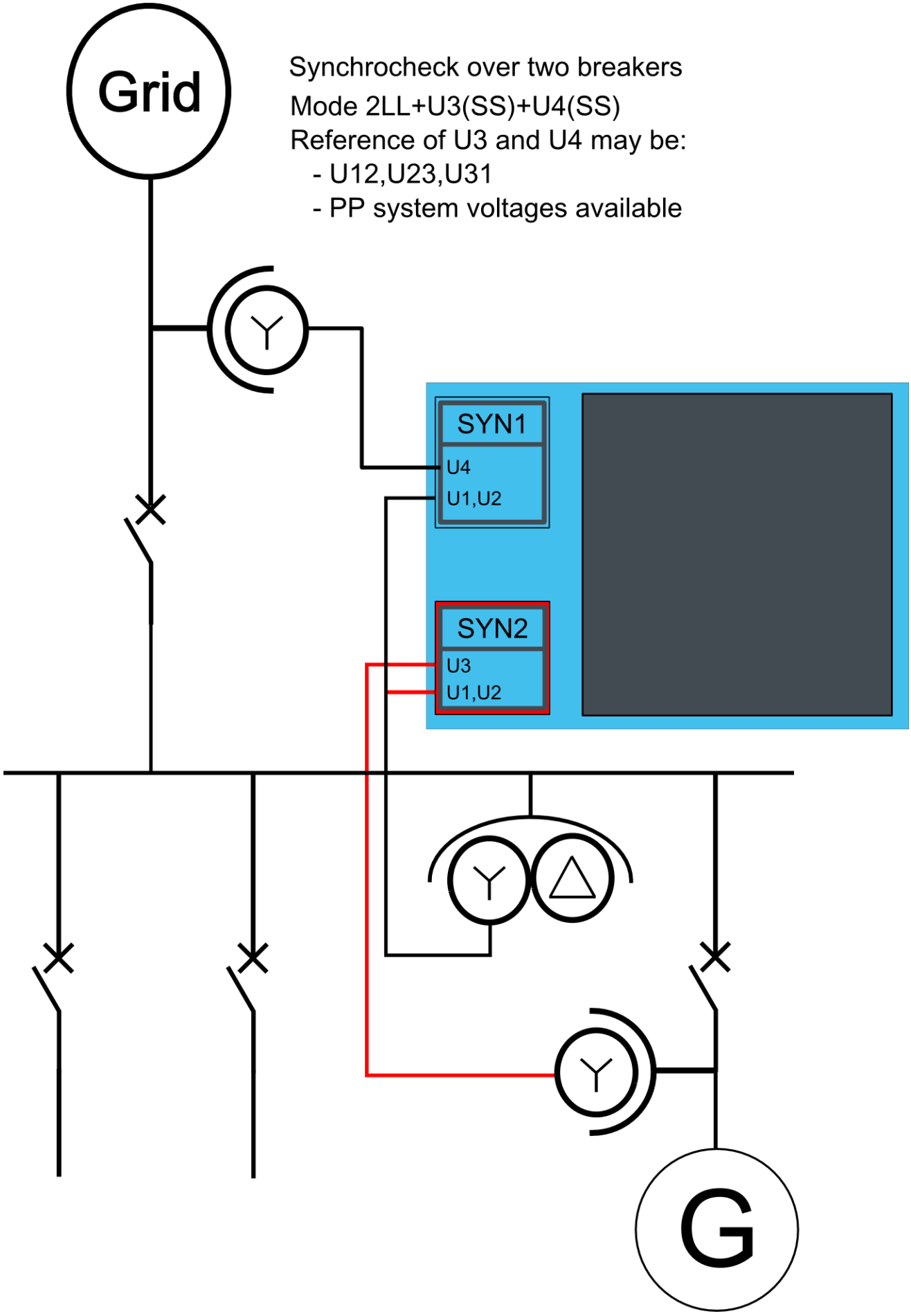
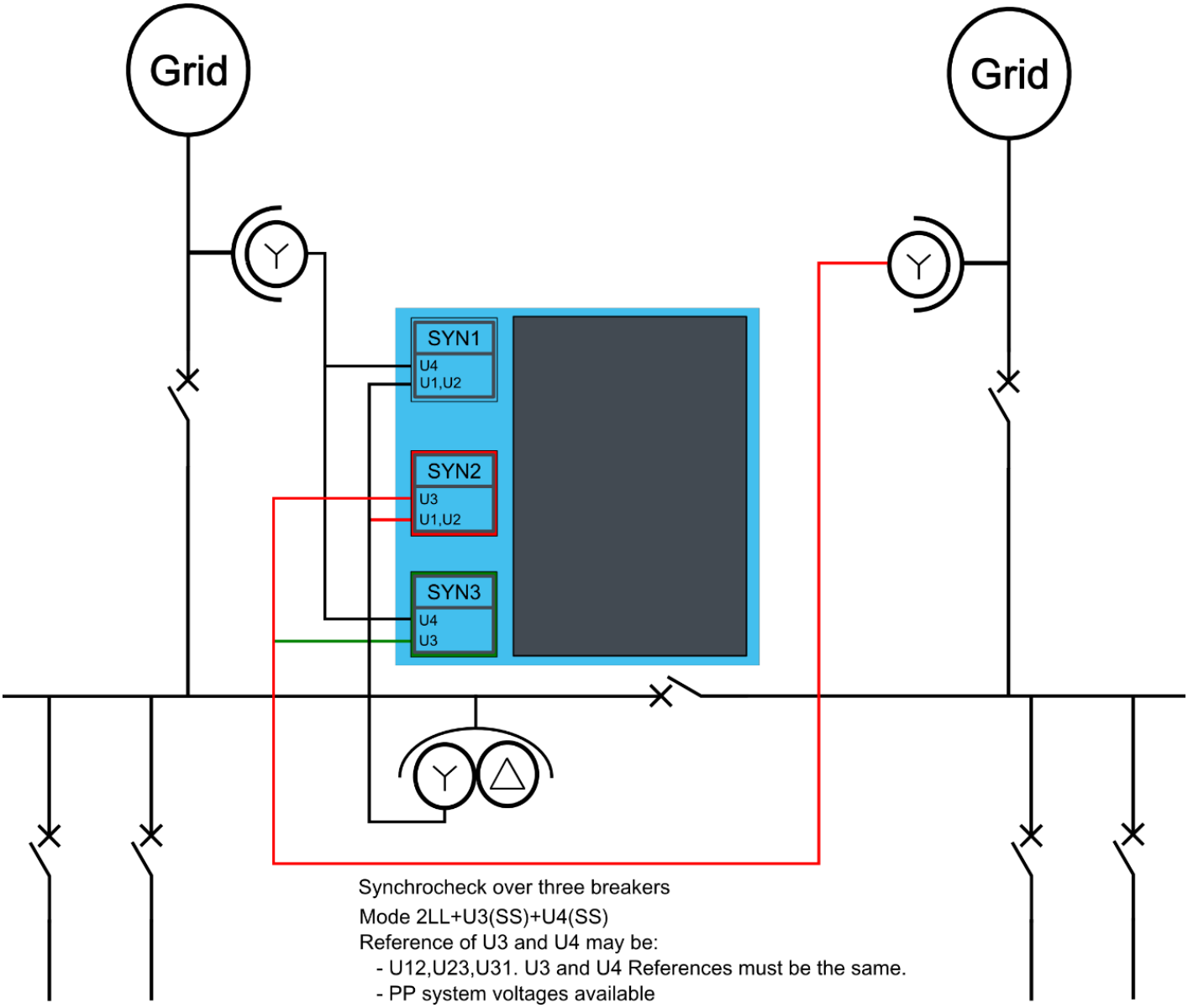


Figure 4.7 Example application of synchrocheck over three beakers (only in available 2LL+U3+U4 VT connection). Reference of the U3 and U4 channels must be the same (U12, U23 or U31).

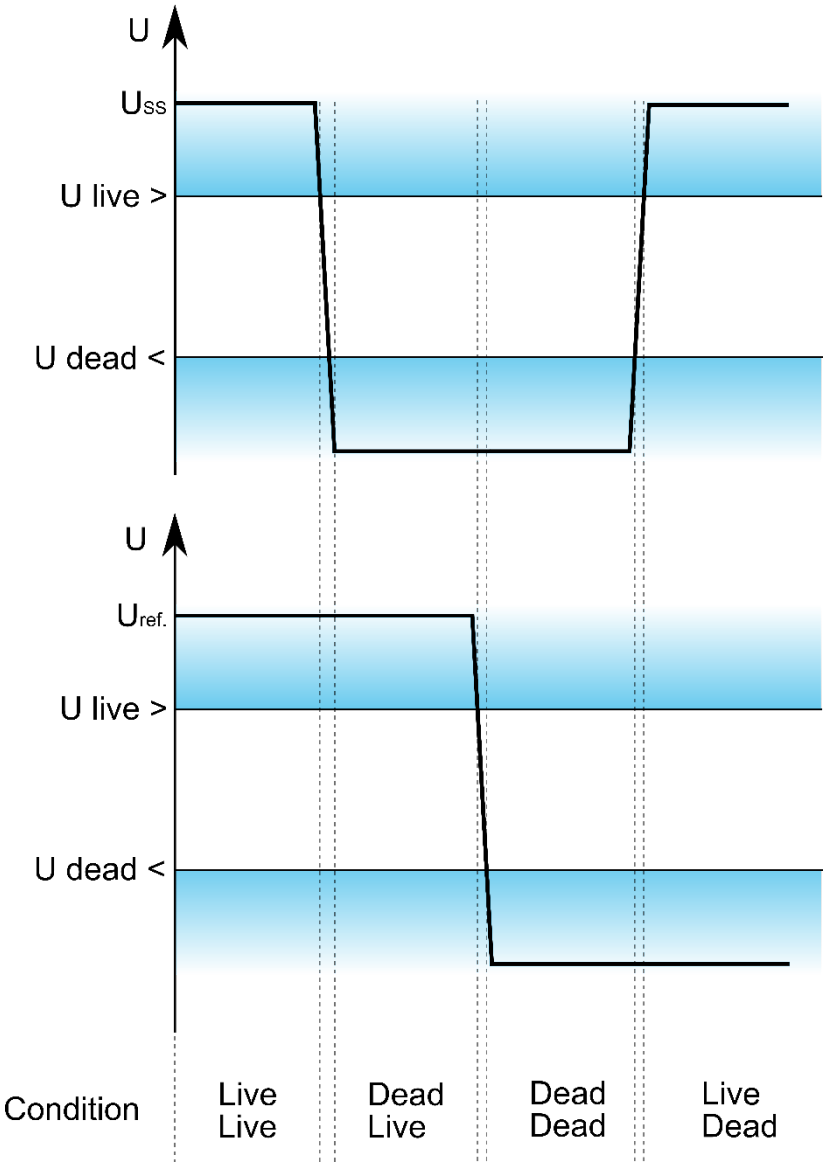


The two systems are synchronized when three aspects of the compared voltages are matched which are magnitudes of the voltages, frequencies of the voltages and phase angles of the voltages. Obviously all of these three aspects are never exactly the same so it is needed to set the maximum difference between the measured voltages.

Outputs of the function are Syn Ok, Bypass and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. Synchrocheck function utilizes total of eight separate setting groups which can be selected from one common source.

Either system can be in either “live” or “dead” state depending on the measured voltage compared to the set *U live >* and *U dead <* parameters. Parameter *Syn U conditions* is used to determine which conditions have to be met in addition to the previously mentioned three aspects to consider the systems synchronized.

Figure 4.8 Different states of the system



Measured input values

Analog voltage measurement values are used for the function block. Function block utilizes always peak-to-peak measurement from samples and the monitored magnitude is fundamental frequency RMS values.

Table 4.4 Analogic magnitudes used by the SYN function.

Signal	Description	Time base
U_1RMS	Fundamental RMS measurement of voltage U_1/V	5 ms
U_2RMS	Fundamental RMS measurement of voltage U_2/V	5 ms
U_3RMS	Fundamental RMS measurement of voltage U_3/V	5 ms
U_4RMS	Fundamental RMS measurement of voltage U_4/V	5 ms

Function blocking

In the blocking element the block signal is checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the synchronization is ok, a SYN OK signal is generated.

If blocking signal is active when SYN OK activates a BLOCKED signal will be generated and the function shall not process the situation further. If SYN OK function has been activated before blocking signal it will reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup voltage values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated. User settable variables are binary signals from the system.

Setting parameters

Table 4.5 General settings of the synchrocheck function

Name	Range	Step	Default	Description
Use SYN1,2,3	No Yes	-	No	Activation of individual stages of the synchrocheck function. Activation of a stage reveals the parameter settings for configuration.
SYN1 (U4) V Reference	Not in use UL12 UL23 UL31 UL1 UL2 UL3	-	Not in use	- Choose the reference voltage of the stage. - In 3LN+U4 and 2LL+U0+U4 mode all references are available. - In 3LL+U4 and 2LL+U3+U4 mode UL12, UL23 and UL31 references are available
SYN2 (U3) V Reference	Not in use UL12 UL23 UL31 UL1 UL2 UL3	-	Not in use	- Choose the reference voltage of the stage. - In 2LL+U3+U0 mode all references are available - In 2LL+U3+U4 mode UL12, UL23 and UL31 are available
SYN3 Reference	Not in use U3-U4	-	Not in use	- Choose if SYN3 stage is activated or disabled - Operable in 2LL+U3+U4 mode - UL12, UL23 and UL31 references are available

Table 4.6 Synchrocheck stage settings

Name	Range	Step	Default	Description
SYN U conditions	LL only LL & LD LL & DL LL & DD LL & LD & DL LL & LD & DD LL & DL & DD Bypass	-	LL only	Allowed states of the supervised systems.
SYN U live >	0.10...120.00%Un	0.01%Un	20%Un	Voltage limit of the live state
SYN U dead <	0.10...120.00%Un	0.01%Un	20%Un	Voltage limit of the dead state
SYN U diff <	0.00...120.00%Un	0.01%Un	2%Un	Maximum allowed voltage difference between the systems.
SYN angle diff <	0.00...90.00deg	0.01deg	0.5deg	Maximum allowed angle difference between the systems.
SYN freq diff <	0.00...0.50Hz	0.01Hz	0.1Hz	Maximum allowed frequency difference between the systems.

NOTE! Remember to set a voltage channel (U3 or U4) into synchrocheck mode in the voltage transformer settings (*Measurements → VT Module*).

Events and registers

The synchrocheck function generates events and registers from the status changes like syn ok, bypass and blocked. To main event buffer is possible to select status “On” or “Off” messages. The synchrocheck function offers three independent instances which events are segregated for each instance operation.

In the function is available 12 last registers where the triggering event of the function is recorded with time stamp and process data values.

Table 4.7 Event codes of the synchrocheck function instance 1 – 3.

Event Number	Event channel	Event block name	Event Code	Description
2880	45	SYN1	0	SYN1 Blocked On
2881	45	SYN1	1	SYN1 Blocked Off
2882	45	SYN1	2	SYN1 Ok On
2883	45	SYN1	3	SYN1 Ok Off
2884	45	SYN1	4	SYN1 Bypass On
2885	45	SYN1	5	SYN1 Bypass Off
2886	45	SYN1	6	SYN1 Volt condition OK
2887	45	SYN1	7	SYN1 Volt cond not match
2888	45	SYN1	8	SYN1 Volt diff Ok
2889	45	SYN1	9	SYN1 Volt diff out of setting
2890	45	SYN1	10	SYN1 Angle diff Ok
2891	45	SYN1	11	SYN1 Angle diff out of setting
2892	45	SYN1	12	SYN1 Frequency diff Ok
2893	45	SYN1	13	SYN1 Frequency diff out of setting
2894	45	SYN1	14	SYN2 Blocked On
2895	45	SYN1	15	SYN2 Blocked Off
2896	45	SYN1	16	SYN2 Ok On
2897	45	SYN1	17	SYN2 Ok Off
2898	45	SYN1	18	SYN2 Bypass On
2899	45	SYN1	19	SYN2 Bypass Off
2900	45	SYN1	20	SYN2 Volt condition OK
2901	45	SYN1	21	SYN2 Volt cond not match
2902	45	SYN1	22	SYN2 Volt diff Ok
2903	45	SYN1	23	SYN2 Volt diff out of setting
2904	45	SYN1	24	SYN2 Angle diff Ok
2905	45	SYN1	25	SYN2 Angle diff out of setting
2906	45	SYN1	26	SYN2 Frequency diff Ok
2907	45	SYN1	27	SYN2 Frequency diff out of setting
2908	45	SYN1	28	SYN3 Blocked On
2909	45	SYN1	29	SYN3 Blocked Off
2910	45	SYN1	30	SYN3 Ok On
2911	45	SYN1	31	SYN3 Ok Off
2912	45	SYN1	32	SYN3 Bypass On

Event Number	Event channel	Event block name	Event Code	Description
2913	45	SYN1	33	SYN3 Bypass Off
2914	45	SYN1	34	SYN3 Volt condition OK
2915	45	SYN1	35	SYN3 Volt cond not match
2916	45	SYN1	36	SYN3 Volt diff Ok
2917	45	SYN1	37	SYN3 Volt diff out of setting
2918	45	SYN1	38	SYN3 Angle diff Ok
2919	45	SYN1	39	SYN3 Angle diff out of setting
2920	45	SYN1	40	SYN3 Frequency diff Ok
2921	45	SYN1	41	SYN3 Frequency diff out of setting
2922	45	SYN1	42	SYN1 Switch On
2923	45	SYN1	43	SYN1 Switch Off
2924	45	SYN1	44	SYN2 Switch On
2925	45	SYN1	45	SYN2 Switch Off
2926	45	SYN1	46	SYN3 Switch On
2927	45	SYN1	47	SYN3 Switch Off

4.2.2 Cold load pick-up (CLPU)

Cold load pick-up function (CLPU) is used for detecting the so called “cold load” situations which relate to the distribution feeder protection after service restoration in which loss of load diversity has occurred. The characteristics of cold load situation will vary according to the types of loads of individual feeders. This means that the CLPU stage needs to be set according to the load type of the feeder it is monitoring specifically. For example in residential areas where is possibly relatively lot of thermostat controlled apparatus, heating or cooling machinery which normally run in asynchronous cycles. After power restoration from longer shortage all of these devices demand full start-up power can cause the current inrush to be significantly higher than the load current was before the shortage. In industrial environment this kind of cases are not common since after an outage the restoration of production process may take up to hours or even days which after the power consumption will be in the level it was before power outage. It is also possible that in some areas of the industrial network CLPU functionality may be useful also.

CLPU function measures constantly phase current magnitudes and magnitude changes which on the operating decisions are based. Blocking signal and setting group selection controls the operating characteristics of the function during normal operation.

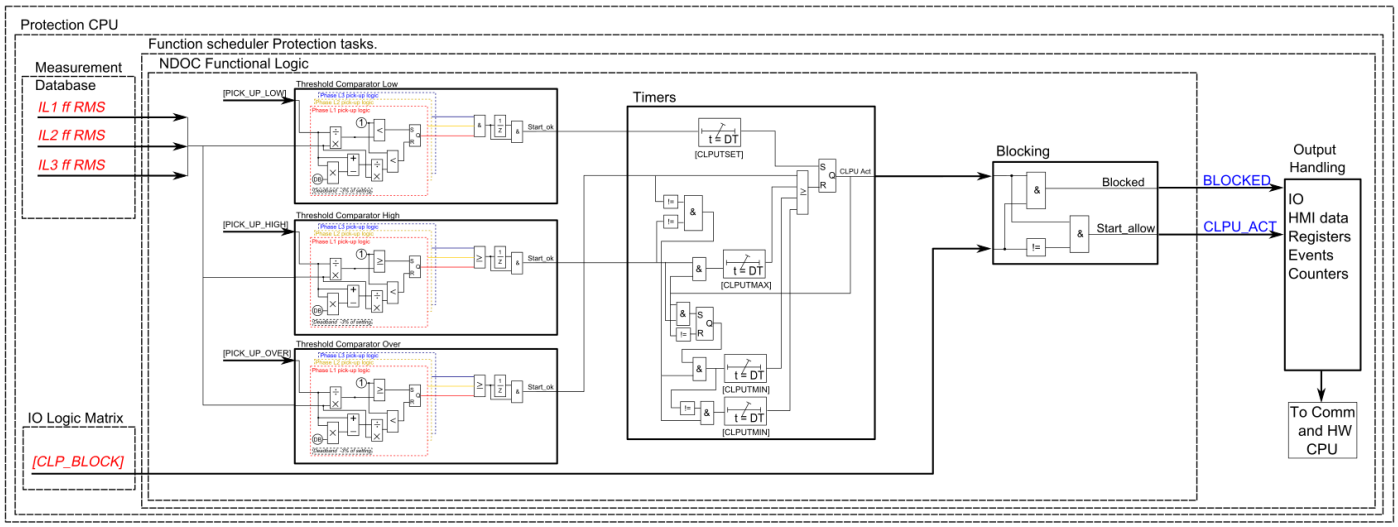
Outputs of the function are CLPU act and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. CLPU function utilizes total of eight separate setting groups which can be selected from one common source.

The operational logic consists of input magnitude processing, threshold comparator, block signal check, time delay characteristics and output processing.

Inputs for the function are setting parameters and measured and pre-processed current magnitudes and binary input signals. Function outputs CLPU act and BLOCKED signals which can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the two output signal. Time stamp resolution is 1ms. Function provides also cumulative counters for CLPU act and BLOCKED events.

In the figure below simplified function block diagram of the CLPU function is presented.

Figure 4.9 Simplified function block diagram of the CLPU function.



Measured input values

Function block uses analog current measurement values. Function block always utilizes peak-to-peak measurement from samples and by user selection the monitored magnitude can be either fundamental frequency RMS values, True RMS values from the whole harmonic specter of 32 components or peak to peak values. -20ms averaged value of the selected magnitude is used for pre-fault data registering.

Table 4.8 Analogic magnitudes used by the CLPU function.

Signal	Description	Time base
IL1RMS	Fundamental RMS measurement of phase L1/A current	5 ms
IL2RMS	Fundamental RMS measurement of phase L2/B current	5 ms
IL3RMS	Fundamental RMS measurement of phase L3/C current	5 ms

Selection of the used AI channel is made with a setting parameter. In all possible input channel variations pre-fault condition is presented with 20 ms averaged history value from -20 ms of Start or Trip event.

General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible change them with setting group switching.

Table 4.9 General settings of the function

Name	Description	Range	Step	Default
Meas side	Defines which current measurement module is used by the function.	1:Side1 2:Side2 3:Side3	-	1:Side1

Pick-up characteristics

Pick-up and activation of the CLPU function is controlled by ILow, IHigh and IOver setting parameters, which defines the maximum and minimum allowed measured current before action from the function. The function constantly calculates the ratio in between of the setting values and measured magnitude (Im) per all three phases. Reset ratio of 97 % is inbuilt in the function and is always related to the settingvalue. The setting value is common for all measured phases and single-, dual- or all phases Im exceed of the Iset value will cause pick-up operation of the function.

Table 4.10 Pick-up characteristics setting

Name	Range	Step	Default	Description
ILow	0.10 ... 40.00xIn	0.01xIn	0.20xIn	Pick-up setting for low current detection. All measured currents must be below this setting in order the CLPU signal shall be activated.
IHigh	0.10 ... 40.00xIn	0.01xIn	1.20xIn	Pick-up setting for high current detection. Any measured current must exceed this setting directly from the ILow condition in order CLPU signal shall be activated.
IOver	0.10 ... 40.00xIn	0.01xIn	2.00xIn	Pick-up setting for over current detection. In case this setting is exceeded by any measured current the CLPU signal shall be released immediately.

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Function blocking

In the blocking element the block signal is checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup current values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Operating time characteristics

The operating timers' behavior of the function can be set for activation and the cold load pick up situation monitoring and release.

In the table below are presented the setting parameters for the function time characteristics.

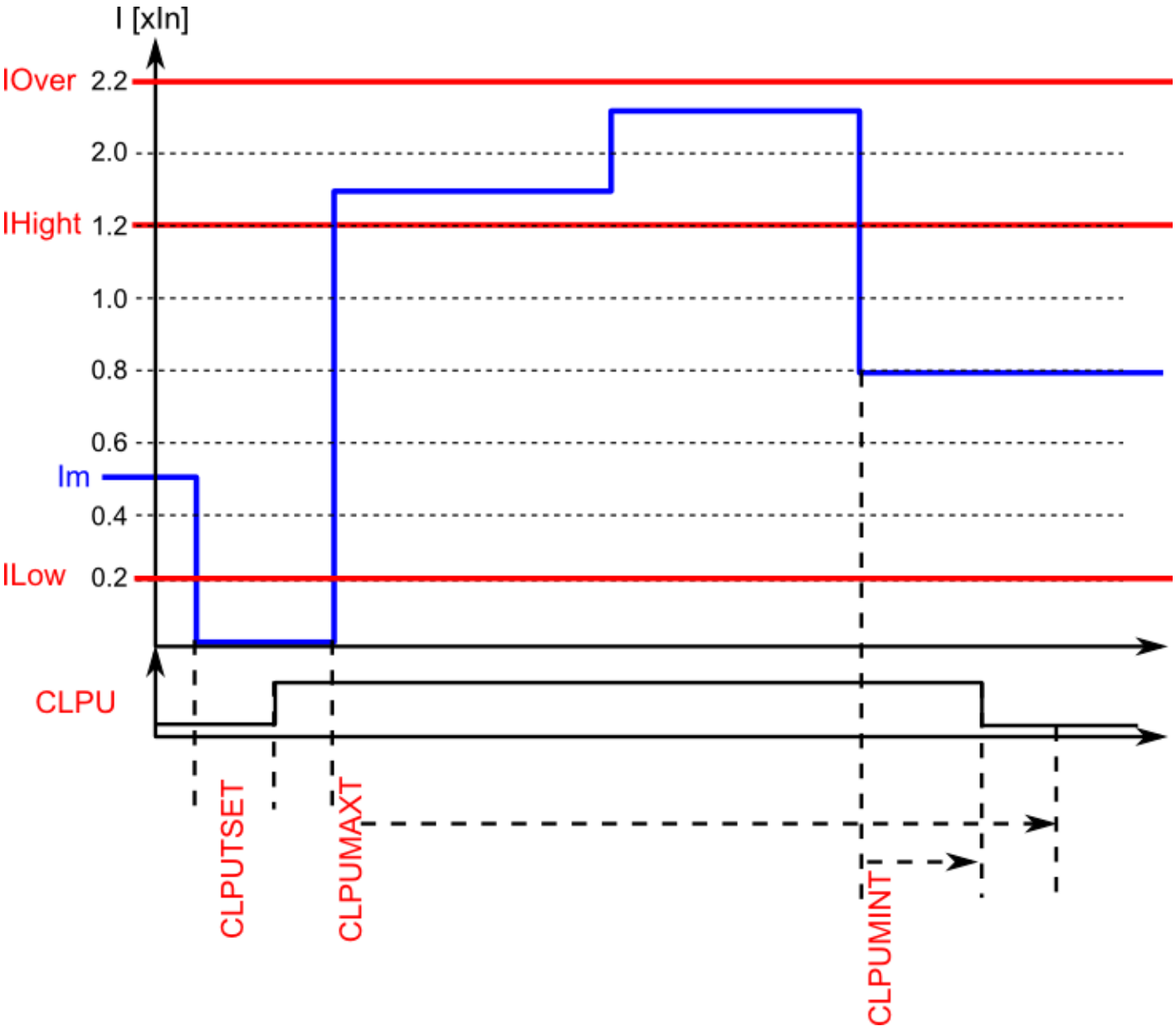
Figure 4.10 Operating time characteristics setting parameters.

Name	Range	Step	Default	Description
Tset	0.000...1800.000s	0.005s	10.000s	CLPU start timer, this setting defines how long the ILow condition has to last before CLPU is activated.
Tmax	0.000...1800.000s	0.005s	30.000s	CLPU max timer, this setting defines how long the starting condition can last and the current is allowed to be over IHigh.

Name	Range	Step	Default	Description
Tmin	0.000...1800.000s	0.005s	0.040s	CLPU min timer, this setting defines how long the starting condition last for minimum time. In case if the start up sequence includes more than one inrush situation this parameter may be used to prolong the CLPU time over the first inrush. Also this parameter operates as “reclaim” time for the CLPU function in case the inrush current is not immediately initiated in the start-up sequence.

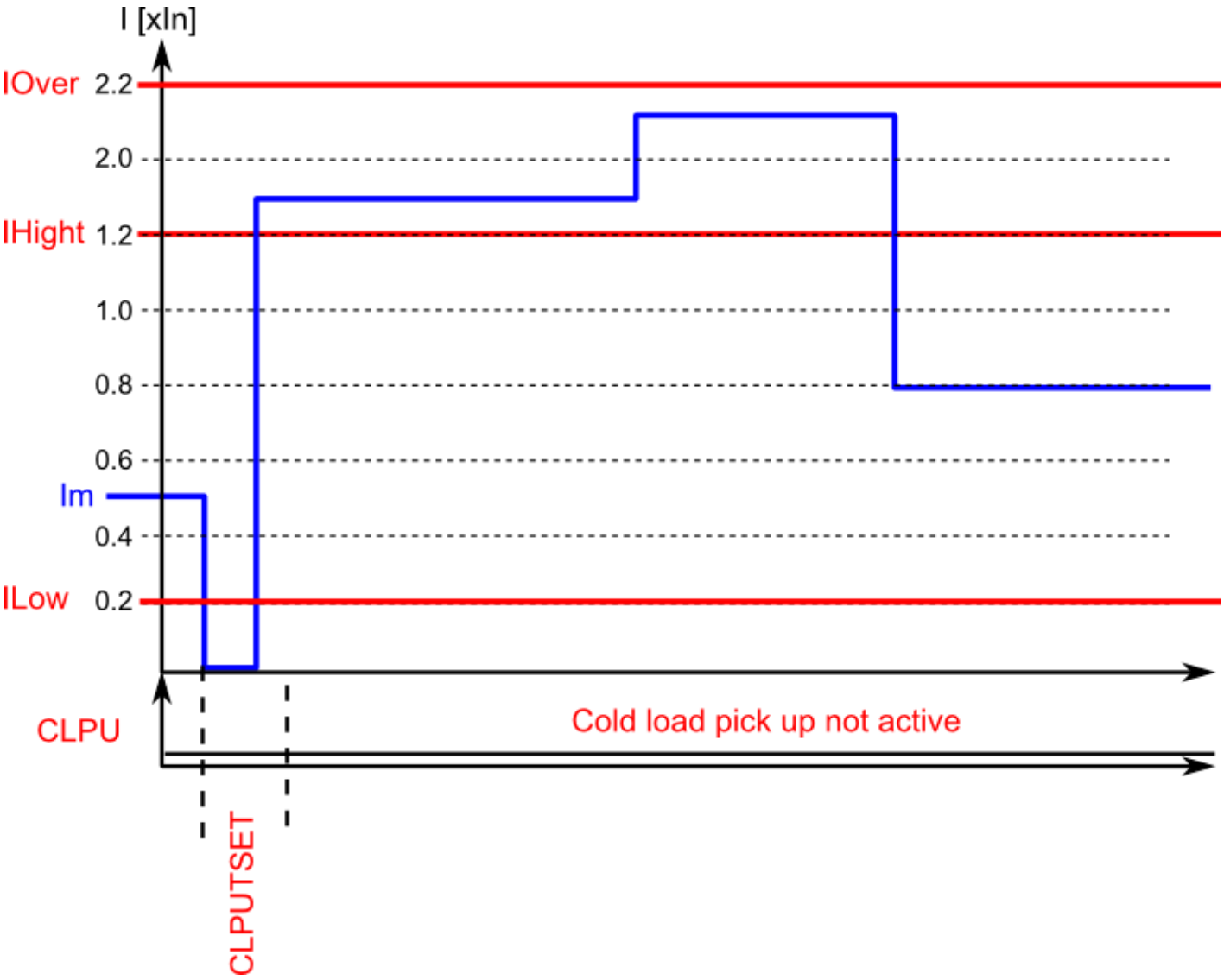
Few typical cases of CLPU situations are presented in the figures below.

Figure 4.11 Example of timers and pick-up parameters. Normal CLPU situation.



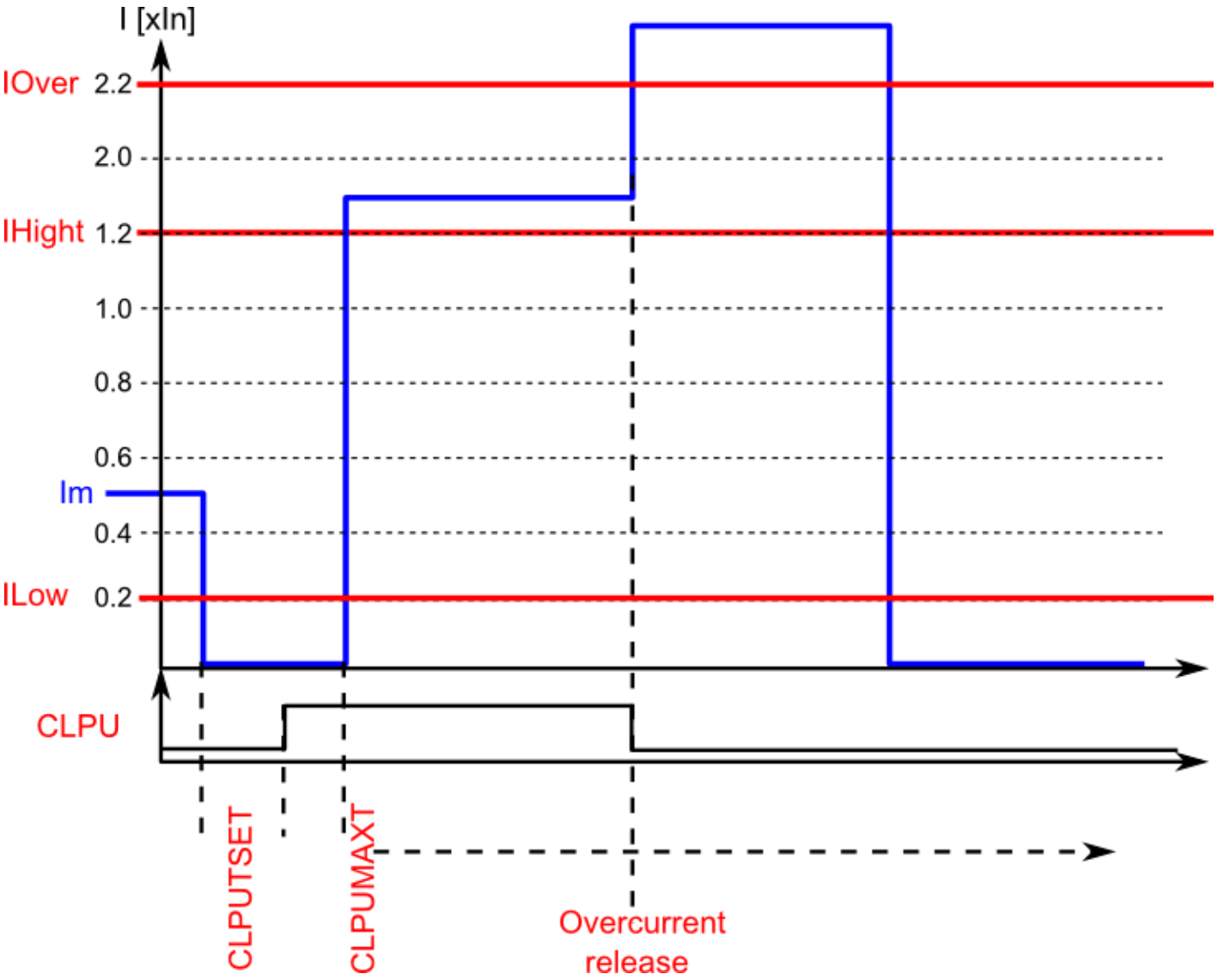
CLPU activates after current has been under ILow setting for time Tset . When current exceed the IHigh setting the maximum allowed CLPU timer start to count until Tmax time. In this example the pick-up current is cleared before the Tmax time. When the measured current is in between of ILow and IHigh the start-up condition is considered to be over. The CLPU signal can be prolonged over this time by setting Tmin to higher value than 0.000s.

Figure 4.12 Example of timers and pick-up parameters. No CLPU pick up since too short current low situation.



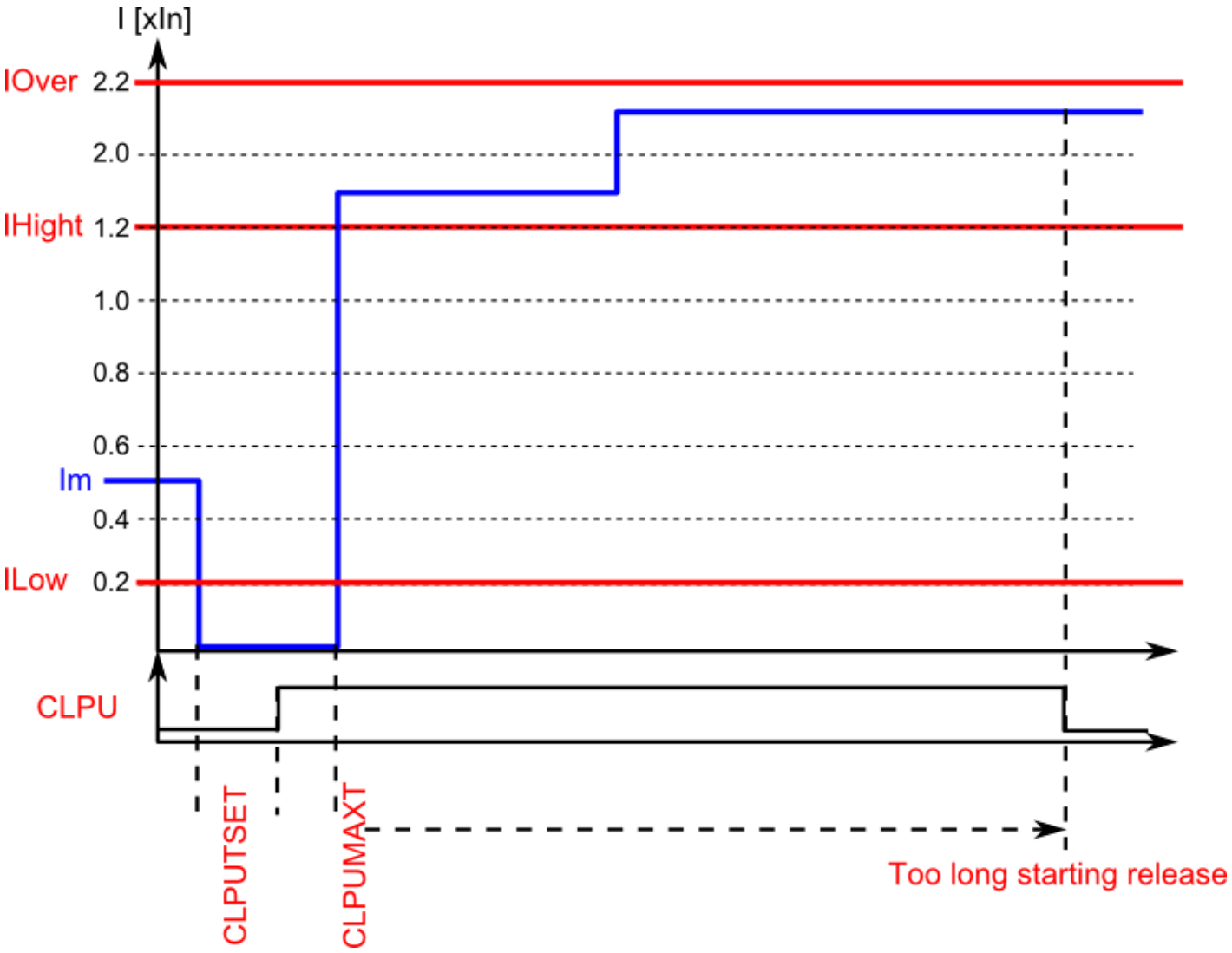
CLPU does not activate even current has been under ILow . The time setting Tset isnot exceed and therefore no CLPU signal is issued. If the CLPU is wanted to be activated in shorter time or directly when the measured current is below the ILow setting the Tset parameter can be set to lower value and even to 0.000s delay for immediate operation.

Figure 4.13 Example of timers and pick-up parameters. Activated CLPU instant release due to overcurrent.



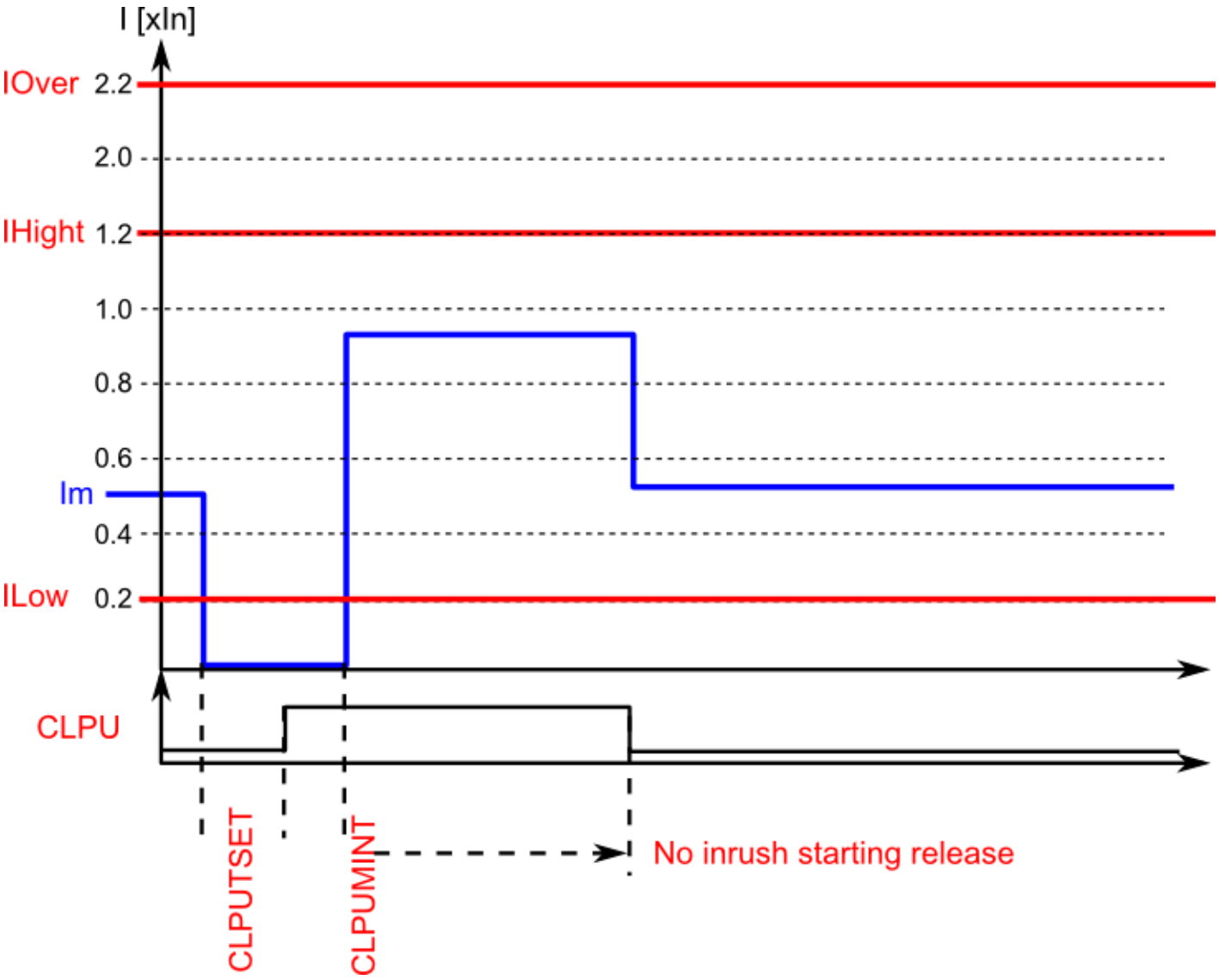
CLPU activates after current has been under ILow setting for time Tset . When current exceed the IHigh setting the maximum allowed CLPU timer start to count until Tmax time. In this example the measured current is exceeding the IOver setting during the startup situation and causes the CLPU signal immediate release.

Figure 4.14 Example of timers and pick-up parameters. Activated CLPU instant release due to too long starting.



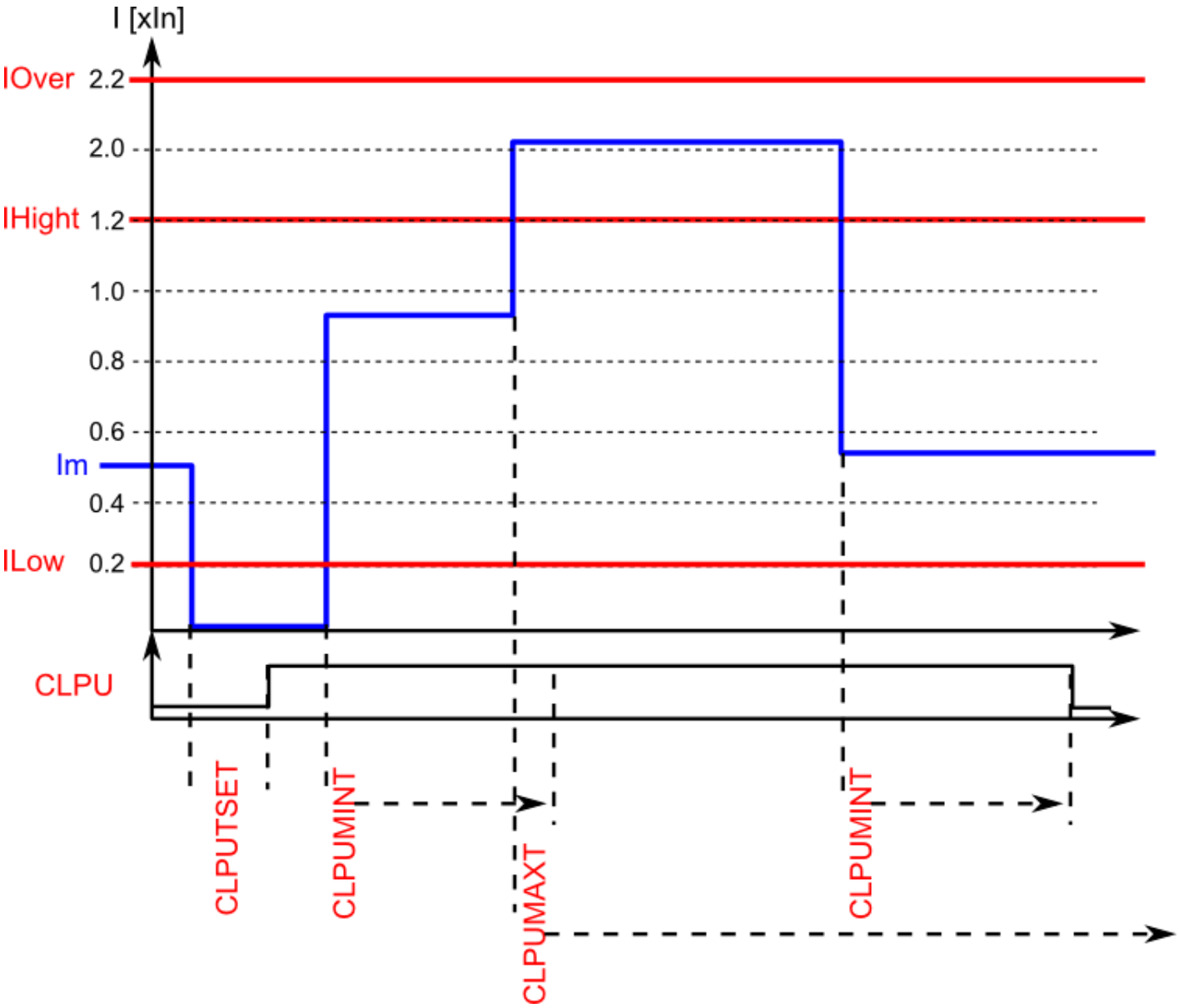
CLPU activates after current has been under ILow setting for time Tset . When current exceed the IHigh setting the maximum allowed CLPU timer start to count until Tmax time. In this example the measured current is over the set IHigh setting until Tmax time and causes the release of the CLPU signal.

Figure 4.15 Example of timers and pick-up parameters. No inrush current detected in the starting.



CLPU activates after current has been under ILow setting for time Tset. When current exceed the ILow setting but not IHigh the CLPU signal is active until the Tmin time. If no inrush is noticed during the Tmin time the CLPU signal is released.

Figure 4.16 Example of timers and pick-up parameters. Inrush current is detected during Tmin time.



CLPU activates after current has been under ILow setting for time Tset. When current exceed the ILow setting but not IHigh the CLPU signal is active until the Tmin time. When the current exceed the IHigh setting the Tmax timer is started. CLPU signal will stay active until the Tmax time is used or the start-up is over and Tmin time is over.

Events and registers

The CLPU function generates events and registers from the status changes of CLPU activated and blocked signals as well as from the internal pick-up comparators. To main event buffer is possible to select status “On” or “Off” messages.

Function includes 12 last registers where the triggering event of the function (CLPU activated or blocked) is recorded with time stamp and process data values.

Table 4.11 Event codes of the CLPU function

Event Number	Event channel	Event block name	Event Code	Description
2688	42	CLP1	0	LowStart ON
2689	42	CLP1	1	LowStart OFF
2690	42	CLP1	2	HighStart ON

Event Number	Event channel	Event block name	Event Code	Description
2691	42	CLP1	3	HighStart OFF
2692	42	CLP1	4	LoadNormal ON
2693	42	CLP1	5	LoadNormal OFF
2694	42	CLP1	6	Overcurrent ON
2695	42	CLP1	7	Overcurrent OFF
2696	42	CLP1	8	CLPUActivated ON
2697	42	CLP1	9	CLPUActivated OFF
2698	42	CLP1	10	Block ON
2699	42	CLP1	11	Block OFF

In the register of the CLPU function recorded events are activated, blocked etc. “On” event process data. Table below presents the structure of CLPU function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 4.12 Register content.

Date & Time	Event code	Trigger current	Time to CLPUact	Act CLPU	Starting time	Recl time	Used SG
dd.mm.yyyy hh:mm:ss.mss	2688-2699 Descr.	Phase currents on trigger time	Time remaining befor CLPU is active	Time CLPU has been active before starting	Recorded starting time	Reclaim time counter	1 - 8

4.2.3 Switch on to fault (SOTF)

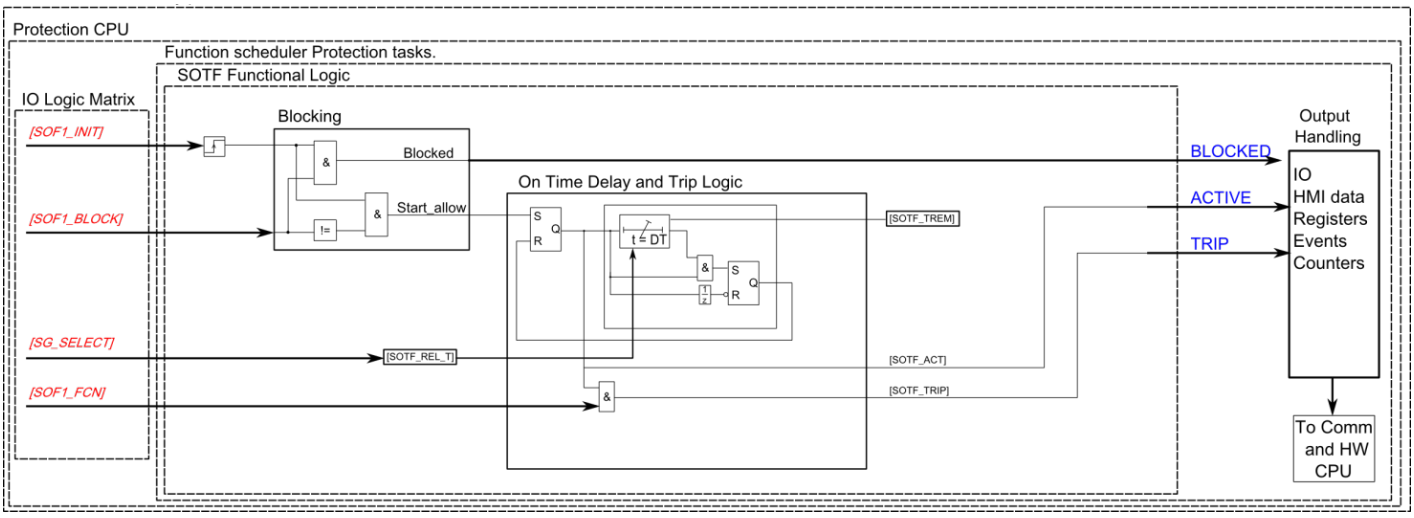
Switch on to fault (SOTF) function is used for speeding up the tripping in case if the breaker is closed towards a fault or forgotten earthing in order to reduce the damage in the fault- or problem location. Switch on to fault function can be used for controlling the protection functions or it can be used directly to trip breaker if any connected protection function starts during the set SOTF time. Operation of the SOTF function is instant after the conditions SOTF active and any signal connected to SOF1_FCN input activates.

SOTF function inputs are Initiating, Blocking, Setting group selection and Function trigger inputs. The function can be initiated from digital input or circuit breaker close command connected to the Init input and the duration of the SOTF armed condition can be set by setting parameter which can be changed if the application so requires by using the setting group selector.

Outputs of the SOTF function are Blocked, Active and Trip signals as well as corresponding events and registers when any of these mentioned signals activate.

In the following figure is presented the simplified function block diagram of the SOTF function.

Figure 4.17 Simplified function block diagram of the SOTF function.



Input signals

For the function block is not used analogic measurements. The operation is based fully into binary signal status.

Table 4.13 Signal inputs used by the SOTF function.

Input	Description
SOTF activate input	Binary input for the function to arm and start calculate the SOTF time. Any binary signal can be used to activate SOTF and start the calculation. Start of the function is applied from rising edge of the signal.
Block input	Input for blocking SOTF function. Any binary signal can be used to block SOTF function from starting.
Function input	Function input for SOTF activates SOTF instant trip if applied simultaneously when the SOTF function is calculating SOTF time.

Settings

Setting for the SOTF function is the active time after function is triggered. During this time if any set signal to Function input activates SOTF trip will be activated.

Table 4.14 Switch on to fault logic settings.

Name	Range	Step	Default	Description
Release time for SOTF	0.000...1800.000s	0.005s	1.000s	SOTF active time after triggering.

Function blocking

SOTF function can be blocked by activating BLOCK input. This will prevent the SOTF active time from starting.

Events and registers

The SOTF function generates events and registers from the status changes of SOTF activated, SOTF trip and blocked. To main event buffer is possible to select status “On” or “Off” messages.

In the function is available 12 last registers where the triggering event of the function is recorded with time stamp and process data values.

Table 4.15 Event codes of the SOTF-function instance

Event Number	Event channel	Event block name	Event Code	Description
3904	61	SOF1	0	SOTF Init On
3905	61	SOF1	1	SOTF Init Off
3906	61	SOF1	2	SOTF Block On
3907	61	SOF1	3	SOTF Block Off
3908	61	SOF1	4	SOTF Active On
3909	61	SOF1	5	SOTF Active Off
3910	61	SOF1	6	SOTF Trip On
3911	61	SOF1	7	SOTF Trip Off

In the register of the SOTF function is recorded activated “On” event process data. In the table below is presented the structure of SOTF function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 4.16 Register content.

Date & Time	Event code	SG in use	SOTF remaining time	SOTF been active time

4.2.4 Object control and monitoring (OBJ)

Object control and monitoring function takes care of circuit breaker and disconnector controlling and status monitoring. Monitor and control is based on the statuses of the IED binary inputs and outputs configured. In the relay the amount of controllable and monitored objects is dependent of available IO. One controllable object requires minimum of 2 output contacts. For status monitoring typically 2 binary inputs are utilized per monitored object. Alternatively, object status monitoring can be performed with single digital input using rising and falling edge monitoring and logic virtual inputs.

Object can be controlled from local control, remote control and HMI mimic manually or by software function automatically. For remote control from protocols the modes “Direct Control” and “Select before Execute” are dealt in the protocol handling itself.

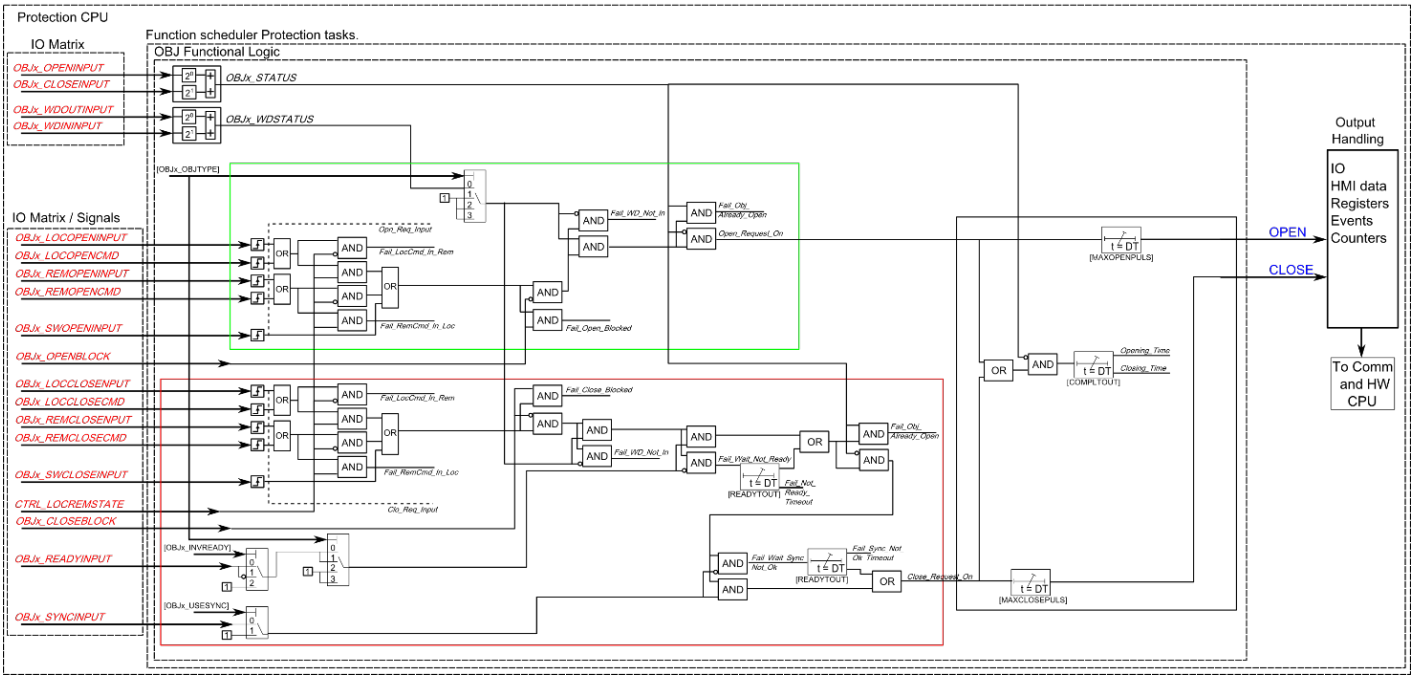
Object control consists of control logic, control monitor and output handler. In addition of these main parts in the object control block can be added object related CBFP and object wear monitor. For the basic version of the object control block these additional functions are not included.

Outputs of the function are Object open and Object close control signals. In addition to these output controls the function will report the monitored object status and applied operations. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function.

Inputs for the function are binary status indications open and close control signals, blockings, object ready and synchrocheck monitor signals. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the two output signal as well as several operational event signals. Time stamp resolution is 1ms. Function provides also cumulative counters for Open and Close act and Open / Close Failed events.

In the following figure is presented the simplified function block diagram of the OBJ function.

Figure 4.18 Simplified function block diagram of the OBJ function.



Input signals for object status monitoring

For the function is used available hardware and software digital signal statuses and command signals. The signals can be divided into Monitor, Command and Control signals based on how they are dealt in the function. These input signals are also setting parameters for the function. The amount of needed control and setting parameters depend of the selected object type.

Table 4.17 Monitor digital signal inputs used by the OBJ function.

Signal	Range	Description
Objectx Open Input	DI1 ... DIx (SWx)	Link to the physical binary input. Monitored object OPEN status. “1” means active open state of the monitored object. Position indication can be done among binary inputs and protection stage signals by using IEC-61850, GOOSE or logical signals.
Objectx Close Input	DI1 ... DIx (SWx)	Link to the physical binary input. Monitored object CLOSE status. “1” means active close state of the monitored object. Position indication can be done among binary inputs and protection stage signals by using IEC-61850, GOOSE or logical signals.
WD Object In	DI1 ... DIx (SWx)	Link to the physical binary input. Monitored withdrawable object position IN. “1” means that the withdrawable object cart is in. Position indication can be done among binary inputs and protection stage signals by using IEC-61850, GOOSE or logical signals.
WD Object Out	DI1 ... DIx (SWx)	Link to the physical binary input. Monitored withdrawable object position OUT. “1” means that the withdrawable object cart is pulled out. Position indication can be done among binary inputs and protection stage signals by using IEC-61850, GOOSE or logical signals.
Object Ready	DI1 ... DIx (SWx)	Link to the physical binary input. Monitored object status.“1” means that the object is ready and spring is charged for close command. Position indication can be done among binary inputs and protection stage signals by using IEC-61850, GOOSE or logical signals. Ready status can be set by application either “1” or “0”.
Syncrocheck permission	DI1 ... DIx (SWx)	Link to the physical binary input or synchrocheck function.“1” means that the synchrocheck conditions are met and object can be closed. Position indication can be done among binary inputs and protection stage signals by using IEC-61850, GOOSE or logical signals.

Signal	Range	Description
Open Block Input	DI1 ... DIx (SWx)	Link to the physical or software binary input.“1” means that the opening of the object is blocked. Position indication can be done among binary inputs and protection stage signals by using IEC-61850, GOOSE or logical signals.
Close Block Input	DI1 ... DIx (SWx)	Link to the physical or software binary input.“1” means that the closing of the object is blocked. Position indication can be done among binary inputs and protection stage signals by using IEC-61850, GOOSE or logical signals.
LOC / REM	Pre-assigned	IED Local / Remote switch status. Control of the object has to be applied in the correct control location. In local status remote controls cannot override the open or close commands.

Status change of the monitor signals will always cause recorded event also in the object registers and object continuous status indications. Events can be enabled or disabled according to the application requirements.

Table 4.18 Command digital signal inputs used by the OBJ function.

Signal	Range	Description
Objectx Local Close control input	DI1 ... DIx	Local Close command from physical digital input for example from pushbutton.
Objectx Local Open control input	DI1 ... DIx	Local Open command from physical digital input for example from pushbutton.
Objectx Remote Close control input	DI1 ... DIx	Remote Close command from physical digital input for example from RTU.
Objectx Remote Open control input	DI1 ... DIx	Remote Open command from physical digital input for example from RTU.
Objectx Remote Close Signal	Pre-assigned	Remote Close signal from communication protocols.
Objectx Remote Open Signal	Pre-assigned	Remote Open signal from communication protocols.
Objectx Local Close Signal	Pre-assigned	Local Close signal from HMI, either select-execute from the mimic SLD or direct from the local panel pushbutton.
Objectx Local Open Signal	Pre-assigned	Local Open signal from HMI either select-execute from the mimic SLD or direct from the local panel pushbutton..
SW Open Input	Configuration assigned	Software controlled open signal. Can be from autoreclosing or user logic.
SW Close Input	Configuration assigned	Software controlled open signal. Can be from autoreclosing, synchroswitch or user logic.

Command signal activations are logged in the function registers when applied. The activation is logged also if the control is failed for any reason.

Table 4.19 Control digital signal outputs used by the OBJ function.

Signal	Range	Description
Close command	OUT1...OUTx	Physical close command pulse to output relay of the IED.
Open command	OUT1...OUTx	Physical open command pulse to output relay of the IED

Setting parameters

For the definition of the object following parameters are provided. Based on these settings the operation of the function will vary according to the type of the object. When Disconnector (NC) is selected as object type only parameters to be set are the position indication inputs and if withdrawable CB is selected, settings for WD cart, position indication of the CB, object

ready, use synchrocheck and control timings are available. The functionality of the selected object is presented in the table below.

Table 4.20 Object type selection

Object type	Functionality	Description
Withdrawable CB	Position indication WD cart position Control Object ready Use synchrocheck Interlocks	Withdrawable circuit breaker monitor and control configuration.
Circuit Breaker	Position indication Control Object ready Use synchrocheck Interlocks	Circuit breaker monitor and control configuration.
Disconnector (MC)	Position indication Control	Disconnector position monitoring and control of the disconnector
Disconnector (NC)	Position indication	Earthing switch position indication

In the following table are presented the setting parameters for withdrawable breaker configuration (maximum set of parameters).

Table 4.21 Object setting parameters

Name	Range	Step	Default	Description
Object type	Withdrawable CB Circuit Breaker Disconnector (MC) Disconnector (NC)	-	-	User selection of object type. Selection defines the amount of required binary inputs for the monitored object. This affects into the HMI and also for the monitoring of the CB, WD cart in or out and if object ready is in use or just monitoring of status (E.switch).
Use Synchrocheck	No Yes	-	No	Selection if synchrocheck condition is in use for circuit breaker close command.
Sync timeout	0.000...1800.000s	0.02s	0.2s	Setting for synchrocheck wait timeout. If the synchrocheck permission is not received during this set time the close command will be rejected with error message. (visible only if Use Synchrocheck is “Yes”)
Use Object ready	Ready High Ready Low Not in use	-	Not in use	Selection if object ready condition is in use for circuit breaker close command. Selection can be either “1” or “0” for object ready or not in use.
Breaker traverse time	0.02...500.00s	0.02s	0.2s	Maximum time between open and close status when breaker switches. If this time is exceeded and both open and closed status inputs are active status Bad is activated. If neither of the status inputs are active after the delay Intermediate status is activated.
Sync wait timeout	0.02...500.00s	0.02s	0.2s	If synchronization ok is not received during this set time the close command will be rejected with error message. (visible only if Use synchrocheck is set to “In use”)
Obj Ready wait timeout	0.000...500.00s	0.02s	0.2s	If the object ready is not received during this set time the close command will be rejected with error message. (visible only if Use Object is either “High” or “Low”)

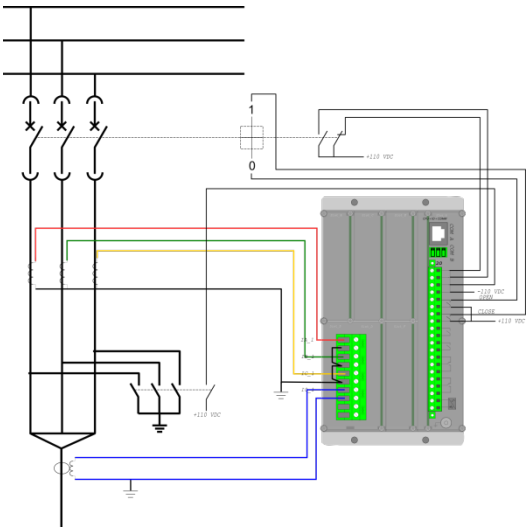
Name	Range	Step	Default	Description
Max Close pulse length	0.000...500.00s	0.02s	0.2s	Maximum length for close pulse from the output relay to the controlled object. If the object operates faster than this set time the control pulse will be reset status change is detected.
Max Open pulse length	0.000...500.00s	0.02s	0.2s	Maximum length for open pulse from the output relay to the controlled object. If the object operates faster than this set time the control pulse will be reset status change is detected.
Control termination timeout	0.000...500.00s	0.02s	10s	Control pulse termination timeout. If the object has not changed it status in this given time the function will issue error event and the control is ended. This parameter is common for both open and close commands.
Final Trip pulse length	0.000...500.00s	0.02s	0.2s	When final trip is executed by the object ObjectX Final Trip signal activates. If this parameter is set to 0s the signal is continuous. This can be used in the matrix or the logic editor.

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Blocking and interlocking

For each controllable object can be set interlocking and blocking conditions for open and close separately. Blocking and interlocking can be based on other object statuses, software function or binary input. For example, interlocking can be set for object close based on earthing disconnector position.

Figure 4.19 Example of interlock application. Closed earthing switch interlocks CB close.



Blocking signal has to reach the function 5 ms before control command in order it is received in time.

Events and registers

The OBJ function generates events and registers from the status changes of monitored signals as well as control command fails and operations. To main event buffer it is possible to select status “On” or “Off” messages.

In the function is available 12 last registers where the triggering event of the function is recorded with time stamp and process data values.

Table 4.22 Event codes of the OBJ function instances 1 – 10.

Event block name	Description
OBJ 1...10	Object Intermediate
OBJ 1...10	Object Open
OBJ 1...10	Object Close
OBJ 1...10	Object Bad
OBJ 1...10	WD Intermediate
OBJ 1...10	WD Out
OBJ 1...10	WD in
OBJ 1...10	WD Bad
OBJ 1...10	Open Request On
OBJ 1...10	Open Fail
OBJ 1...10	Open Request Off
OBJ 1...10	Open Command On
OBJ 1...10	Open Command Off
OBJ 1...10	Close Request On
OBJ 1...10	Close Fail
OBJ 1...10	Close Request Off
OBJ 1...10	Close Command On
OBJ 1...10	Close Command Off
OBJ 1...10	Status Change On
OBJ 1...10	Status Change Off

Table 4.23 Event codes of the OBJ function instances 1 – 5.

Event block name	Description
OBJ 1...5	Object Intermediate
OBJ 1...5	Object Open
OBJ 1...5	Object Close
OBJ 1...5	Object Bad
OBJ 1...5	WD Intermediate
OBJ 1...5	WD Out
OBJ 1...5	WD in
OBJ 1...5	WD Bad
OBJ 1...5	Open Request On
OBJ 1...5	Open Fail
OBJ 1...5	Open Request Off
OBJ 1...5	Open Command On
OBJ 1...5	Open Command Off
OBJ 1...5	Close Request On
OBJ 1...5	Close Fail

Event block name	Description
OBJ 1...5	Close Request Off
OBJ 1...5	Close Command On
OBJ 1...5	Close Command Off
OBJ 1...5	Status Change On
OBJ 1...5	Status Change Off

Table 4.24 Event codes of the OBJ function instances 1.

Event block name	Description
OBJ 1	Object Intermediate
OBJ 1	Object Open
OBJ 1	Object Close
OBJ 1	Object Bad
OBJ 1	WD Intermediate
OBJ 1	WD Out
OBJ 1	WD in
OBJ 1	WD Bad
OBJ 1	Open Request On
OBJ 1	Open Fail
OBJ 1	Open Request Off
OBJ 1	Open Command On
OBJ 1	Open Command Off
OBJ 1	Close Request On
OBJ 1	Close Fail
OBJ 1	Close Request Off
OBJ 1	Close Command On
OBJ 1	Close Command Off
OBJ 1	Status Change On
OBJ 1	Status Change Off

4.2.5 Indicator object monitoring (CIN)

Indicator function takes care of circuit breaker and disconnector status monitoring. Indicator function is only for indication purposes which means it doesn't have any control functionality. For circuit breaker/disconnector controlling use objects. Monitoring is based into the statuses of the configured IED binary inputs. In the relay the number of monitored indicators is dependent of available IO. For status monitoring, typically 2 binary inputs are utilized per monitored indicator. Alternatively, indicator status monitoring can be performed with single digital input using rising and falling edge monitoring and logic virtual inputs. Selection of the type of object is selected in the mimic editor.

Outputs of the function are monitored indicator statuses Open/Close. Setting parameters are static inputs of the function which are changed only by user input in the setup phase of the function.

Inputs for the function are binary status indications. The function generates general time stamped ON/OFF events to the common event buffer from each of the open, close, bad and intermediate event signals. Time stamp resolution is 1ms.

Input signals for indication status monitoring

Function uses available hardware and software digital signal statuses. These input signals are also setting parameters for the function.

Table 4.25 Monitor digital signal inputs used by the CIN function.

Signal	Range	Description
IndicatorX Open Input	DI1 ... DIx (SWx)	Link to the physical binary input. Monitored indicator OPEN status. “1” means active open state of the monitored indicator. Position indication can be done among binary inputs and protection stage signals by using IEC-61850, GOOSE or logical signals.
IndicatorX Close Input	DI1 ... Dix (SWx)	Link to the physical binary input. Monitored indicator CLOSE status. “1” means active close state of the monitored indicator. Position indication can be done among binary inputs and protection stage signals by using IEC-61850, GOOSE or logical signals.

Status change of the signals will always cause recorded event also in the indicators continuous status indications. Events can be enabled or disabled according to the application requirements.

Events

The indicator function generates events and registers from the status changes of monitored signals. To main event buffer is possible to select status “On” or “Off” messages.

Table 4.26 Event codes of CIN function instances 1 – 5.

Event Number	Event channel	Event block name	Event Code	Description
6656	104	CIN1	0	Intermediate
6657	104	CIN1	1	Open
6658	104	CIN1	2	Close
6659	104	CIN1	3	Bad
6720	105	CIN2	0	Intermediate
6721	105	CIN2	1	Open
6722	105	CIN2	2	Close
6723	105	CIN2	3	Bad
6784	106	CIN3	0	Intermediate
6785	106	CIN3	1	Open
6786	106	CIN3	2	Close
6787	106	CIN3	3	Bad
6848	107	CIN4	0	Intermediate
6849	107	CIN4	1	Open
6850	107	CIN4	2	Close
6851	107	CIN4	3	Bad
6912	108	CIN5	0	Intermediate
6913	108	CIN5	1	Open
6914	108	CIN5	2	Close
6915	108	CIN5	3	Bad

Table 4.27 Event codes of CIN function instances 1-10

Event Number	Event channel	Event block name	Event Code	Description
6656	104	CIN1	0	Intermediate
6657	104	CIN1	1	Open
6658	104	CIN1	2	Close
6659	104	CIN1	3	Bad
6720	105	CIN2	0	Intermediate
6721	105	CIN2	1	Open
6722	105	CIN2	2	Close
6723	105	CIN2	3	Bad
6784	106	CIN3	0	Intermediate
6785	106	CIN3	1	Open
6786	106	CIN3	2	Close
6787	106	CIN3	3	Bad
6848	107	CIN4	0	Intermediate
6849	107	CIN4	1	Open
6850	107	CIN4	2	Close
6851	107	CIN4	3	Bad
6912	108	CIN5	0	Intermediate
6913	108	CIN5	1	Open
6914	108	CIN5	2	Close
6915	108	CIN5	3	Bad
10752	168	CIN6	0	Intermediate
10753	168	CIN6	1	Open
10754	168	CIN6	2	Close
10755	168	CIN6	3	Bad
10816	169	CIN7	0	Intermediate
10817	169	CIN7	1	Open
10818	169	CIN7	2	Close
10819	169	CIN7	3	Bad
10880	170	CIN8	0	Intermediate
10881	170	CIN8	1	Open
10882	170	CIN8	2	Close
10883	170	CIN8	3	Bad
10944	171	CIN9	0	Intermediate
10945	171	CIN9	1	Open
10946	171	CIN9	2	Close
10947	171	CIN9	3	Bad
11008	172	CIN10	0	Intermediate
11009	172	CIN10	1	Open

Event Number	Event channel	Event block name	Event Code	Description
11010	172	CIN10	2	Close
11011	172	CIN10	3	Bad

Table 4.28 Event codes of CIN function instances 1-20

Event Number	Event channel	Event block name	Event Code	Description
6656	104	CIN1	0	Intermediate
6657	104	CIN1	1	Open
6658	104	CIN1	2	Close
6659	104	CIN1	3	Bad
6720	105	CIN2	0	Intermediate
6721	105	CIN2	1	Open
6722	105	CIN2	2	Close
6723	105	CIN2	3	Bad
6784	106	CIN3	0	Intermediate
6785	106	CIN3	1	Open
6786	106	CIN3	2	Close
6787	106	CIN3	3	Bad
6848	107	CIN4	0	Intermediate
6849	107	CIN4	1	Open
6850	107	CIN4	2	Close
6851	107	CIN4	3	Bad
6912	108	CIN5	0	Intermediate
6913	108	CIN5	1	Open
6914	108	CIN5	2	Close
6915	108	CIN5	3	Bad
10752	168	CIN6	0	Intermediate
10753	168	CIN6	1	Open
10754	168	CIN6	2	Close
10755	168	CIN6	3	Bad
10816	169	CIN7	0	Intermediate
10817	169	CIN7	1	Open
10818	169	CIN7	2	Close
10819	169	CIN7	3	Bad
10880	170	CIN8	0	Intermediate
10881	170	CIN8	1	Open
10882	170	CIN8	2	Close
10883	170	CIN8	3	Bad
10944	171	CIN9	0	Intermediate
10945	171	CIN9	1	Open
10946	171	CIN9	2	Close

Event Number	Event channel	Event block name	Event Code	Description
10947	171	CIN9	3	Bad
11008	172	CIN10	0	Intermediate
11009	172	CIN10	1	Open
11010	172	CIN10	2	Close
11011	172	CIN10	3	Bad
11072	173	CIN11	0	Intermediate
11073	173	CIN11	1	Open
11074	173	CIN11	2	Close
11075	173	CIN11	3	Bad
11136	174	CIN12	0	Intermediate
11137	174	CIN12	1	Open
11138	174	CIN12	2	Close
11139	174	CIN12	3	Bad
11200	175	CIN13	0	Intermediate
11201	175	CIN13	1	Open
11202	175	CIN13	2	Close
11203	175	CIN13	3	Bad
11264	176	CIN14	0	Intermediate
11265	176	CIN14	1	Open
11266	176	CIN14	2	Close
11267	176	CIN14	3	Bad
11328	177	CIN15	0	Intermediate
11329	177	CIN15	1	Open
11330	177	CIN15	2	Close
11331	177	CIN15	3	Bad
11392	178	CIN16	0	Intermediate
11393	178	CIN16	1	Open
11394	178	CIN16	2	Close
11395	178	CIN16	3	Bad
11456	179	CIN17	0	Intermediate
11457	179	CIN17	1	Open
11458	179	CIN17	2	Close
11459	179	CIN17	3	Bad
11520	180	CIN18	0	Intermediate
11521	180	CIN18	1	Open
11522	180	CIN18	2	Close
11523	180	CIN18	3	Bad
11584	181	CIN19	0	Intermediate
11585	181	CIN19	1	Open
11586	181	CIN19	2	Close
11587	181	CIN19	3	Bad

Event Number	Event channel	Event block name	Event Code	Description
11648	182	CIN20	0	Intermediate
11649	182	CIN20	1	Open
11650	182	CIN20	2	Close
11651	182	CIN20	3	Bad

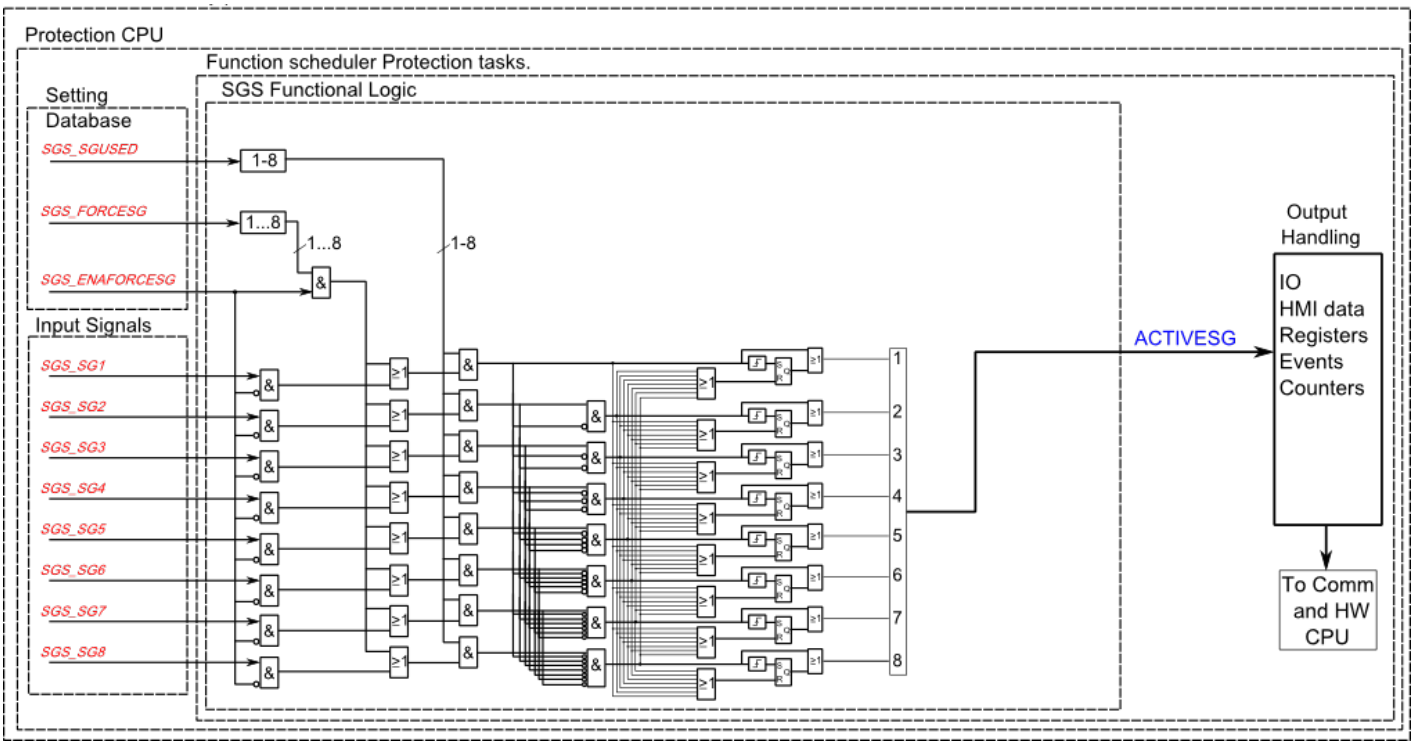
4.2.6 Setting group selection (SGS)

Up to eight (8) separate setting groups are supported. Availability and selection is controlled by SGS function block. By default, only SG1 is active and thus the selection logic is idle. When more than one setting group is enabled the setting group selector logic shall take control of the setting group activations based on the user programmed logic and conditions.

Setting group activation for use in the application is set in the SGS function block which after all available functions enable corresponding setting groups. If setting group is not activated but is tried to control on with SGS an event of failed setting group change is issued.

In the following figure is presented the simplified function block diagram of the SGS function.

Figure 4.20 Simplified function block diagram of the SGS function.



Setting group selection can be applied by activating the SGS_SG1...SG8 inputs by the device internal logic or connected binary inputs. Also it is possible to force any of the setting group on by enabling the Force SG and give the wanted setting group as number from the communication bus or from local HMI. When force parameter is enabled the local device automatic control is overridden and full control of setting group is with user until the force SG change is disabled again.

For the application controlled setting group switch and selection is available either pulse controlled change or signal level change options. In the setting group controller block is prioritized the setting groups so that if higher one is controlled simultaneously with lower priority setting group the higher request shall be taken into use.

If the control is applied with steady state signals then lower priority setting group requests will not be applied. If pulse control is applied for the setting group selection control of the setting group has to be applied for all setting groups e.g. if

setting group 2 is selected with signal and when it is released the setting group 1 shall not be automatically selected and the logic needs separate control to set the active setting group back to group 1.

Figure 4.21 Group changing example sequence with pulse control only or with pulses and static signal.

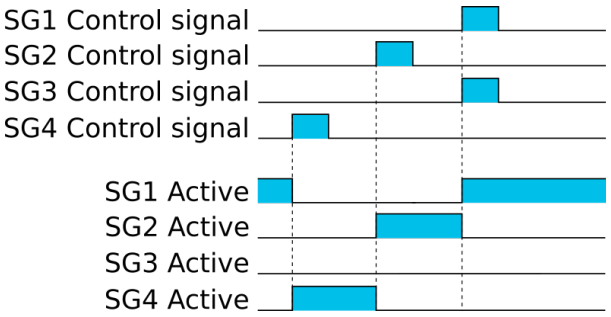
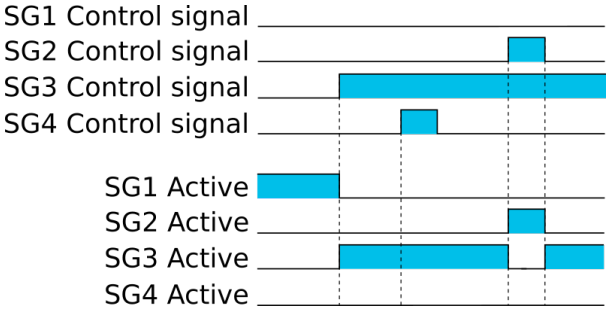


Figure 4.22 Second group changing example sequence with pulse control only or with pulses and static signal.



Settings and signals

Settings of the setting group control function includes the amount of available setting groups, selection of force change enable and forced setting group selection. If the setting group is forced to change it requires that the corresponding setting group is enabled and the force change is activated. After this the setting group can be set from communications or from HMI to any available group. In case if the setting group control is applied with steady state signals right after force setting group parameter is released application shall take control of the setting group selection.

Table 4.29 Settings of the SGS function.

Name	Range	Step	Default	Description
Used setting groups	0:SG1 1:SG1...2 2:SG1...3 3:SG1...4 4:SG1...5 5:SG1...6 6:SG1...7 7:SG1...8	-	0:SG1	Selection of activated setting groups in the application. If setting group is enabled it cannot be controlled to active. When enabling new setting groups the activated setting groups shall copy values from the SG1. Default setting is that only SG1 is active.
Force SG change enabled	0:Disabled 1:Enabled	-	0:Disabled	Setting of force setting group change either enabled or disabled. This setting has to be active before the setting group can be changed remotely or from local HMI. This parameter is overriding local control of the setting groups and is not time dependable which means that in user activation this override shall be on until it is disabled by user again.
Force SG change	0:none 1:SG1 2:SG2 3:SG3 4:SG4 5:SG5	-	0:none	Selection of override setting group. After force SG change is enabled any of the configured setting groups can be override on to the device. This control is always based on pulse operating mode and also requires that the setting group selected is specifically controlled to “On” after force SG is disabled if there is no other controls the last set SG shall remain active.

Name	Range	Step	Default	Description
	6:SG6 7:SG7 8:SG8			

Table 4.30 Signals of the SGS function

Name	Range	Step	Default	Description
Setting group1	0:Not active 1:Active	-	0:Not active	Setting group 1 selection, highest priority input for setting group control. Can be controlled with pulse or steady state signals. If steady state signal is applied no other SG requests shall be processed.
Setting group2	0:Not active 1:Active	-	0:Not active	Setting group 2 selection, second highest priority input for setting group control. Can be controlled with pulse or steady state signals. If steady state signal is applied no lower priority than SG1 requests shall be processed.
Setting group3	0:Not active 1:Active	-	0:Not active	Setting group 3 selection, third highest priority input for setting group control. Can be controlled with pulse or steady state signals. If steady state signal is applied no lower priority than SG1 and SG2 requests shall be processed.
Setting group4	0:Not active 1:Active	-	0:Not active	Setting group 4 selection, fourth highest priority input for setting group control. Can be controlled with pulse or steady state signals. If steady state signal is applied no lower priority than SG1,SG2 and SG3 requests shall be processed.
Setting group5	0:Not active 1:Active	-	0:Not active	Setting group 6 selection, fourth lowest priority input for setting group control. Can be controlled with pulse or steady state signals. If steady state signal is applied SG6, SG7 and SG8 requests shall not be processed.
Setting group6	0:Not active 1:Active	-	0:Not active	Setting group 6 selection, third lowest priority input for setting group control. Can be controlled with pulse or steady state signals. If steady state signal is applied SG7 and SG8 requests shall not be processed.
Setting group7	0:Not active 1:Active	-	0:Not active	Setting group 7 selection, second lowest priority input for setting group control. Can be controlled with pulse or steady state signals. If steady state signal is applied only SG8 requests shall not be processed.
Setting group8	0:Not active 1:Active	-	0:Not active	Setting group 8 selection, lowest priority input for setting group control. Can be controlled with pulse or steady state signals. If steady state signal is applied all other SG requests shall be processed no matter of this signal status.
Active SG	0...7	1	0	Active SG at the moment. This output signal is used by all other functions.

Events

SG selection function block generates events from its controlling status and applied input signals as well as unsuccessful control changes and enabled setting groups. For this function is no register available.

Table 4.31 Event codes of SGS function.

Event Number	Event channel	Event block name	Event Code	Description
4160	65	SGS	0	SG2 Enabled
4161	65	SGS	1	SG2 Disabled
4162	65	SGS	2	SG3 Enabled
4163	65	SGS	3	SG3 Disabled
4164	65	SGS	4	SG4 Enabled
4165	65	SGS	5	SG4 Disabled
4166	65	SGS	6	SG5 Enabled

Event Number	Event channel	Event block name	Event Code	Description
4167	65	SGS	7	SG5 Disabled
4168	65	SGS	8	SG6 Enabled
4169	65	SGS	9	SG6 Disabled
4170	65	SGS	10	SG7 Enabled
4171	65	SGS	11	SG7 Disabled
4172	65	SGS	12	SG8 Enabled
4173	65	SGS	13	SG8 Disabled
4174	65	SGS	14	SG1 Request On
4175	65	SGS	15	SG1 Request Off
4176	65	SGS	16	SG2 Request On
4177	65	SGS	17	SG2 Request Off
4178	65	SGS	18	SG3 Request On
4179	65	SGS	19	SG3 Request Off
4180	65	SGS	20	SG4 Request On
4181	65	SGS	21	SG4 Request Off
4182	65	SGS	22	SG5 Request On
4183	65	SGS	23	SG5 Request Off
4184	65	SGS	24	SG6 Request On
4185	65	SGS	25	SG6 Request Off
4186	65	SGS	26	SG7 Request On
4187	65	SGS	27	SG7 Request Off
4188	65	SGS	28	SG8 Request On
4189	65	SGS	29	SG8 Request Off
4190	65	SGS	30	Remote Change SG Req On
4191	65	SGS	31	Remote Change SG Req Off
4192	65	SGS	32	Local Change SG Req On
4193	65	SGS	33	Local Change SG Req On
4194	65	SGS	34	Force Change SG On
4195	65	SGS	35	Force Change SG Off
4196	65	SGS	36	SG Req. Fail Not configured SG On
4197	65	SGS	37	SG Req. Fail Not configured SG On
4198	65	SGS	38	Force Req. Fail Force not On
4199	65	SGS	39	Force Req. Fail Off
4200	65	SGS	40	SG Req. Fail Lower priority Req. On
4201	65	SGS	41	SG Req. Fail Lower priority Req. Off
4202	65	SGS	42	SG1 Active On
4203	65	SGS	43	SG1 Active Off
4204	65	SGS	44	SG2 Active On
4205	65	SGS	45	SG2 Active Off
4206	65	SGS	46	SG3 Active On
4207	65	SGS	47	SG3 Active Off

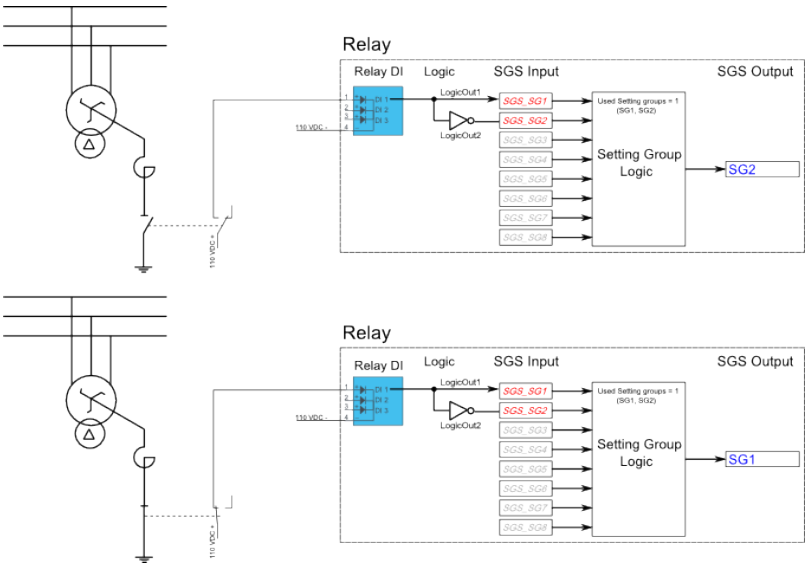
Event Number	Event channel	Event block name	Event Code	Description
4208	65	SGS	48	SG4 Active On
4209	65	SGS	49	SG4 Active Off
4210	65	SGS	50	SG5 Active On
4211	65	SGS	51	SG5 Active Off
4212	65	SGS	52	SG6 Active On
4213	65	SGS	53	SG6 Active Off
4214	65	SGS	54	SG7 Active On
4215	65	SGS	55	SG7 Active Off
4216	65	SGS	56	SG8 Active On
4217	65	SGS	57	SG8 Active Off

Example applications for setting group control

In this chapter are presented some of most common applications for setting group changing requirements.

In a Petersen coil compensated network is usually used directional sensitive earth fault protection which characteristics is wanted to be controlled in between Varmetric and Wattmetric based on if the Petersen coil is connected when the network is compensated or is it open when the network is unearthed.

Figure 4.23 Setting group control with 1 wire connection from Petersen coil status.



By monitoring the state of the Petersen coil connection the setting group control can be applied either with 1 wire or 2 wire connection depending of the application requirements. In case of 1 wire connection is allowed the setting group change logic can be applied as in the figure above. Petersen coil status on controls SG1 to be active and if the coil is disconnected SG2 is active. With this practice if the wire is broken for some reason the setting group would always be controlled to SG2.

With 2 wires connection when the Petersen coil state is monitored in both status more security can be achieved. In addition to the direct connection below also additional logic can be added to the control similarly to the 1 wire control. By that way single wire loss will not effect to the correct setting group selection.

Figure 4.24 Setting group control with 2 wire connection from Petersen coil status.

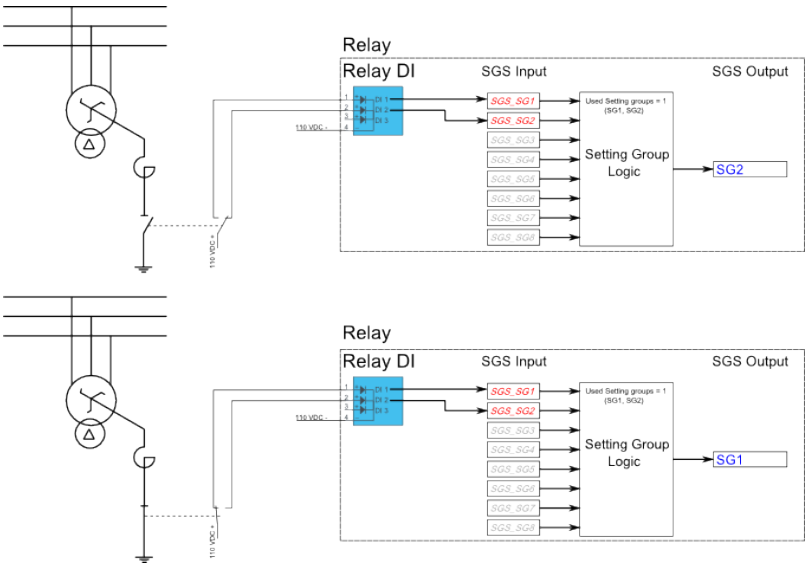
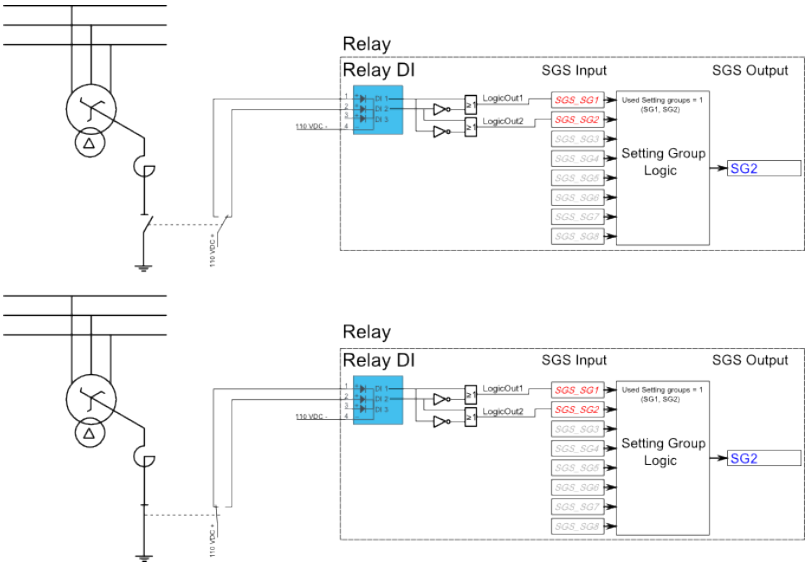
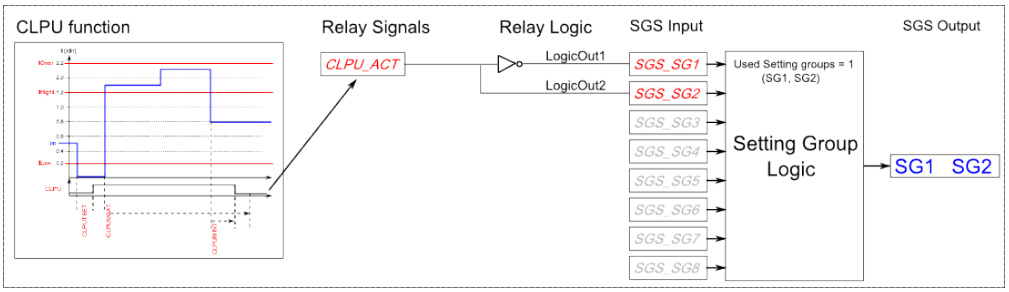


Figure 4.25 Setting group control with 2 wire connection from Petersen coil status and additional logic.



Application controlled setting group change can be applied also completely from the relays internal logics. One example can be setting group change based on cold load pick up function.

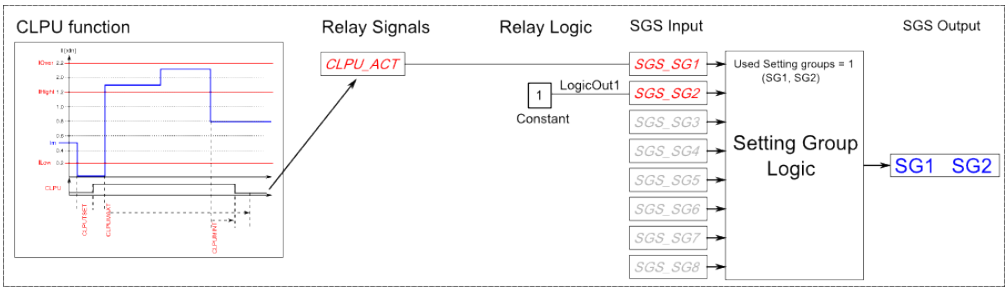
Figure 4.26 Example of fully application controlled setting group change with CLPU function.



In this example the CLPU function output is used for the automatic setting group change. Similarly to this application, any combination of the available signals in the relay database can be programmed to be used for in the setting group selection logic.

As can be seen from these presented examples the setting group selection with application control has to be built fully when using this approach for the setting group control. Setting group will not change back to SG1 if it is not controlled back to SG1 by the application. This explains the inverted signal “NOT” and use of logics in the SG control. Another approach can be that the SG2 in these cases would be selected as primary SG while with “On” signal would be controlled higher priority SG1. By this way after the automatic control is over SG would return automatically to SG2.

Figure 4.27 Example of setting default SG constant signal.



4.2.7 mA Output control

The milliamp current loop is the prevailing process control signal in many industries. It is an ideal method of transferring process information because current does not change as it travels from transmitter to receiver. It is also much simpler and cost effective.

Benefits of 4...20mA loops:

- The 4-20 mA current loop is the dominant standard in many industries.
- It is the simplest option to connect and configure.
- It uses less wiring and connections than other signals, greatly reducing initial setup costs.
- Better for traveling long distances, as current does not degrade over long connections like voltage.
- It is less sensitive to background electrical noise.
- Since 4 mA is equal to 0% output, it is incredibly simple to detect a fault in the system.

Milliamp outputs

Up to two independent milliamp option cards are supported. Each card has 4 milliamp -outputs and one milliamp -input. If the IED has milliamp option card, enable mA-outputs by selecting: *Control → Device IO → mA Outputs*:

Figure 4.28 Milliamp outputs are activated two at the time, channel 1&2 / channel 3&4 activation. Option card order code is “I”.

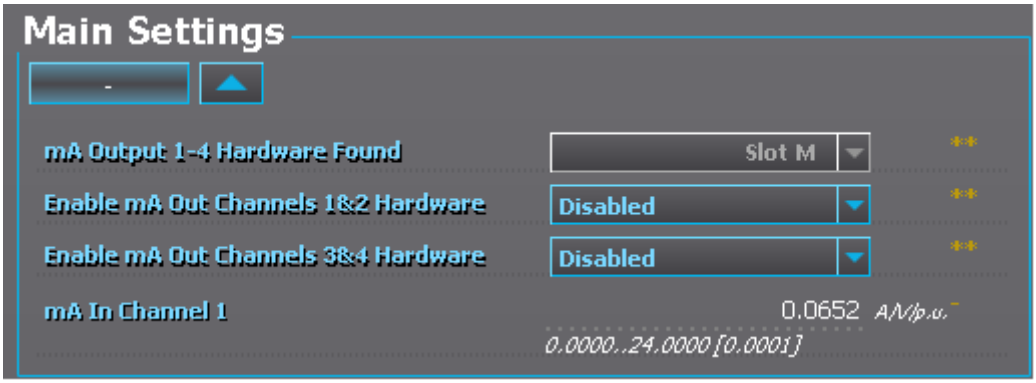
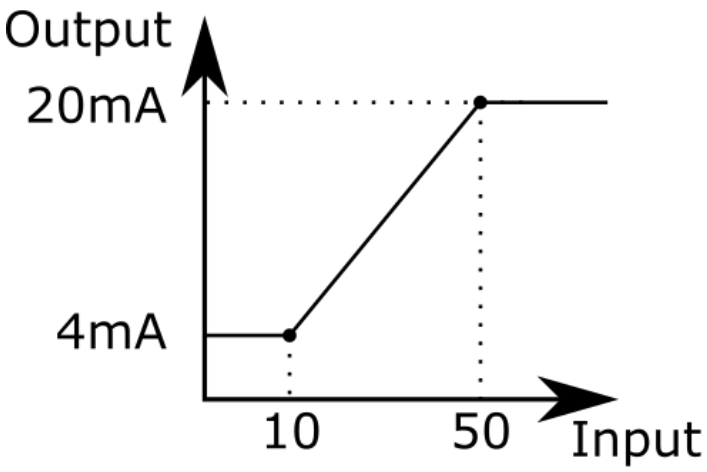


Table 4.32 Main settings of the mA outputs

Name		Range	Default	Description
mA option card 1	Enable mA Out Channels 1&2	0:Disabled 1:Enabled	0:Disabled	Enables mA output cards outputs.
	Enable mA Out Channels 3&4			
mA option card 2	Enable mA Out Channels 5&6	0:Disabled 1:Enabled	0:Disabled	Enables mA output cards outputs.
	Enable mA Out Channels 7&8			

Figure 4.29 Example of the effects mA output Channel settings have.



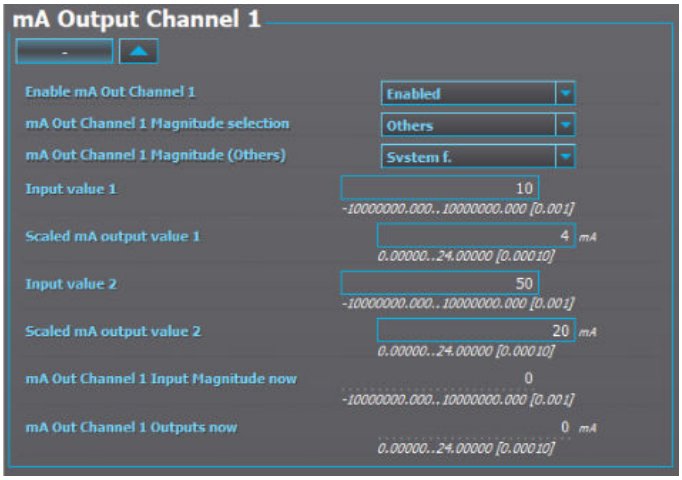


Table 4.33 mA output channel settings

Name	Range	Step	Default	Description
Enable mA Out Channel	0:Disabled 1:Enabled	-	0:Disabled	Enables the mA Output channel. If channel is disabled channel settings are hidden.
mA Out Channel Magnitude selection	0:Currents 1:Voltages 2:Powers 3:Imp./Adm. 4:Other	-	0:Currents	Defines the category of measurement used for mA output control.
mA Out Channel Magnitude	Dependent on category selection	-	Dependent on category selection	Defines the measurement used for mA output control. Available measurements depends on parameter mA Out Channel Magnitude selection.
Input value 1	$-10^7...10^7$	0.001	0	First input point in the mA output control curve.
Scaled mA output value 1	0.00000... 24.00000mA	0.0001mA	0mA	mA output value when measured value is equal or less than Input value 1.
Input value 2	$-10^7...10^7$	0.001	1	Second input point in the mA output control curve.
Scaled mA output value 2	0.00000... 24.00000mA	0.0001mA	0mA	mA output value when measured value is equal or greater than Input value 2.

Table 4.34 Hardware indications

Name	Range	Step	Description
mA Output 1-4 Hardware found mA Output 5-8 Hardware found	0=None; 1=SlotA; 2=SlotB; 3=SlotC; 4=SlotD; 5=SlotE; 6=SlotF; 7=SlotG; 8=SlotH; 9=SlotI; 10=SlotJ; 11=SlotK; 12=SlotL; 13=SlotM; 14=SlotN; 15=Too many cards installed	-	Indicates in which option card slot mA output card is located in.

Table 4.35 Measurement values reported by mA output card

Name	Range	Step	Description
mA In Channel 1 mA In Channel 2	0.0000...24.0000mA	0.0001 mA	Measured mA value of the input channel.
mA Out Channel Input Magnitude now	$-10^7...10^7$	0.001	Value of the selected measurement value at the moment for the output channel control.
mA Out Channel Outputs now	0.0000...24.0000mA	0.0001mA	Current output value of the mA output channel at the moment.

Milliamp input

Up to two independent milliamp option cards are supported. Each card has 4 milliamp -outputs and one mA -input. If the IED has milliamp option card, enable mA-input by selecting: *Measurements → AI(mA, DI volt) scaling*:

Figure 4.30 Each milliamp option card (order code “I”) has one mA-input channel. Activate analogue input and create a scaling curve.

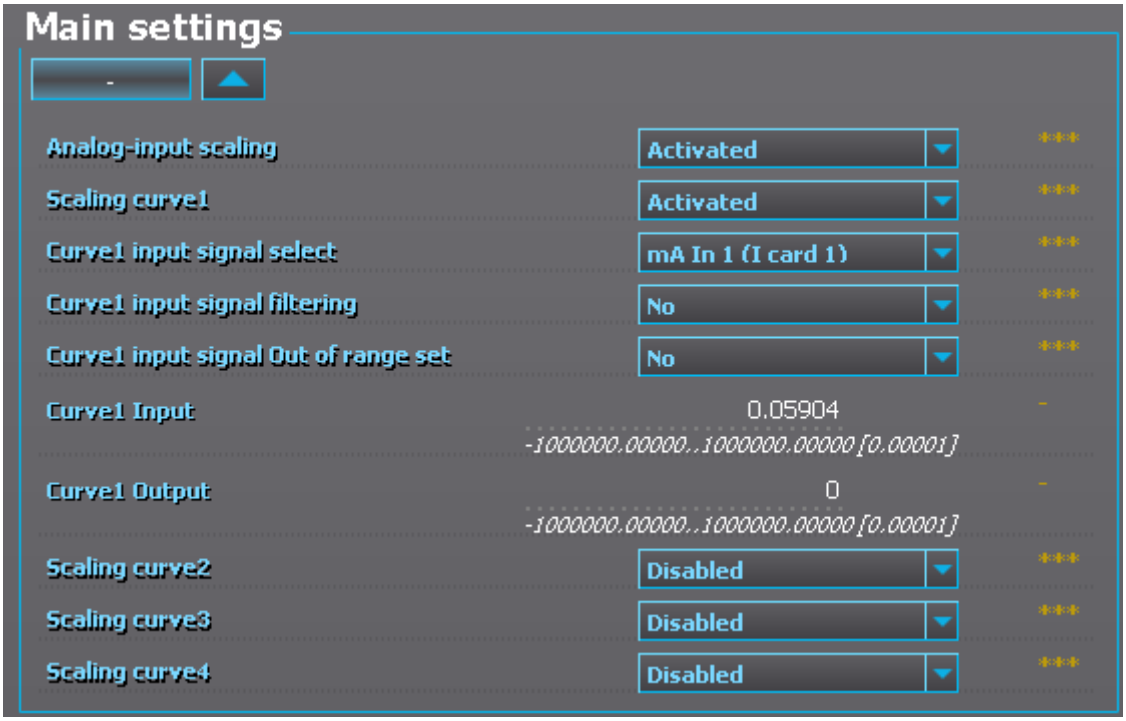


Table 4.36 Main settings of the mA inputs

Name	Range	Default	Description
Analog-input scaling	0:Disabled 1:Activated	0:Disabled	Enables mA input.
Scaling curve 1...4	0:Disabled 1:Activated	0:Disabled	Enables scaling curve and mA input measurement.
Curve1...4 input signal select	0:RTD S1 resistance ... 15:RTD S16 resistance 16:mA In 1 (I card 1) 17:mA In 2 (I card 2)	0:RTD S1 resistance	Defines the category of measurement used for mA input control.

Input signal filter calculates an average for received mA signal according to set time constant. Therefore, rapid changes and disturbances like fast spikes are smothered. The Nyquist rate states that the filter time constant must be at least double the period time of the disturbance process signal. For example, a value for the filter time constant is 2 seconds for a 1 second period time of a disturbance oscillation.

$$H(s) = \frac{Wc}{S+Wc} = \frac{1}{1+s/Wc}$$

Figure 4.31 First order low pass filter



Curve signal out of range activates “out of range” -alarm that can be used inside logic or with other relay functions. The signal can be assigned directly to output relay or LED in IO matrix. Out of range signal is activated when measured mA signal falls below the set input minimum or exceeds the input maximum limit. Out of range signal is valuable when for example 4...20mA input signal is used.

Figure 4.32 If in some case the mA input signal is lost, the value will be fixed in to the last actual measured cycle value (value will not go to minimum if it has been something else when signal breaks).

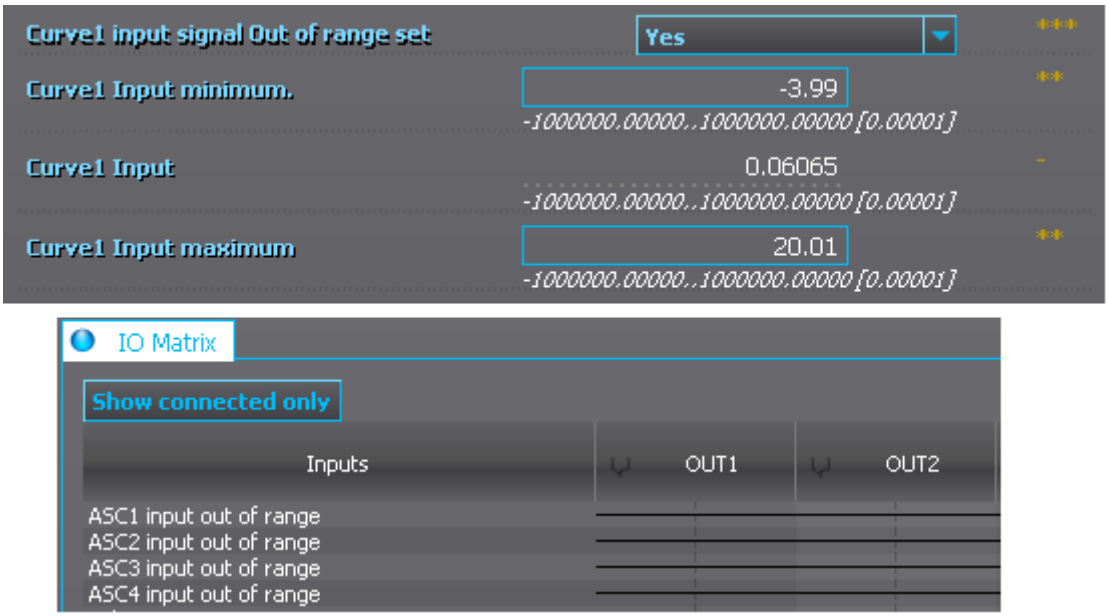


Figure 4.33 Example of the effects mA input channel settings have.

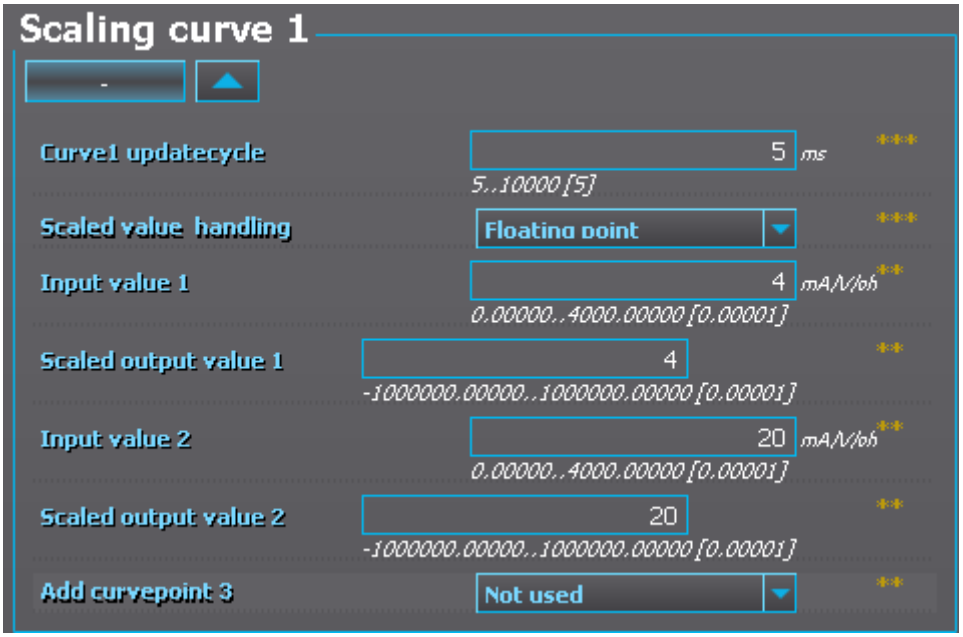


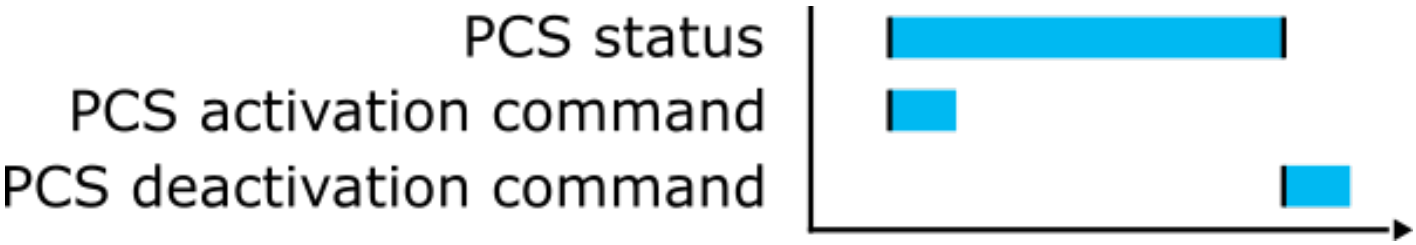
Table 4.37 mA Output settings and indications

Name	Range	Step	Default	Description
Curve1...4 updatecycle	5...10000ms	5ms	150ms	mA input measurement update cycle. For fast operation a lower setting should be implemented.
Scaled value handling	0:Floating point 1:Integer out (Floor)	n/a	0:Floating point	Rounds the milliamp signal output as selected,

Name	Range	Step	Default	Description
	2:Integer (Ceiling) 3:Integer (Nearest)			
Input value 1	0...4000	0.00001	0	Measured milliamp input value at curve point 1.
Scaled output value 1	-10^7...10^7	0.00001	0	To where measured milliamp signal should be scaled at point 1.
Input value 2	0...4000	0.00001	1	Measured milliamp input value at curve point 2.
Scaled output value 1	-10^7...10^7	0.00001	0	To where measured milliamp signal should be scaled at point 2.
Add curvepoint 3...20	0:Not used 1:Used	n/a	0:Not used	Instead of using linear curve between two points, create your own curve with up to 20 curve points.

4.2.8 Programmable control switch

Programmable Control Switch is a control function that controls its binary output signal on/off. This output signal can be controlled locally from the IED mimic (appears as square box) or remotely from RTU. Programmable Control Switches main purpose is to change function properties by changing the setting group by other means or block/enable functions. This binary signal can be also used for any other kind of purpose just like all other binary signals.



Once Programmable Control Switch output has been activated (1) or disabled (0) it will remain in this state until given a new control command to the opposite state. The switch cannot be controlled by any “auxiliary” input like digital input or logic signals, only local mimic control or remote RTU control are available.

Events

The PCS function generates events from the status changes. To main event buffer it is possible to select status “On” or “Off” messages. The PCS function offers five independent instances.

Table 4.38 Event codes of the PCS function

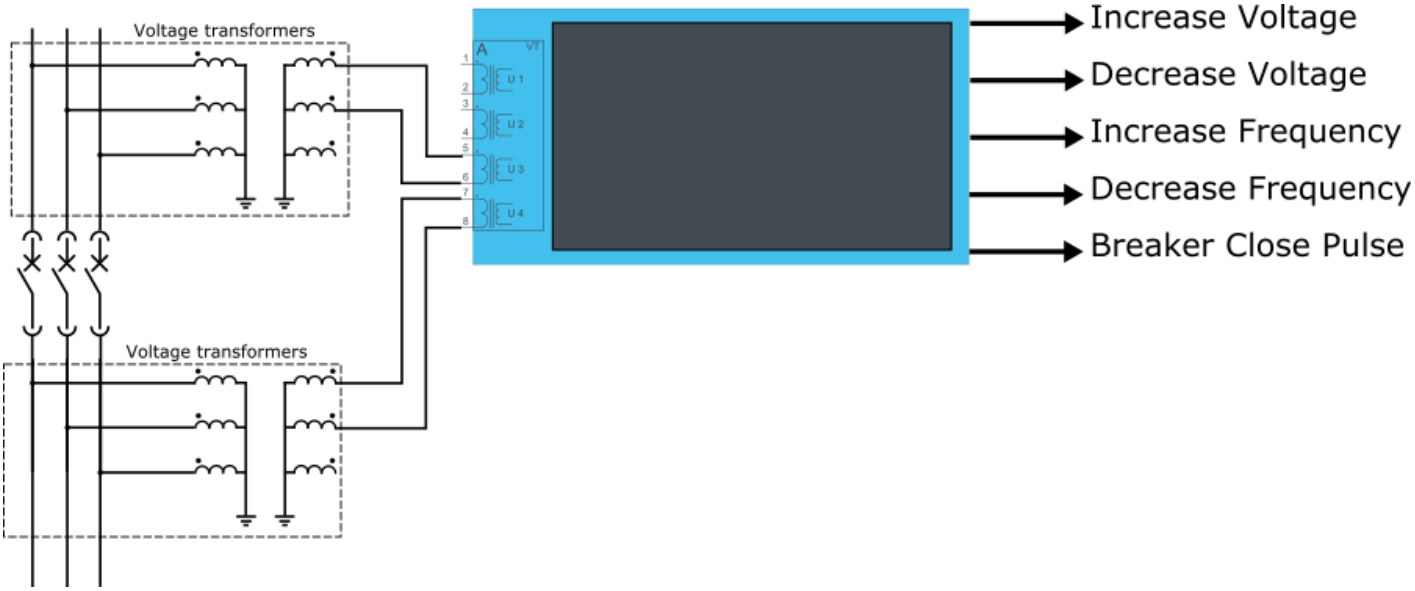
Event Number	Event channel	Event block name	Event Code	Description
384	6	PCS	0	Switch1 On
385	6	PCS	1	Switch1 Off
386	6	PCS	2	Switch2 On
387	6	PCS	3	Switch2 Off
388	6	PCS	4	Switch3 On
389	6	PCS	5	Switch3 Off
390	6	PCS	6	Switch4 On
391	6	PCS	7	Switch4 Off
392	6	PCS	8	Switch5 On
393	6	PCS	9	Switch5 Off

4.2.9 Synchronizing function

The synchronizing function is used for automatic synchronizing of generators to power grids. Proper synchronizing is essential to avoid inrush currents and power system oscillations as well as thermal and mechanical stress on the generator when connecting a synchronous generator to the grid.

By using different setting groups and the logic editor up to eight circuit breakers can be synchronized with the same synchronizing function.

For paralleling or energizing of power lines the synchro-check function shall be used.



The synchronizing function uses voltage signal from each side of the circuit breaker to be closed.

- The difference in amplitude of the two voltages are used to send increase and decrease commands to the generator's voltage regulator. Pulse length for increase and decrease commands can be set and is automatically adjusted depending on difference in the two measured signals.
- The difference in frequency of the two voltages, the slip, is used to send increase and decrease commands to the turbine's speed governor. Pulse length for increase and decrease commands can be adjusted individually to allow for turbine governors with different speed change whether increasing or decreasing. Pulse length is automatically adjusted depending on difference in the two measured signals.
- Setting can be done to allow for only positive slip. This will avoid reverse power at synchronizing.
- When amplitude, speed and phase-angle between the two voltages match, within preset limits, a close command signal is sent to the generator circuit breaker.

To allow for delay time in circuit breaker and any auxiliary relays a pre-closing time can be used. Depending on slip frequency the pre-closing angle is adjusted automatically.

Outputs of the function are the following signals:

- Voltage Mag.Difference Ok
- Voltage Freq.Difference Ok
- Voltage Ang.Difference Ok
- Blocked
- Running
- Increase Voltage
- Decrease Voltage
- Increase Frequency

- Decrease Frequency
- Breaker Close Pulse
- Long Sync Time
- Nets Standstill
- Nets Departing
- Nets Enclosing

Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function.

Inputs for the function are the operating mode selections, setting parameters and measured and pre-processed voltage magnitudes and binary input signals. Function output signals which can be used for direct IO controlling and also for user logic programming. Time stamp resolution is 1ms.

Measured input values

Analog voltage measurement values are used for the function block. Function block utilizes always peak-to-peak measurement from samples and the monitored magnitude is fundamental frequency RMS values.

Table 4.39 Analogic magnitudes used by the GSYN function

Signal	Description	Time base
U_1RMS	Fundamental RMS measurement of voltage U_1/V	5 ms
U_2RMS	Fundamental RMS measurement of voltage U_2/V	5 ms
U_3RMS	Fundamental RMS measurement of voltage U_3/V	5 ms
U_4RMS	Fundamental RMS measurement of voltage U_4/V	5 ms

Setting parameters

Table 4.40 General setting parameters

Description	Range	Step	Default
Voltage difference calculation mode	0:System is reference 1:U3/U4 Input is reference	-	System is reference
Synchronizer voltage reference	0:UL12 1:UL23 2:UL31 3:UL1 4:UL2 5:UL3	-	UL12
Magnitude difference fine tune	-200.000...200.000 %	0.001 %	0.00 %
Frequency difference fine tune	-100.000...100.000 Hz	0.001 Hz	0.00 Hz
Angle difference fine tune	-360.000...360.000 deg	0.001 deg	0.00 deg

Table 4.41 Synchronizing settings

Description	Range	Step	Default
Maximum allowed voltage difference	0.1...50.0 %Un	0.01 %Un	2.00 %Un
Max.Time for synchronizing	0.000...1800.000 s	0.005 s	300.000 s
Maximum allowed angular disposition to allow synchronizing	0.01...25.00 deg	0.01 deg	10.00 deg

Description	Range	Step	Default
Adjustment for measurement inaccuracy or set of desired volt. offset	0.00...25.00 %Un	0.01 %Un	0.00 %Un
Adjustment for measurement inaccuracy or set of desired angular offset	0.00...25 deg	0.01 deg	0.00 deg
Adjustment for measurement inaccuracy or set of desired freq. offset	-0.50...2.00 Hz	0.01 Hz	-0.10 Hz
Voltage adjustment slope	0.00...25.00 %/s	0.01 %/s	0.20 %/s
Volt. Max. adjustment pulse length	0.000...1800.000 s	0.005 s	3.000 s
Volt. Min. adjustment pulse length	0.000...1800.000 s	0.005 s	0.100 s
Volt. Min. Resting time between pulses	0.000...1800.000 s	0.005 s	2.500 s
Freq. Max. adjustment pulse length	0.000...1800.000 s	0.005 s	3.000 s
Freq. Min. adjustment pulse length	0.000...1800.000 s	0.005 s	0.100 s
Freq. Min. Resting time between pulses	0.000...1800.000 s	0.005 s	2.500 s
Maximum allowed voltage difference to start synchronizing	0.00...50.00 %Un	0.01 %Un	20.00 %Un
Frequency adjustment slope when increasing	0.00...10.00 Hz/s	0.01 Hz/s	0.10 Hz/s
Frequency adjustment slope when decreasing	-10.00...0.00 Hz/s	0.01 Hz/s	-0.10 Hz/s
Circuit breaker pre-closing time incl auxiliary relays	0.000...1800.000 s	0.005 s	0.100 s
Lenght of circuit breaker closing pulse	0.000...1800.000 s	0.005 s	0.250 s
Multiple On pulses	0=Single On pulse;1=Multiple pulses	-	Single On pulse

Table 4.42 Synchronizer Internal Parameters

Description	Range	Step	Default
Maximum allowed frequency difference to start synchronizing	0.00...25.00 Hz	0.01 Hz	5.00 Hz
Integrator sum when frequency adjustment pulse is generated	0.00...50.00 Hz	0.01 Hz	1.00 Hz
Voltage adjustment pulse length constant	0.00...5000.00	0.01	1000.00
Maximum allowed overfrequency difference to allow synchronizing	0.00...2.00 Hz	0.01 Hz	0.20 Hz
Maximum allowed underfrequency difference to allow synchronizing	0.00...2.00 Hz	0.01 Hz	0.00 Hz
Integrator sum when voltage adjustment pulse is generated	0.00...50.00 %	0.01 %	10.00 %
Frequency adjustment pulse length constant	0.00...5000.00	0.01	1000.00
Filter time for angle derivative	0.000...1800.000 s	0.005 s	1.000 s
Circuit breaker pre-closing adjustment constant	0.00...10.00	0.01	0.10

Function blocking

In the blocking element, the block signal is checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a Breaker Close Pulse signal is generated.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup current values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Events

The GSYN function generates events and registers from the status changes of Voltage Mag/Freq/Ang difference Ok, Running, Decrease/Increase Voltage/Frequency, Breaker Close Pulse, Long Sync Time and Blocked. To main event buffer is possible to select status “On” or “Off” messages.

Table 4.43 Event codes of GSYN-function.

Event Number	Event channel	Event block name	Event Code	Description
10368	162	GSYN	0	Synchronizing Blocked On
10369	162	GSYN	1	Synchronizing Blocked Off
10370	162	GSYN	2	Synchronizing Running On
10371	162	GSYN	3	Synchronizing Running Off
10372	162	GSYN	4	Synchr. Increase Voltage On
10373	162	GSYN	5	Synchr. Increase Voltage Off
10374	162	GSYN	6	Synchr. Decrease Voltage On
10375	162	GSYN	7	Synchr. Decrease Voltage Off
10376	162	GSYN	8	Synchr. Increase Frequency On
10377	162	GSYN	9	Synchr. Increase Frequency Off
10378	162	GSYN	10	Synchr. Decrease Frequency On
10379	162	GSYN	11	Synchr. Decrease Frequency Off
10380	162	GSYN	12	Synchronizer BRK Close On
10381	162	GSYN	13	Synchronizer BRK Close Off
10382	162	GSYN	14	Synchronizer Long Sync. Time On
10383	162	GSYN	15	Synchronizer Long Sync. Time Off
10384	162	GSYN	16	Synchroswitch Close fail Re-init On
10385	162	GSYN	17	Synchroswitch Close fail Re-init Off
10386	162	GSYN	18	Synchroswitching requested On
10387	162	GSYN	19	Synchroswitching requested Off

4.3 Monitoring functions

4.3.1 Fuse failure VTS (60)

Fuse failure voltage transformer supervision is used to detect errors in the secondary circuit of the voltage transformer. This signal is mostly used as alarming function or to disable functions that require adequate voltage measurement.

Measured input values

The function block uses analog voltage measurement values. Function uses the fundamental frequency magnitude of the voltage measurement inputs and calculated positive-, negative- and zero sequence currents.

Table 4.44 Analogic magnitudes used by the VTS function.

Signal	Description	Time base
U_{L12}RMS	Fundamental RMS measurement of voltage U_{L12}/V	5 ms
U_{L23}RMS	Fundamental RMS measurement of voltage U_{L23}/V	5 ms
U_{L31}RMS	Fundamental RMS measurement of voltage U_{L31}/V	5 ms
U_{L1}RMS	Fundamental RMS measurement of voltage U_{L1}/V	5 ms
U_{L2}RMS	Fundamental RMS measurement of voltage U_{L2}/V	5 ms
U_{L3}RMS	Fundamental RMS measurement of voltage U_{L3}/V	5 ms
U1P	Positive sequence voltage	5 ms
U2N	Negative sequence voltage	5 ms
UZ0	Zero sequence voltage	5 ms
U_{L12}Ang	Fundamental angle of U_{L12} voltage	5 ms
U_{L23}Ang	Fundamental angle of U_{L23} voltage	5 ms
U_{L31}Ang	Fundamental angle of U_{L31} voltage	5 ms
U_{L1}Ang	Fundamental angle of U_{L1} voltage	5 ms
U_{L2}Ang	Fundamental angle of U_{L2} voltage	5 ms
U_{L3}Ang	Fundamental angle of U_{L3} voltage	5 ms

Selection of the used AI channel is made with a setting parameter. In all possible input channel variations pre-fault condition is presented with 20 ms averaged history value from -20 ms of Start or Trip event.

Pick-up characteristics

Voltage dependent pick-up and activation of the VTS function is controlled by *Voltage low* pick-up and *Voltage high* detectsetting parameters. If at least one measured voltage of the three are under the set low value, VTS pick-up will activate. Also if at least two of the three voltages are over high detect value VTS pick-up will activate. The function constantly calculates the ratio in between of the setting values and measured magnitude per all three phases.

Table 4.45 Pick-up characteristics setting

Name	Range	Step	Default	Description
Voltage low pickup	0.00 ... 0.50xUn	0.01xUn	0.05xUn	If at least one of the measured voltages are under this set value the function will pick up
Voltage high detect	0.01 ... 40.00xUn	0.01xUn	0.10xUn	If at least two of the measured voltages are over this set value the function will pick up
Angle shift limit	2.00 ... 90.00deg	0.10deg	5.00deg	If the difference between the angle in present time and -40ms before is lower than the set value function will pick up
Line Fuse fail check	No Yes	-	Yes	Selection if the state of the line fuse will be supervised. The supervised signal is determined in IOà Fuse-Failure Inputs
Bus Fuse fail check	No Yes	-	Yes	Selection if the state of the bus fuse will be supervised. The supervised signal is determined in IOà Fuse-Failure Inputs

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active. From binary signals the activation of the pick-up is immediate when the monitored signal is activated.

Voltage transformer supervision can also report several different states of the measured voltage. These can be seen in the INFO-page of the function in the relay HMI or in the MVR utility software.

Name	Description
Bus dead	No voltages
Bus Live VTS Ok	All of the voltages are within the set limits
Bus Live VTS Ok SEQ Rev	All of the voltages are within the set limits BUT the voltages are in reversed sequence
Bus Live VTS Ok SEQ Undef	Voltages are within the set limits BUT sequence cannot be defined.
Bus Live VTS problem	Any of the VTS pick-up conditions are valid!

Function blocking

In the blocking element the block signal is checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup current values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Operating time characteristics for activation

This function supports definite time delay (DT). For detailed information on this delay type refer to chapter General properties of a protection function.

Events and registers

The VTS function generates events and registers from the status changes of the ALARM activated and blocked signals. To main event buffer is possible to select status “On” or “Off” messages.

In the function is available 12 last registers where the triggering event of the function (ALARM activated or blocked) is recorded with time stamp and process data values.

Table 4.46 Event codes of VTS function

Event Number	Event channel	Event block name	Event Code	Description
3392	53	VTS1	0	Bus VT fail Start On
3393	53	VTS1	1	Bus VT fail Start Off
3394	53	VTS1	2	Bus VT fail Trip On

Event Number	Event channel	Event block name	Event Code	Description
3395	53	VTS1	3	Bus VT fail Trip Off
3396	53	VTS1	4	Bus VT fail Block On
3397	53	VTS1	5	Bus VT fail Block Off
3398	53	VTS1	6	Line VT fail On
3399	53	VTS1	7	Line VT fail Off
3400	53	VTS1	8	Bus Fuse fail On
3401	53	VTS1	9	Bus Fuse fail Off
3402	53	VTS1	10	Line Fuse fail On
3403	53	VTS1	11	Line Fuse fail Off

In the register of the VTS function is recorded activated, blocked etc. “On” event process data. In the table below is presented the structure of VTS function register content. This information is available in 12 last recorded events for all provided instances separately.

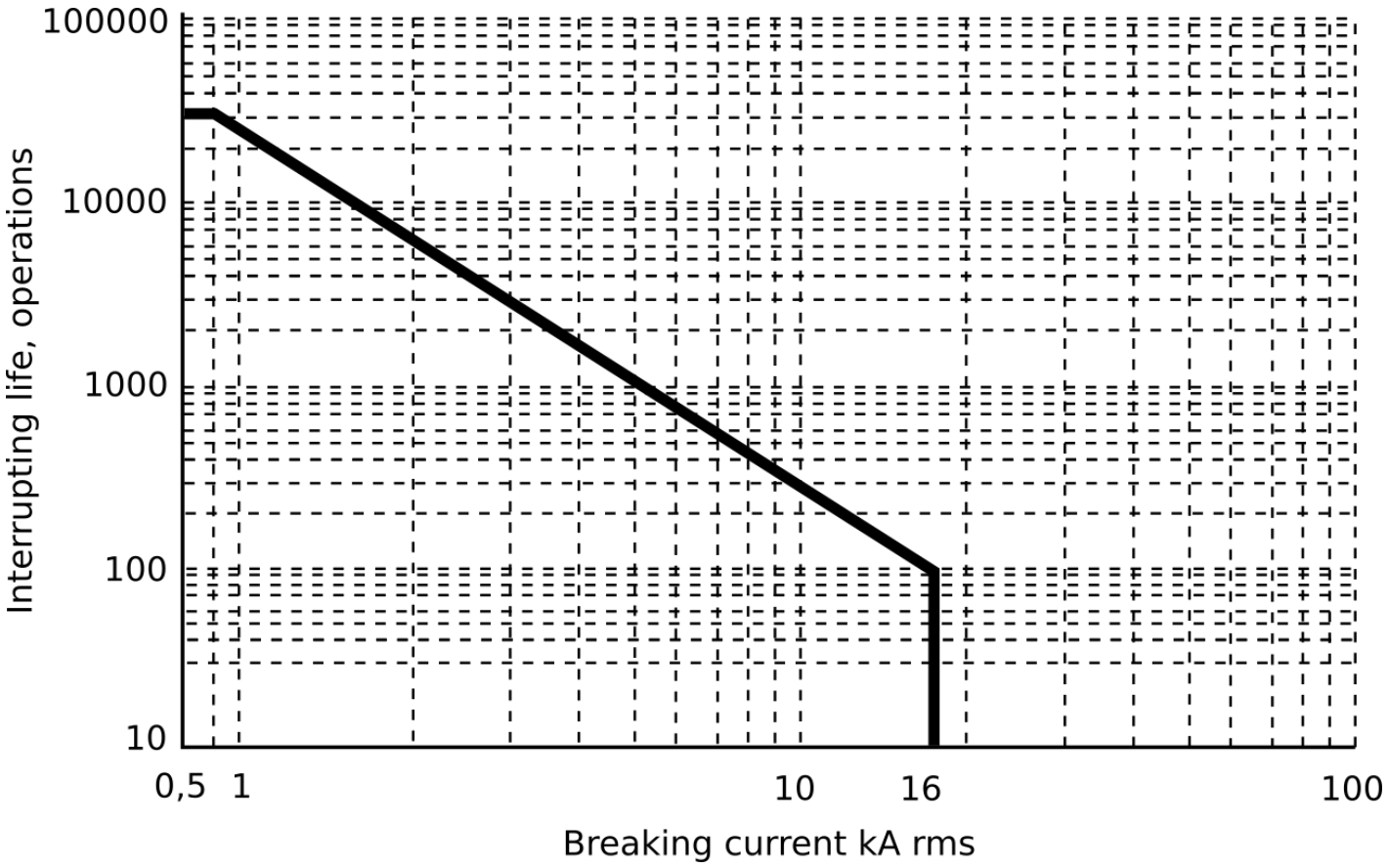
Table 4.47 Register content.

Date & Time	Event code	Volt 1,2,3 status	System status	Input A,B,C angle diff	Trip time remaining	Used SG
dd.mm.yyyy hh:mm:ss.mss	3392-3403 Descr.	0b:No Voltage; 1b:Voltage Ok; 2b:Low Voltage	0:BusDead; 1:BusLive VTSok SeqOk; 2:BusLive VTSok SeqRev; 3:BusLive VTSok SeqUndef; 4:BusLive VTS fault;	-	-	1 - 8

4.3.2 Circuit breaker wear-monitor (CBW)

Circuit breaker wear (CBW) function is used for monitoring the circuit breaker lifetime before maintenance needs due to interrupting currents and mechanical wearing. CBW function uses the circuit breaker manufacturer given data for the breaker operating cycles in relation to the current breaker has operated. CBW function is integrated into the controllable object function and can be enabled and set under object function. CBW function is independent function and initializes as separate independent instance which has own events and settings not related to the object it is linked to.

Figure 4.34 Example of the circuit breaker interrupting life operations.



Function is triggered from the circuit breaker open command output and it monitors the three phase current values in the tripping/opening moment. The maximum interrupting life operations value per each phase are calculated from these currents which is cumulatively deducted from the starting value of the operations. It is possible to set up two separate alarm levels which are activated when the interrupting life operations value is below the setting limit.

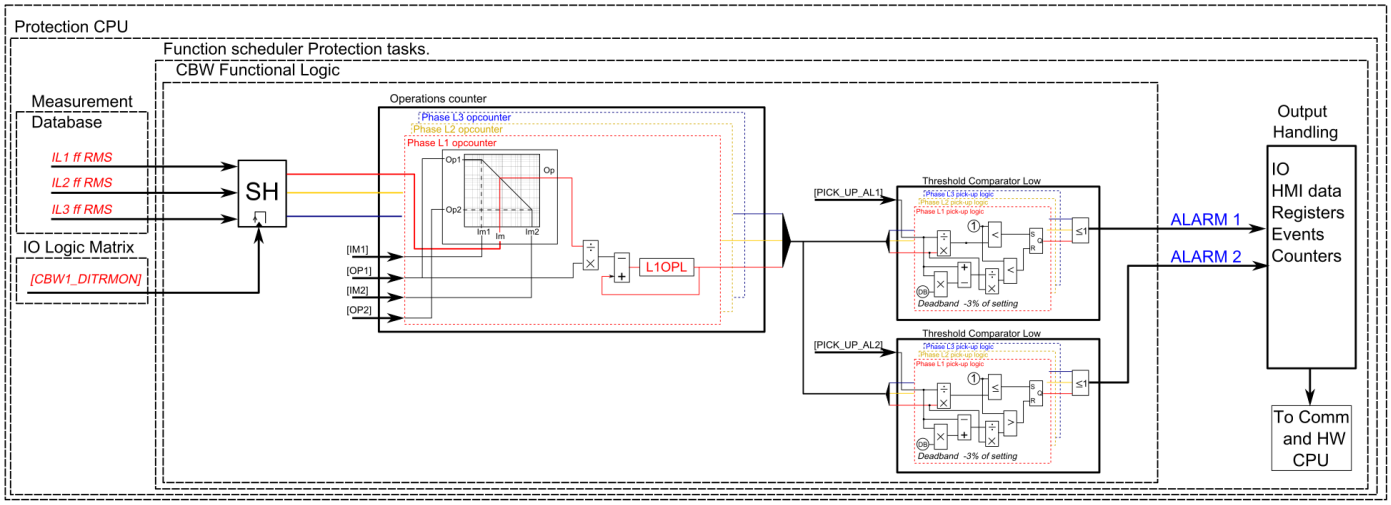
Trip contact setting defines the output that triggers the current monitoring at breaker open command.

Outputs of the function are Alarm 1 and Alarm 2 signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function.

Inputs for the function are setting parameters and measured and pre-processed current magnitudes and binary output signals. Function output signals can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the two output signal. Time stamp resolution is 1ms. Function provides also cumulative counters for Open operations, Alarm 1 and Alarm 2 events. Operations left for each phase can be monitored also in the function.

In the following figure the simplified function block diagram of the CBW function is presented.

Figure 4.35 Simplified function block diagram of the CBW function.



Measured input values

Function block uses analog current measurement values. Function always uses the fundamental frequency magnitude of the current measurement input.

Table 4.48 Analogic magnitudes used by the CBW function.

Signal	Description	Time base
IL1RMS	Fundamental RMS measurement of phase L1/A current	5 ms
IL2RMS	Fundamental RMS measurement of phase L2/B current	5 ms
IL3RMS	Fundamental RMS measurement of phase L3/C current	5 ms

General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible change them with setting group switching.

Table 4.49 General settings of the function

Name	Description	Range	Step	Default
THD in side	Defines which current measurement module is used by the function.	1:Side1 2:Side2 3:Side3	-	1:Side1

Circuit breaker characteristics settings

The circuit breaker characteristics is set by two operating points where are defined the maximum allowed breaking current of the breaker, nominal breaking current and corresponding interrupts allowed. This data is provided by the circuit breaker manufacturer.

Name	Range	Step	Default	Description
Current 1 (Inom)	0.00...100.00kA	0.01kA	1.00kA	Nominal operating current of the breaker (rms)
Operations (Inom)	0... 200000Op	1Op	50000Op	Interrupting life operations at rated current (Close - Open)
Current 2 (Imax)	0.00...100.00kA	0.01kA	20.00kA	Rated short circuit breaking current (rms)
Operations (Imax)	0... 200000Op	1Op	100Op	Interrupting life operations at rated breaking current (Open)

Pick-up characteristics for alarming

For the alarm stages Alarm 1 and Alarm 2 can be set pick-up level for the remaining operations left. The pick-up setting is common for all phases and the alarm stage shall pick-up if any of the phases is below this setting.

Table 4.50 Pick-up characteristics setting

Name	Range	Step	Default	Description
Enable Alarm 1	0: Disabled 1: Enabled	-	Enabled	Enable / Disable selection of the Alarm 1 stage
Alarm 1 Set	0 ... 200000 operations	1 operation	1000op	Pick-up threshold for remaining operations. When the remaining operations is below this setting Alarm 1 signal is activated.
Enable Alarm 2	0: Disabled 1: Enabled	-	Enabled	Enable / Disable selection of the Alarm 2 stage
Alarm 2 Set	0 ... 200000 operations	1 operation	100 op	Pick-up threshold for remaining operations. When the remaining operations is below this setting Alarm 2 signal is activated.

Setting example

Setting example: Tavrida ISM/TEL-24-16 / 800 – 057 circuit breaker

Rated voltage,kV	24
Rated normal current, A	800
Rated power frequency test voltage, kV	50
Rated frequency, Hz	50/60
Rated impulse test voltage, kV peak	125
Rated short-circuit breaking current, kA	16
Rated short-circuit making current, kA peak	40
Short time withstand current, 4s, kA	16
Mechanical life, CO cycles, not less than	30000
Interrupting life operations, not less than	
-at rated current, close-open	30000
-at rated breaking current, close	30
-at rated breaking current, open	100
Closing time, ms, not more than	36 (with FCM module) 50 (with CM module)
Opening time, ms, not more than	15
Standard operating duty	25
Maximum number of CO cycles per hour	0-0,3s-CO-15s-CO (with CM module) 0-0,1s-CO-10s-CO (with FCM module)
Main contacts resistance, µ Ohm, not more than	600
Maximum ambient temperature	40
Minimum ambient temperature	+55C
Design class with regard to severity of service conditions in accordance with IEC 932	-40C
Mechanical vibrations withstand capability in accordance with IEC 721-3-4	1
Maximum altitude above sea level, m	Class 4M4
Maximum humidity	1000
Weights, kg	98% non condensing
ISM/TEL-24-16/800-057	36
ISM/TEL-24-16/800-058	38

Set the CBW stage as follows:

Parameter	**Value**
Current 1 (Inom)	0.80 kA
Operation 1 (Inom)	30000 Op

Parameter	Value
Current 2 (Imax)	16.00 kA
Operations 2 (Imax)	100 Op
Enable Alarm 1	1: Enabled
Alarm 1 Set	1000 operations
Enable Alarm 2	1: Enabled
Alarm 2 Set	100 operations

With these settings Alarm 1 will be issued when any of the three phases cumulative interruptions counter is below the set 1000 operations left and similarly when any of the counters is below the set 100 operations left Alarm 2 will be issued.

Events and registers

The CBW function generates events and registers from the status changes of Retrip, CBW activated and blocked signals as well as from the internal pick-up comparators. To main event buffer is possible to select status “On” or “Off” messages.

Function includes 12 last registers where the triggering event of the function is recorded with time stamp and process data values.

Table 4.51 Event codes of the CBW function instance

Event Number	Event channel	Event block name	Event Code	Description
3712	58	CBW1	0	CBWEAR1 Triggered
3713	58	CBW1	1	CBWEAR1 Alarm1 On
3714	58	CBW1	2	CBWEAR1 Alarm1 Off
3715	58	CBW1	3	CBWEAR1 Alarm2 On
3716	58	CBW1	4	CBWEAR1 Alarm2 Off

In the register of the CBW function recorded events are activated “On” event process data. In the table below is presented the structure of CBW function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 4.52 Register content.

Date & Time	Event code	Trigger current	All.Op.ITrg	Deduct. Op	Op.Left
dd.mm.yyyy hh:mm:ss.mss	3713-3717 Descr.	Phase currents on trigger time	Allowed operations with trigger current	Deducted operations from the cumulative sum	Operations left

4.3.3 Disturbance recorder (DR)

The disturbance recorder is high capacity (60 Mbyte) and fully digital recorder integrated to protection relay. Maximum sample rate of the recorder analog channels is 64 samples per cycle. The recorder supports 32 digital channels simultaneously with measured 20 analog channels.

The recorder provides great tool to analyze the performance of the power system in network disturbance situations. Recorder output is in general comtrade format and it is compatible with most viewers and injection devices. Comtrade file is based on standard IEEE Std C37.111-1999. Captured recordings can be injected as playback with secondary testing tools those support comtrade file format. Playback of files might help to analyze the fault or can be simply used in educational purposes.

Analog and digital recording channels

Up to 9 analog recording channels and 32 digital channels are supported simultaneously. Possible analog channels vary according the IED type. All analog channels are presented below:

Table 4.53 Analogue recording channels can be chosen between channels represented in table below. Availability of signals depend on the hardware if the IED.

Signal	Description	Sample rate
I_{L1}	Phase current I_{L1}	8/16/32/64s/c
I_{L2}	Phase current I_{L2}	8/16/32/64s/c
I_{L3}	Phase current I_{L3}	8/16/32/64s/c
I_{01c}	Residual current I_{01} coarse*	8/16/32/64s/c
I_{01f}	Residual current I_{01} fine*	8/16/32/64s/c
I_{02c}	Residual current I_{02} coarse*	8/16/32/64s/c
I_{02f}	Residual current I_{02} fine*	8/16/32/64s/c
$I_{L1''}$	Phase current I_{L1} (CT card 2)	8/16/32/64s/c
$I_{L2''}$	Phase current I_{L2} (CT card 2)	8/16/32/64s/c
$I_{L3''}$	Phase current I_{L3} (CT card 2)	8/16/32/64s/c
$I_{01''c}$	Residual current I_{01} coarse* (CT card 2)	8/16/32/64s/c
$I_{01''f}$	Residual current I_{01} fine* (CT card 2)	8/16/32/64s/c
$I_{02''c}$	Residual current I_{02} coarse* (CT card 2)	8/16/32/64s/c
$I_{02''f}$	Residual current I_{02} fine* (CT card 2)	8/16/32/64s/c
$U_{1(2)}$	Line to neutral U_{L1} or line to line voltage U_{12}	8/16/32/64s/c
$U_{2(3)}$	Line to neutral U_{L2} or line to line voltage U_{23}	8/16/32/64s/c
$U_{3(1)}$	Line to neutral U_{L3},line to line voltage U_{31}, zero sequence voltage U_0 or synchrocheck voltage U_{SS}	8/16/32/64s/c
$U_{0(ss)}$	Zero sequence voltage U_0 or synchrocheck voltage U_{SS}	8/16/32/64s/c
F tracked 1	Tracked frequency of reference 1	8/16/32/64s/c
F tracked 2	Tracked frequency of reference 2	8/16/32/64s/c
F tracked 3	Tracked frequency of reference 3	8/16/32/64s/c

***NOTE**: In disturbance recorder there are two signals per each current channel, coarse and fine. Coarse signal is capable of sampling in full range of the current channel but suffers loss of accuracy at very low currents (under 3 amps). Fine signal is capable of sampling at very low currents but will cut off at higher currents (I01 15A peak and I02 8A peak)

Recording settings and triggering

Disturbance recorder can be triggered manually or automatically by using dedicated triggers. Every signal listed in “Digital recording channels” –list can be selected to trig the recorder.

IED has no maximum limit for number of recordings. Maximum amount is related to the size of the recording. Amount of analog and digital channels together with sample rate and time setting do affect to the recording size. For example in case that analogue channels IL1, IL2, IL3, I01, UL1, UL2, UL3 and U0 are selected, sample rate is 64 s/c and recording length is set to 1.0 seconds, the IED has memory for 623 recordings.

Table 4.54 Disturbance recorder setting table is presented below.

Name	Range	Step	Default	Description
Recorder enabled	0:Disabled 1:Enabled	-	1:Enabled	Enables/Disabled recorder function.
Recorder status	0:Recorder ready; 1:Recording triggered; 2:Recording and storing; 3:Storing recording; 4:Recorder full; 5:Wrong config	-	0:Recorder ready	Indicates the status of recorder.
Manual Trigger	0:- 1:Trig	-	0:Disabled	Trig the disturbance recorder manually.
Clear all records	0:- 1:Clear	-	0:Disabled	Clears all disturbance recordings.
Clear newest record	0:- 1:Clear	-	0:Mega	Clears the latest of stored recordings.
Clear oldest record	0:- 1:Clear	-	-	Clears the oldest stored recording.
Max amount of recordings	0...2^{32}-1	1	-	Maximum amount of recordings possible to store in the memory of IED.
Max length of recording	0...1800 s	0.001	-	Maximum settable length of a single recording,
Recordings in memory	0...2^{32}-1	1	0	How many recordings stored in the memory of IED.
Recorder trigger	Enable by checking the box	-	Unchecked	Enable triggers by checking the boxes. Check “Digital recording channels” –list for possible trigger inputs.
Recording length	0.1...1800s	0.001	1.0 s	Measured energy per phase in kilo –or mega values.
Recording mode	0:FIFO 1:KEEP OLDS	-	0:FIFO	First in first out replaces the oldest stored recording by the latest one if the memory is full. Keep olds won’t accept new recordings when the memory is full.
Analog channel samples	0:8 s/c 1:16 s/c 2:32 s/c 3:64 s/c	-	3:64s/c	Sample rate of the disturbance recorder. Samples are saved from the measured wave according the setting.
Digital channel samples	Fixed 5ms	-	5ms	Fixed sample rate of the recorded digital channels.
Pre triggering time	0.1...15.0s	0.1 s	0.5s	Recording length before the triggering.

Name	Range	Step	Default	Description
Analog Recording CH1...20	0...8 freely selectable channels	-	None selected	Check available analog channels from the “Analogue recording channels” –list for possible recorder inputs.
Auto. get recordings	0:Disbaled 1:Enabled	-	0:Disbaled	Transfer recordings to relay FTP directory automatically to be fetched to SCADA system via FTP client. Please note that when this is activated any disturbance recordings made will be pushed to FTP. Up to 6 recordings can be stored in FTP at once. Once the 6 recordings have been retrieved and removed, more recordings will then be pushed to FTP.
Rec.Digital Channels	0...32 freely selectable channels	-	None selected	Check available digital channels from the “Digital recording channels” –list for possible recorder inputs.

Notice that disturbance recorder is not ready unless the “Max length of recording” is showing some value other than zero. At least one trigger input has to be selected to “Recorder Trigger” -menu to fulfill this term.

Events

Disturbance recorder generates an event each time when it is triggered either manually or by using dedicated signals. Event cannot be masked off.

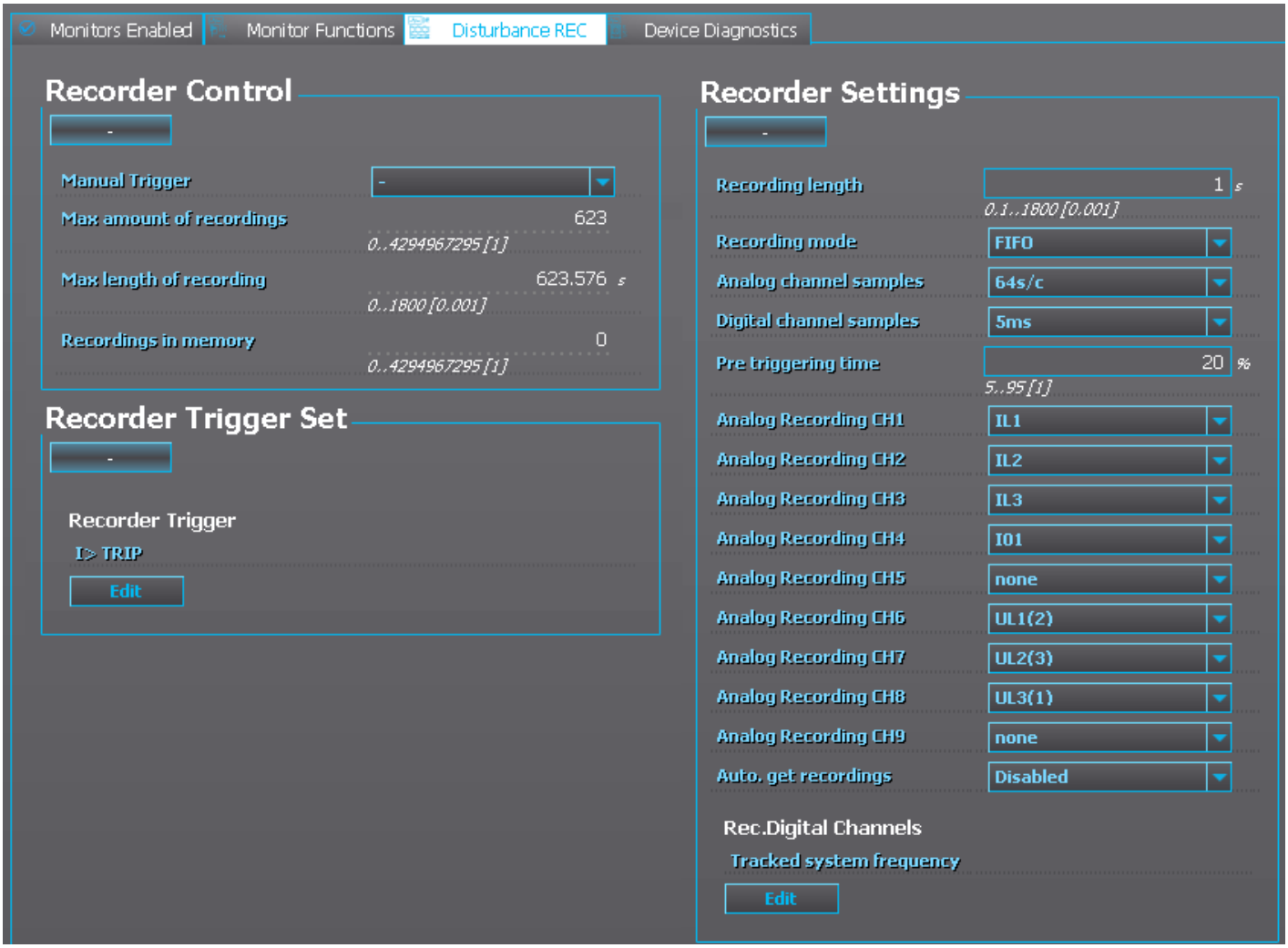
Application example

This chapter presents an application example of setting and analyzing the disturbance recorder. Configuration is done by using the MVR utility software –configuration and setting tool and the MVR Viewer is used for analyzing the recording.

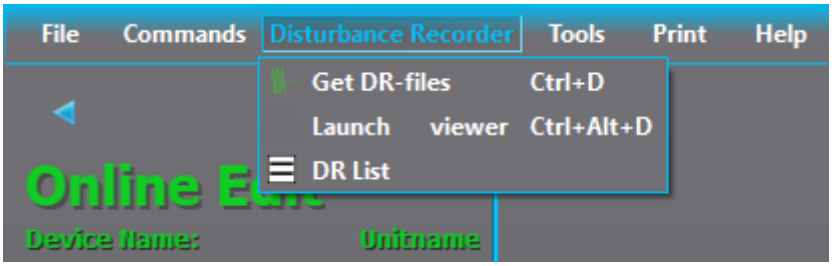
In table “Disturbance recorder settings” the recorder is set as specified below.

1. Maximum amount of recordings and maximum length of recording is calculated according the memory size and following settings: Recording length 1.0 second, Analog channel samples 32s/c, Analog recording channel 1,2,3,4,6,7 and 8 are used and Recorder digital channels is taking samples of tracked system frequency every 5ms.
2. First overcurrent stage trip (I> TRIP) activation will trigger the recorder.
3. Length of the recording is 1.0 seconds. Pre-triggering time 20 percent affects to the recording in a way that 200ms is recorded before “I> TRIP” and 800ms is recorder after.
4. Sample of each recorder analog signal is taken 64 times in a cycle. With 50Hz system frequency it means that sample is taken every 312.5µs. Digital channels are tracked every 5 milliseconds.

Figure 4.36 Disturbance recorder settings.



When there is at least one recording in the memory of the IED the recording can be analyzed by using the MVR Viewer software.



First the recording has to be read from the memory of the IED by selecting *Disturbance Recorder → Get DR-files* or loading the recordings individually with *Disturbance recorder → DR List*. The file is stored to folder in PC hard disk drive. The location of the folder is described in *Tools → Settings → DR path*.

The MVR Viewer is launched from Disturbance recorder menu as well.

How to estimate the max length of total recording time

When the disturbance recorder settings have been made and loaded into IED, disturbance recorder function will display the total length of recording in seconds it is possible to record. Though if needed it is also possible to confirm the length by using the following calculation. Please note that the following calculation assumes that DR doesn't share the 64MB space with any other files in the FTP.

$$\frac{16076647\ samples}{(fn * (AnCh + 1) * SR) + (200Hz * DiCh)}$$

Where:

- fn is
- AnCh is the amount of recorded analog channels (which is then summed with 1 which stand for time stamp for each recorded sample)
- SR is the sample rate chosen by parameter (8,16,32 or 64 samples per cycle)
- 200Hz is the rate at which digital channels are always recorded (5ms)
- DiCh is the amount of digital channels recorded
- 16076647 is the amount of samples available in FTP if no other types of files are saved.

As an example if nominal frequency is 50Hz and sample rate is 64s/c, all nine analog channels are used and 2 digital channels are recorded the result is the following.

$$\frac{16076647\ samples}{(50Hz * (9 + 1) * 64) + (200Hz * 2)} = 496s$$

Total sample reserve 16076647 is derived from the knowledge that one sample is always 4 bytes and the DR can use 64306588 bytes (total amount of bytes available divided by size of one sample in bytes).

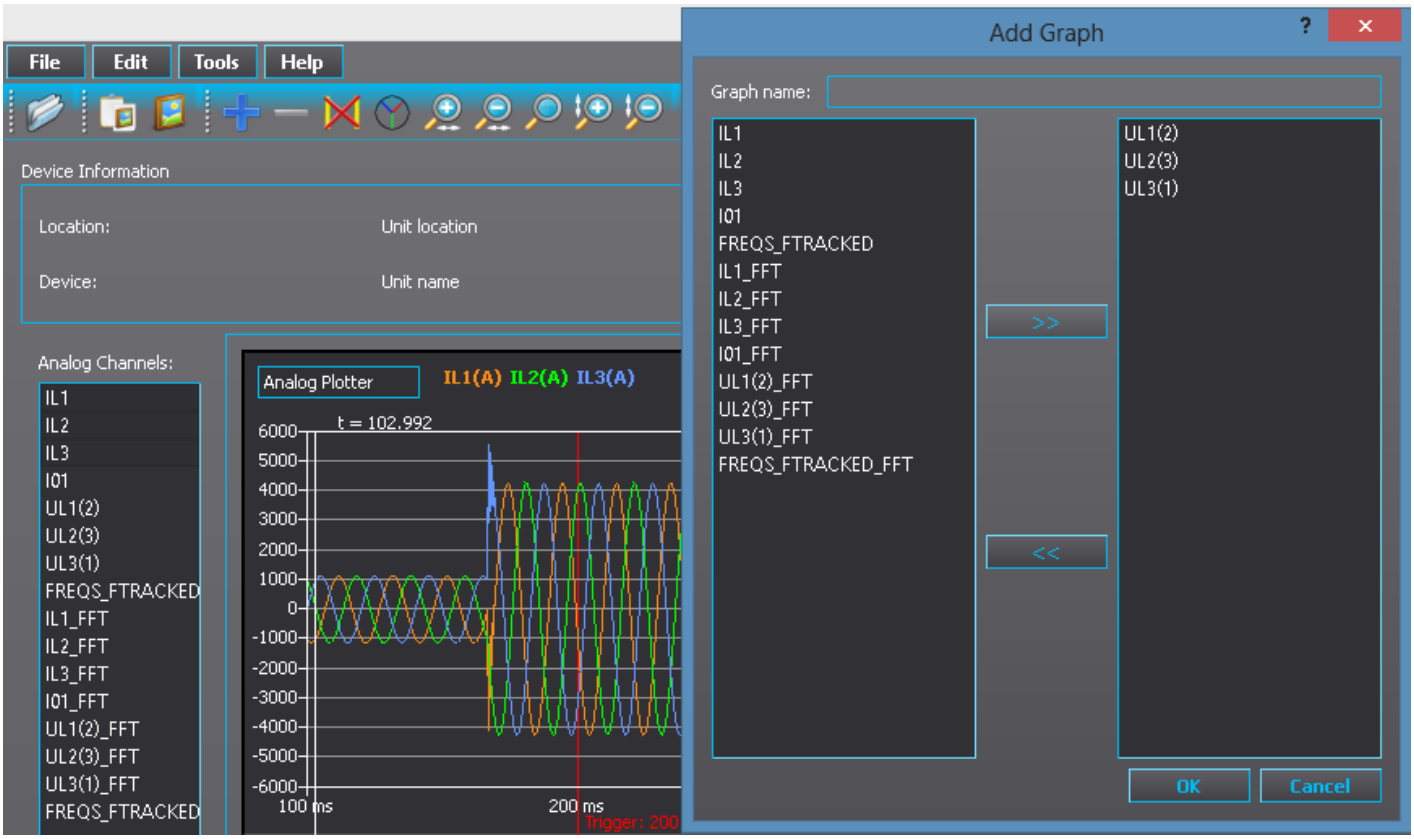
MVR Viewer

Disturbance recordings can be opened by choosing open folder icon or by going to *File → Open*. Recordings are packed comtrade files. Zip-file includes *.cfg and *.dat. The MVR Viewer is capable to open original packed zip files directly or comtrade files as they are as far as both *.cfg and *.dat are located in same directory.

Figure 4.37 Open stored recordings.

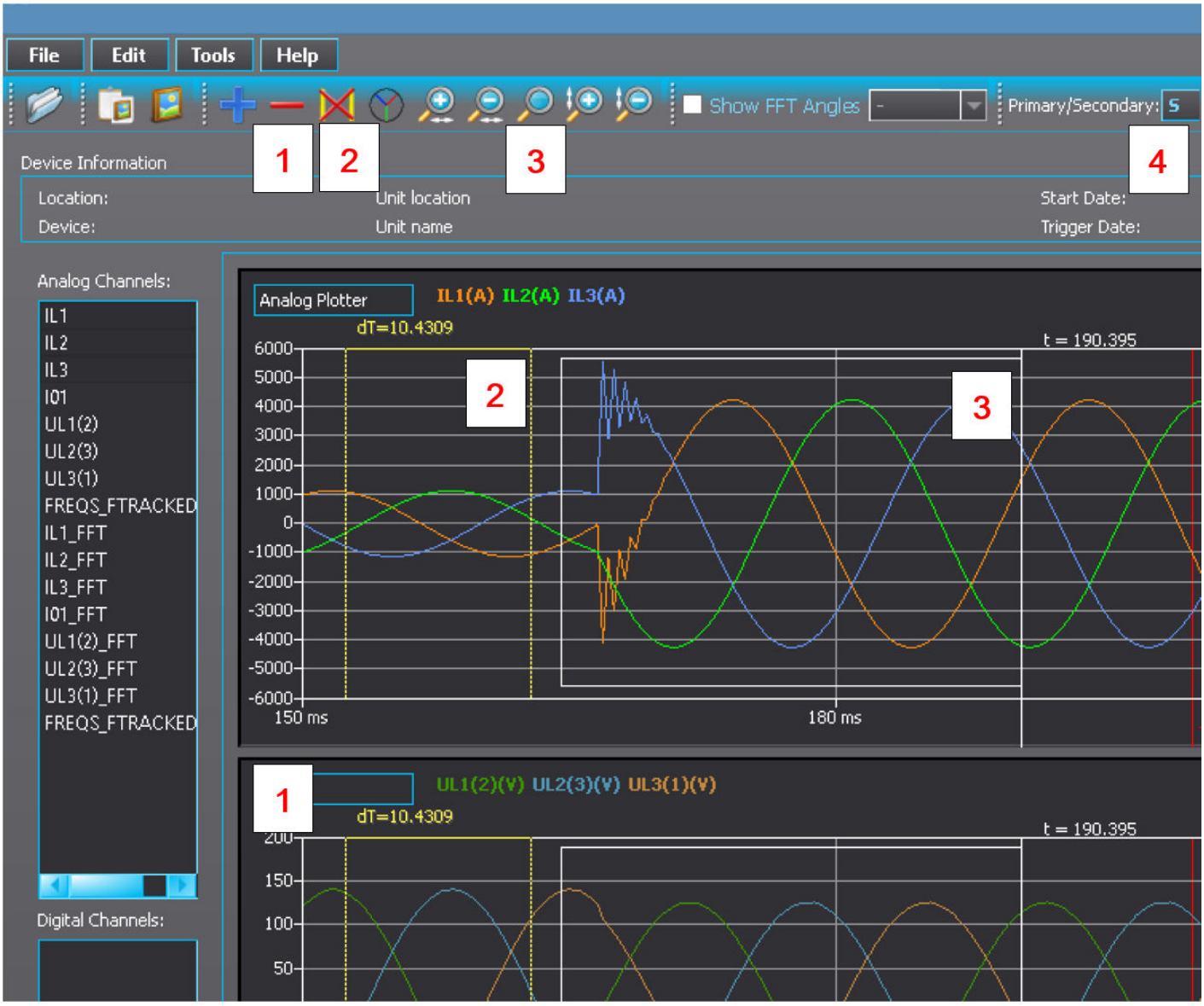


Figure 4.38 Add signals to plotters.



1. Default plotter is empty by default. Choose measured signals on the left to move them to the plotter. In this example phase currents IL1, IL2 and IL3 are selected.
2. To have another plotter choose blue plus key icon that can be found on top. Note, “Add Plotter” -text appears when moving mouse cursor is on top of the icon. In this example line to neutral voltages UL1, UI2 and UL3 are selected and moved to the right side. Confirm plotter by pressing OK –key.

Figure 4.39 Zooming and general use of the MVR Viewer



1. To remove plotters one at the time use red minus key icon “1” that can be found on top. Note, “Remove Plotter” -text appears when moving mouse on top of the icon.
2. Add cursors to measure time. While staying on top of any plotter double click mouse left to add cursor. It is possible to add 5 cursors simultaneously. To remove cursors choose icon “2” that can be found on top. Note, “Remove All Cursors” -text appears when moving mouse on top of the icon.
3. Zoom in manually by going on top of any plotter and holding down mouse left. Move mouse to create area how you want to zoom in. Zooming in and out is possible by using vertical and horizontal + and – icons as well. It is possible to reset zooming by pressing corresponding icon in the middle “3”. Zoom amplitude of individual plotters by holding down shift and scrolling mouse wheel up and down. Scroll time by holding down Ctrl and scrolling mouse wheel up and down.
4. Toggle between primary (P) and secondary (S) signals.

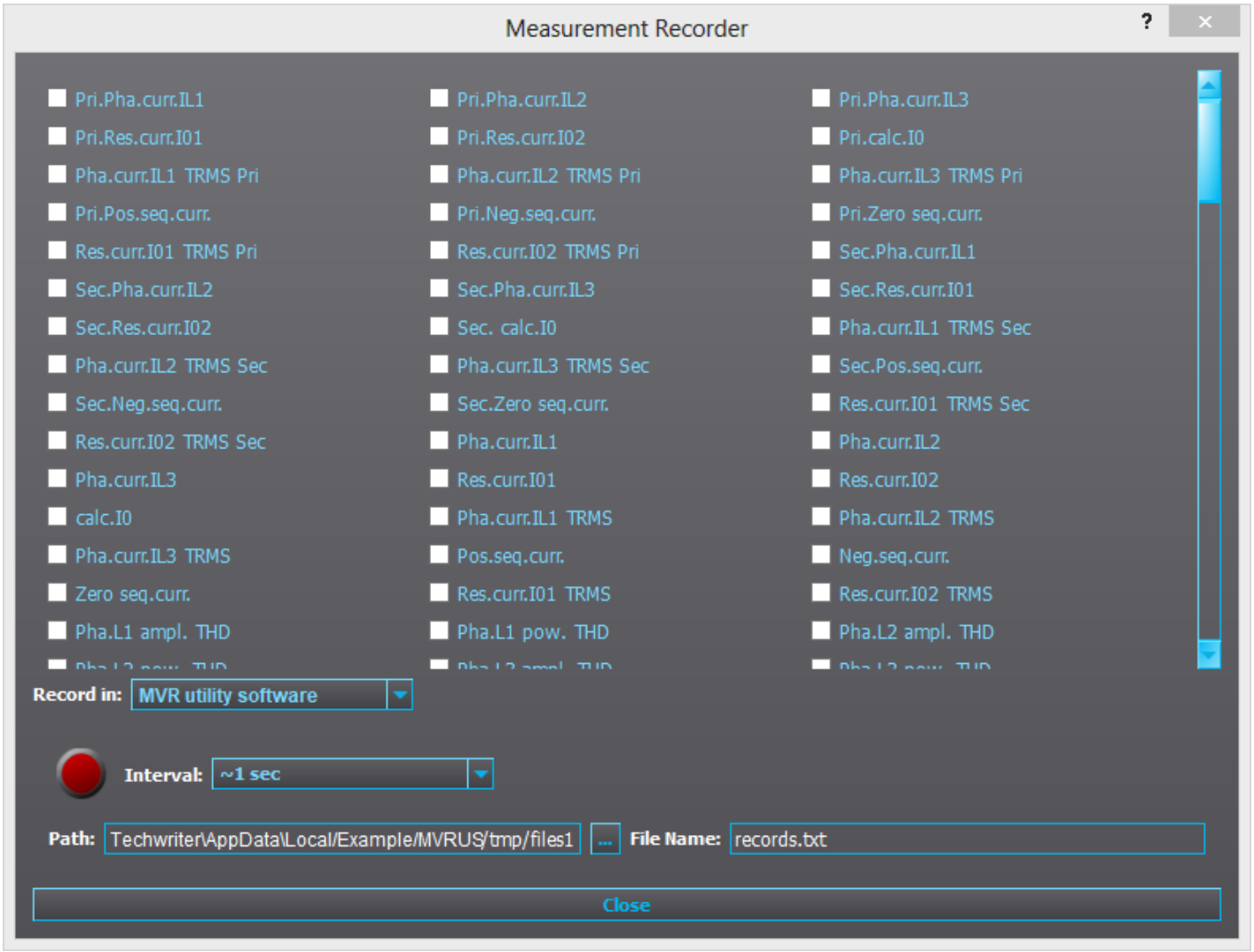
Events

The DR function generates events from the status changes of the function. To main event buffer is possible to select status “On” or “Off” messages.

Table 4.55 Event codes of DR function.

Event Number	Event channel	Event block name	Event Code	Description
4096	64	DR1	0	Recorder triggered On
4097	64	DR1	1	Recorder triggered Off
4098	64	DR1	2	Recorder memory cleared
4099	64	DR1	3	Oldest record cleared
4100	64	DR1	4	Recorder memory full On
4101	64	DR1	5	Recorder memory full Off
4102	64	DR1	6	Recording On
4103	64	DR1	7	Recording Off
4104	64	DR1	8	Storing recording On
4105	64	DR1	9	Storing recording Off
4106	64	DR1	10	Newest record cleared

4.3.4 Measurement recorder



Measurements can be recorded to a file by using the measurement recorder. Chose measurements will be recorded at given interval. In the measurement recorder-dialog, the desired measurements to be recorded can be selected by checking the checkboxes. A connection to a relay must be established via the MVR utility software and live edit mode must be enabled,

for the measurement recorder to be able to activate. Navigate to measurement recorder through *Tools → Measurement recorder*. Recording interval can be changed from the “Interval”-combo box. It is possible to choose if the measurements are recorded in the MVR utility software or in the relay with Record in dropdown box.

If you have chosen to record in the MVR utility software, the MVR utility software and live edit-mode need to be activated to record. Record file location can be changed by editing the “Path”-field. File name can be changed from the “File Name”-field. Hitting the red “Record”-button will start the recorder. Closing the measurement recorder-dialog will not stop the recording. To stop the recording, blue “Stop”-button must be pressed.

If the measurements are recorder into the relay you just need to set the recording interval and start the recording. The MVR utility software estimates the max recording time which depends on the recording interval. When measurement recorder is running in the relay the measurements can be then viewed in graph form with the MVR PRO utility software.

Figure 4.40 Measurement recorder values viewed in MVR PRO utility software



Table 4.56 Available analog signals

Current measurements	P-P Curr.I”L3	L1 Imp.React.Ind.E.Mvarh
Pri.Pha.Curr.IL1	P-P Curr.I”01	L1 Imp.React.Ind.E.kvarh
Pri.Pha.Curr.IL2	P-P Curr.I”02	L1 Exp/Imp React.Ind.E.bal.Mvarh
Pri.Pha.Curr.IL3	Pha.angle I”L1	L1 Exp/Imp React.Ind.E.bal.kvarh
Pri.Res.Curr.I01	Pha.angle I”L2	L2 Exp.Active Energy MWh
Pri.Res.Curr.I02	Pha.angle I”L3	L2 Exp.Active Energy kWh
Pri.Calc.I0	Res.Curr.angle I”01	L2 Imp.Active Energy MWh
Pha.Curr.IL1 TRMS Pri	Res.Curr.angle I”02	L2 Imp.Active Energy kWh
Pha.Curr.IL2 TRMS Pri	Calc.I”0.angle	L2 Exp/Imp Act. E balance MWh
Pha.Curr.IL3 TRMS Pri	I” Pos.Seq.Curr.angle	L2 Exp/Imp Act. E balance kWh
Pri.Pos.Seq.Curr.	I” Neg.Seq.Curr.angle	L2 Exp.React.Cap.E.Mvarh

Pri.Neg.Seq.Curr.	I” Zero.Seq.Curr.angle	L2 Exp.React.Cap.E.kvarh
Pri.Zero.Seq.Curr.	**Voltage measurements**	L2 Imp.React.Cap.E.Mvarh
Res.Curr.I01 TRMS Pri	U1Volt Pri	L2 Imp.React.Cap.E.kvarh
Res.Curr.I02 TRMS Pri	U2Volt Pri	L2 Exp/Imp React.Cap.E.bal.Mvarh
Sec.Pha.Curr.IL1	U3Volt Pri	L2 Exp/Imp React.Cap.E.bal.kvarh
Sec.Pha.Curr.IL2	U4Volt Pri	L2 Exp.React.Ind.E.Mvarh
Sec.Pha.Curr.IL3	U1Volt Pri TRMS	L2 Exp.React.Ind.E.kvarh
Sec.Res.Curr.I01	U2Volt Pri TRMS	L2 Imp.React.Ind.E.Mvarh
Sec.Res.Curr.I02	U3Volt Pri TRMS	L2 Imp.React.Ind.E.kvarh
Sec.Calc.I0	U4Volt Pri TRMS	L2 Exp/Imp React.Ind.E.bal.Mvarh
Pha.Curr.IL1 TRMS Sec	Pos.Seq.Volt.Pri	L2 Exp/Imp React.Ind.E.bal.kvarh
Pha.Curr.IL2 TRMS Sec	Neg.Seq.Volt.Pri	L3 Exp.Active Energy MWh
Pha.Curr.IL3 TRMS Sec	Zero.Seq.Volt.Pri	L3 Exp.Active Energy kWh
Sec.Pos.Seq.Curr.	U1Volt Sec	L3 Imp.Active Energy MWh
Sec.Neg.Seq.Curr.	U2Volt Sec	L3 Imp.Active Energy kWh
Sec.Zero.Seq.Curr.	U3Volt Sec	L3 Exp/Imp Act. E balance MWh
Res.Curr.I01 TRMS Sec	U4Volt Sec	L3 Exp/Imp Act. E balance kWh
Res.Curr.I02 TRMS Sec	U1Volt Sec TRMS	L3 Exp.React.Cap.E.Mvarh
Pha.Curr.IL1	U2Volt Sec TRMS	L3 Exp.React.Cap.E.kvarh
Pha.Curr.IL2	U3Volt Sec TRMS	L3 Imp.React.Cap.E.Mvarh
Pha.Curr.IL3	U4Volt Sec TRMS	L3 Imp.React.Cap.E.kvarh
Res.Curr.I01	Pos.Seq.Volt.Sec	L3 Exp/Imp React.Cap.E.bal.Mvarh
Res.Curr.I02	Neg.Seq.Volt.Sec	L3 Exp/Imp React.Cap.E.bal.kvarh
Calc.I0	Zero.Seq.Volt.Sec	L3 Exp.React.Ind.E.Mvarh
Pha.Curr.IL1 TRMS	U1Volt p.u.	L3 Exp.React.Ind.E.kvarh
Pha.Curr.IL2 TRMS	U2Volt p.u.	L3 Imp.React.Ind.E.Mvarh
Pha.Curr.IL3 TRMS	U3Volt p.u.	L3 Imp.React.Ind.E.kvarh
Pos.Seq.Curr.	U4Volt p.u.	L3 Exp/Imp React.Ind.E.bal.Mvarh
Neg.Seq.Curr.	U1Volt TRMS p.u.	L3 Exp/Imp React.Ind.E.bal.kvarh
Zero.Seq.Curr.	U2Volt TRMS p.u.	Exp.Active Energy MWh
Res.Curr.I01 TRMS	U3Volt p.u.	Exp.Active Energy kWh
Res.Curr.I02 TRMS	U4Volt p.u.	Imp.Active Energy MWh
Pha.L1 ampl. THD	Pos.Seq.Volt. p.u.	Imp.Active Energy kWh
Pha.L2 ampl. THD	Neg.Seq.Volt. p.u.	Exp/Imp Act. E balance MWh
Pha.L3 ampl. THD	Zero.Seq.Volt. p.u.	Exp/Imp Act. E balance kWh
Pha.L1 pow. THD	U1Volt Angle	Exp.React.Cap.E.Mvarh
Pha.L2 pow. THD	U2Volt Angle	Exp.React.Cap.E.kvarh
Pha.L3 pow. THD	U3Volt Angle	Imp.React.Cap.E.Mvarh
Res.I01 ampl. THD	U4Volt Angle	Imp.React.Cap.E.kvarh
Res.I01 pow. THD	Pos.Seq.Volt. Angle	Exp/Imp React.Cap.E.bal.Mvarh
Res.I02 ampl. THD	Neg.Seq.Volt. Angle	Exp/Imp React.Cap.E.bal.kvarh
Res.I02 pow. THD	Zero.Seq.Volt. Angle	Exp.React.Ind.E.Mvarh

P-P Curr.IL1	System Volt UL12 mag	Exp.React.Ind.E.kvarh
P-P Curr.IL2	System Volt UL12 mag (kV)	Imp.React.Ind.E.Mvarh
P-P Curr.IL3	System Volt UL23 mag	Imp.React.Ind.E.kvarh
P-P Curr.I01	System Volt UL23 mag (kV)	Exp/Imp React.Ind.E.bal.Mvarh
P-P Curr.I02	System Volt UL31 mag	Exp/Imp React.Ind.E.bal.kvarh
Pha.angle IL1	System Volt UL31 mag (kV)	**Other measurements**
Pha.angle IL2	System Volt UL1 mag	TM> Trip expect mode
Pha.angle IL3	System Volt UL1 mag (kV)	TM> Time to 100% T
Res.Curr.angle I01	System Volt UL2 mag	TM> Reference T curr.
Res.Curr.angle I02	System Volt UL2 mag (kV)	TM> Active meas curr.
Calc.I0.angle	System Volt UL3 mag	TM> T est.with act. curr.
Pos.Seq.Curr.angle	System Volt UL3 mag (kV)	TM> T at the moment
Neg.Seq.Curr.angle	System Volt U0 mag	TM> Max.Temp.Rise All.
Zero.Seq.Curr.angle	System Volt U0 mag (kV)	TM> Temp.Rise atm.
Pri.Pha.Curr.I"L1	System Volt U1 mag	TM> Hot Spot estimate
Pri.Pha.Curr.I"L2	System Volt U1 mag (kV)	TM> Hot Spot Max. All
Pri.Pha.Curr.I"L3	System Volt U2 mag	TM> Used k for amb.temp
Pri.Res.Curr.I"01	System Volt U2 mag (kV)	TM> Trip delay remaining
Pri.Res.Curr.I"02	System Volt U3 mag	TM> Alarm 1 time to rel.
Pri.Calc.I"0	System Volt U3 mag (kV)	TM> Alarm 2 time to rel.
Pha.Curr.I"L1 TRMS Pri	System Volt U4 mag	TM> Inhibit time to rel.
Pha.Curr.I"L2 TRMS Pri	System Volt U4 mag (kV)	TM> Trip time to rel.
Pha.Curr.I"L3 TRMS Pri	System Volt UL12 ang	S1 Measurement
I" Pri.Pos.Seq.Curr.	System Volt UL23 ang	S2 Measurement
I" Pri.Neg.Seq.Curr.	System Volt UL31 ang	S3 Measurement
I" Pri.Zero.Seq.Curr.	System Volt UL1 ang	S4 Measurement
Res.Curr.I"01 TRMS Pri	System Volt UL2 ang	S5 Measurement
Res.Curr.I"02 TRMS Pri	System Volt UL3 ang	S6 Measurement
Sec.Pha.Curr.I"L1	System Volt U0 ang	S7 Measurement
Sec.Pha.Curr.I"L2	System Volt U1 ang	S8 Measurement
Sec.Pha.Curr.I"L3	System Volt U2 ang	S9 Measurement
Sec.Res.Curr.I"01	System Volt U3 ang	S10 Measurement
Sec.Res.Curr.I"02	System Volt U4 ang	S11 Measurement
Sec.Calc.I"0	**Power measurements**	S12 Measurement
Pha.Curr.I"L1 TRMS Sec	L1 Apparent Power (S)	Sys.meas.frqs
Pha.Curr.I"L2 TRMS Sec	L1 Active Power (P)	f atm.
Pha.Curr.I"L3 TRMS Sec	L1 Reactive Power (Q)	f meas from
I" Sec.Pos.Seq.Curr.	L1 Tan(phi)	SS1.meas.frqs
I" Sec.Neg.Seq.Curr.	L1 Cos(phi)	SS1f meas from
I" Sec.Zero.Seq.Curr.	L2 Apparent Power (S)	SS2 meas.frqs
Res.Curr.I"01 TRMS Sec	L2 Active Power (P)	SS2f meas from
Res.Curr.I"02 TRMS Sec	L2 Reactive Power (Q)	L1 Bias current

Pha.Curr.I”L1	L2 Tan(phi)	L1 Diff current
Pha.Curr.I”L2	L2 Cos(phi)	L1 Char current
Pha.Curr.I”L3	L3 Apparent Power (S)	L2 Bias current
Res.Curr.I”01	L3 Active Power (P)	L2 Diff current
Res.Curr.I”02	L3 Reactive Power (Q)	L2 Char current
Calc.I”0	L3 Tan(phi)	L3 Bias current
Pha.Curr.I”L1 TRMS	L3 Cos(phi)	L3 Diff current
Pha.Curr.I”L2 TRMS	3PH Apparent Power (S)	L3 Char current
Pha.Curr.I”L3 TRMS	3PH Active Power (P)	HV I0d> Bias current
I” Pos.Seq.Curr.	3PH Reactive Power (Q)	HV I0d> Diff current
I” Neg.Seq.Curr.	3PH Tan(phi)	HV I0d> Char current
I” Zero.Seq.Curr.	3PH Cos(phi)	LV I0d> Bias current
Res.Curr.I”01 TRMS	**Energy measurements**	LV I0d> Diff current
Res.Curr.I”02 TRMS	L1 Exp.Active Energy MWh	LV I0d> Char current
Pha.IL”1 ampl. THD	L1 Exp.Active Energy kWh	Curve1 Input
Pha.IL”2 ampl. THD	L1 Imp.Active Energy MWh	Curve1 Output
Pha.IL”3 ampl. THD	L1 Imp.Active Energy kWh	Curve2 Input
Pha.IL”1 pow. THD	L1 Exp/Imp Act. E balance MWh	Curve2 Output
Pha.IL”2 pow. THD	L1 Exp/Imp Act. E balance kWh	Curve3 Input
Pha.IL”3 pow. THD	L1 Exp.React.Cap.E.Mvarh	Curve3 Output
Res.I”01 ampl. THD	L1 Exp.React.Cap.E.kvarh	Curve4 Input
Res.I”01 pow. THD	L1 Imp.React.Cap.E.Mvarh	Curve4 Output
Res.I”02 ampl. THD	L1 Imp.React.Cap.E.kvarh	Control mode
Res.I”02 pow. THD	L1 Exp/Imp React.Cap.E.bal.Mvarh	Motor status
P-P Curr.I”L1	L1 Exp/Imp React.Cap.E.bal.kvarh	Active setting group
P-P Curr.I”L2	L1 Exp.React.Ind.E.Mvarh	
	L1 Exp.React.Ind.E.kvarh	

4.3.5 Measurement value recorder

Measurement value recorder function records the value of selected magnitudes at the time of given trigger signal. An example application for this function is to record fault currents or voltages at the time of tripping the breaker but it can be used also to record the values from any user set trigger signal. Value recorder is capable of recording either per unit value or primary value which is user settable. Optionally it is possible to set the function to record the overcurrent or voltage fault type. The function operates instantly from trigger signal.

Additionally, the measurement value recorder function has integrated fault display which displays the current fault values in case of I>, Idir>, I0>, I0dir>, f<, f>, U< or U> trips. When any of these functions trip fault values and fault type are displayed over the mimic view. The view can be enabled by activating *VREC Trigger On* in menu *Tools → Events and logs → Set alarm events*. Resetting of the fault values is done by input selected in General menu.

Measured input values

Function block uses analog current and voltage measurement values. From these values relay calculates the secondary and primary values of currents, voltages, powers, impedances and other values.

Up to 8 magnitudes can be set to be recorded when function is triggered. Overcurrent fault type, voltage fault type and tripped stage can be recorded and reported forward to SCADA.

NOTE: Available measurement values depend on the IED type. If only current analog measurements are available, it is possible to use only signals which use just current. The same applies if only voltage is available.

Currents	**Description**
IL1ff, IL2ff, IL3ff, I01ff, I02ff	Fundamental frequency current measurement values of phase currents and residual currents
IL1TRMS, IL2TRMS, IL3TRMS, I01TRMS, I02TRMS	TRMS current measurement values of phase currents and residual currents
IL1,2,3 & I01/I02 2^{nd} h., 3^{rd} h., 4^{th} h., 5^{th} h., 7^{th} h., 9^{th} h., 11^{th} h., 13^{th} h., 15^{th} h., 17^{th} h., 19^{th} h.	Magnitudes of phase current components: Fundamental, 2^{nd} harmonic, 3^{rd} harmonic, 4^{th} harmonic, 5^{th} harmonic 7^{th}, harmonic 9^{th}, harmonic 11^{th}, harmonic 13^{th}, harmonic 15^{th}, harmonic 17^{th}, harmonic 19^{th} harmonic current.
I1,I2,I0Z	Positive sequence current, negative sequence current and zero sequence current
I0CalcMag	Residual current calculated from phase currents
IL1Ang, IL2Ang, IL3Ang, I01Ang, I02Ang, I0CalcAng, I1Ang, I2Ang	Angles of each measured current
Voltages	Description
UL1Mag, UL2Mag, UL3Mag, UL12Mag, UL23Mag, UL31Mag U0Mag, U0CalcMag	Magnitudes of phase voltages, phase-to-phase voltages and residual voltages.
U1 Pos.seq V mag, U2 Neg.seq V mag	Positive and negative sequence voltages.
UL1Ang, UL2Ang, UL3Ang, UL12Ang, UL23Ang, UL31Ang U0Ang, U0CalcAng	Angles of phase voltages, phase-to-phase voltages and residual voltages.

Currents	**Description**
U1 Pos.seq V Ang, U2 Neg.seq V Ang	Positive and negative sequence angles.
Powers	Description
S3PH, P3PH, Q3PH	Three phase apparent, active and reactive power
SL1, SL2, SL3, PL1, PL2, PL3, QL1, QL2, QL3	Phase apparent, active and reactive powers
tanfi3PH, tanfiL1, tanfiL2, tanfiL3	Tan (φ) of three phase powers and phase powers
cosfi3PH, cosfiL1, cosfiL2, cosfiL3	Cos (φ) of three phase powers and phase powers
Impedances and admittances	Description
RL12, RL23, RL31 XL12, XL23, XL31, RL1, RL2, RL3 XL1, XL2, XL3 Z12, Z23, Z31 ZL1, ZL2, ZL3	Phase-to-phase/Phase-to-neutral resistances, reactances and impedances
Z12Ang, Z23Ang, Z31Ang, ZL1Ang, ZL2Ang, ZL3Ang	Phase-to-phase/Phase-to-neutral impedance angles
Rseq, Xseq, Zseq RseqAng, XseqAng, ZseqAng	Positive sequence resistance, reactance and impedance values and angles
GL1, GL2, GL3, G0 BL1, BL2, BL3, B0	Conductances, susceptances and admittances

Currents	Description
YL1, YL2, YL3, Y0	
YL1angle, YL2angle, YL3angle Y0angle	Admittance angles
Others	Description
System f.	Used tracking frequency at the moment
Ref f1	Reference frequency 1
Ref f2	Reference frequency 1
M thermal T	Motor thermal temperature
F thermal T	Feeder thermal temperature
T thermal T	Transformer thermal temperature
RTD meas 1...16	RTD measurement channels 1...16
Ext RTD meas 1...8	External RTD measurement channels 1...8 (ADAM module)

Reported values

When triggered function will hold the recorded values of the set up 8 channels. In addition to this tripped stage, overcurrent fault type and voltage fault types are reported to SCADA.

Table 4.57 Reported values of measurement value recorder

Name	Range	Step	Description
Tripped stage	0:- 1:I> Trip 2:I>> Trip 3:I>>> Trip 4:I>>>> Trip 5:IDir> Trip 6:IDir>> Trip	-	Tripped stage

Name	Range	Step	Description
	7:IDir>>> Trip 8:IDir>>>> Trip 9:U> Trip 10:U>> Trip 11:U>>> Trip 12:U>>>> Trip 13:U< Trip 14:U<< Trip 15:U<<< Trip 16:U<<<< Trip		
Overcurrent fault type	0:- 1:A-G 2:B-G 3:A-B 4:C-G 5:A-C 6:B-C 7:A-B-C	-	Overcurrent fault type
Voltage fault type	0:- 1:A(AB) 2:B(BC) 3:A-B(AB-BC) 4:C(CA) 5:A-C(AB-CA) 6:B-C(BC-CA) 7:A-B-C	-	Voltage fault type
Magnitude 1...8	0.000...1800.000A/V/p.u.	0.001A/V/p.u.	Recorded value in one of the eight channels.

Events

VREC function generates events from function triggering. To main event buffer it is possible to select “On” or “Off” status messages.

Table 4.58 Event codes of the VREC function.

Event Number	Event channel	Event block name	Event Code	Description
9984	156	VREC1	0	Recorder triggered On
9985	156	VREC1	1	Recorder triggered Off

4.3.6 Current transformer supervision (CTS)

Current transformer supervision (CTS) function is meant to be used for monitoring the CTs, wirings in between of the IED and IED CT inputs in case of malfunction or wire breaks. Open CT circuit can generate dangerously high voltages into the CT secondary side as well as cause not intended activation of current balance monitoring functions.

CTS function constantly monitors phase current instant values as well as key calculated magnitudes of the phase currents. Also, residual current circuit can be monitored if the residual current is measured from dedicated residual current CT. Residual circuit monitoring can be enabled or disabled by user selection.

Blocking signal and setting group selection controls the operating characteristics of the function during normal operation.

Outputs of the function are CTS alarm and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. CTS function utilizes total of eight separate setting groups which can be selected from one common source. Also, the operating mode of the CTS can be changed by setting group selection.

The operational logic consists of input magnitude processing, threshold comparator, block signal check, time delay characteristics and output processing.

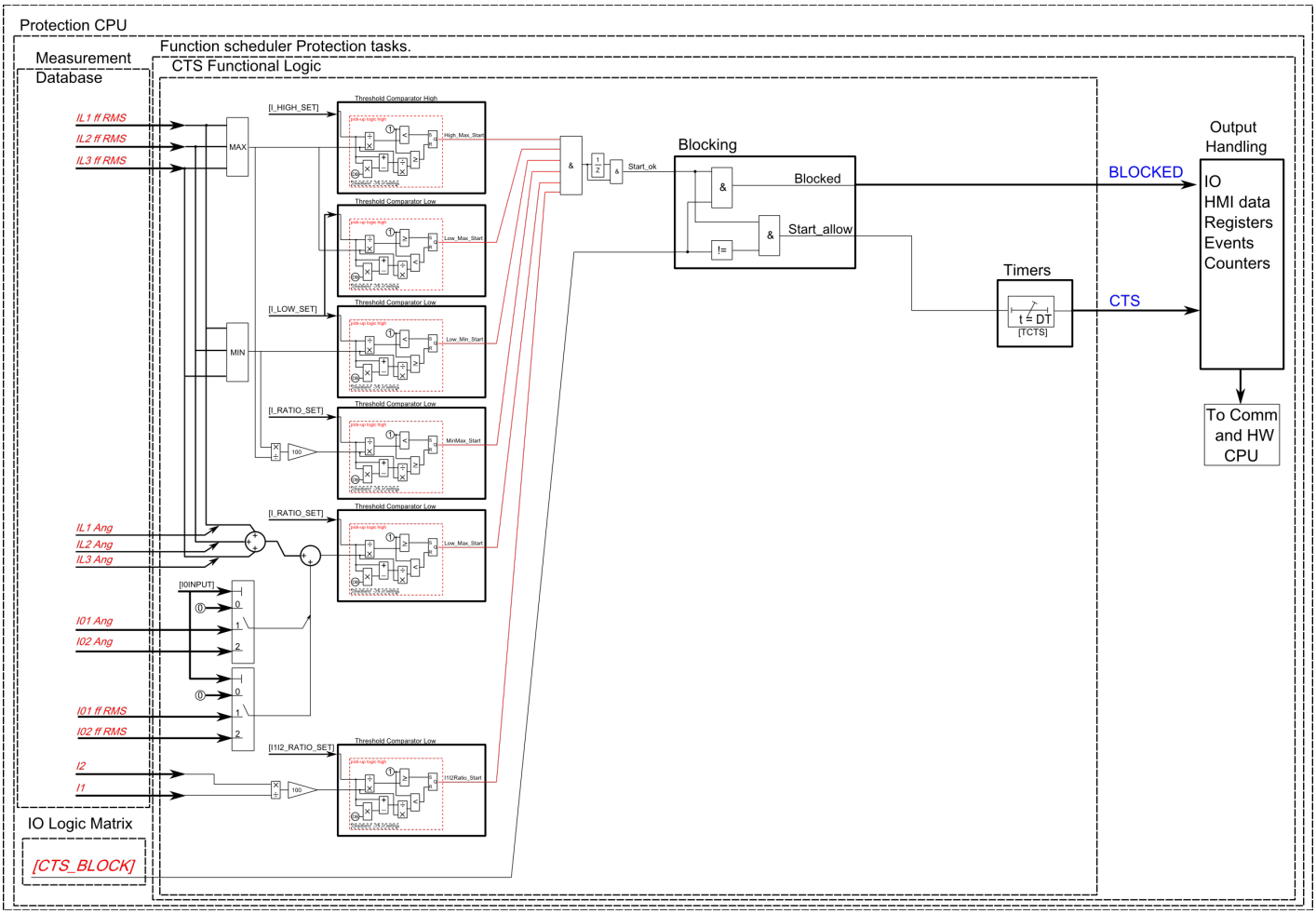
For the CTS function alarm activation following conditions has to be met simultaneously:

- None of the three phase currents is over the set Iset Highlimit setting
- At least one of the three phase currents are over the Iset Lowlimit setting
- At least one of the three phase currents are under the Iset Lowlimit setting
- Three phase current calculated Min/Max ratio is under the Iset ratio setting
- Negative sequence / Positive sequence ratio is over the I2/I1 ratio setting
- Calculated (IL1+IL2+IL3+I0) difference is over the Isum difference setting (optional)
- Above mentioned condition is met until the set TCTS time

Inputs for the function are setting parameters and measured and pre-processed current magnitudes. Function output signals can be used for direct IO controlling and also for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the two output signal. Time stamp resolution is 1ms. Function provides also cumulative counters for CTS alarm and BLOCKED events.

Simplified function block diagram of CTS functionIn is presented in the following figure .

Figure 4.41 Simplified function block diagram of the CTS function.



Measured input values

Function block uses analog current measurement values. Function uses the fundamental frequency magnitude of the current measurement inputs and calculated positive and negative sequence currents. For residual current measurement can be selected: None, I01 fundamental component or I02 fundamental component.

Table 4.59 Analogic magnitudes used by the CTS function.

Signal	Description	Time base
IL1RMS	Fundamental RMS measurement of phase L1/A current	5 ms
IL2RMS	Fundamental RMS measurement of phase L2/B current	5 ms
IL3RMS	Fundamental RMS measurement of phase L3/C current	5 ms
I01RMS	Fundamental RMS measurement of residual input I01	5 ms
I02RMS	Fundamental RMS measurement of residual input I02	5 ms
I1	Phase currents positive sequence component	5 ms
I2	Phase currents negative sequence component	5 ms
IL1Ang	Fundamental angle of phase L1/A current	5 ms
IL2 Ang	Fundamental angle of phase L2/B current	5 ms
IL3 Ang	Fundamental angle of phase L3/C current	5 ms
I01 Ang	Fundamental angle of residual input I01	5 ms
I02 Ang	Fundamental angle of residual input I02	5 ms

Selection of the used AI channel is made with a setting parameter. In all possible input channel variations pre-fault condition is presented with 20 ms averaged history value from -20 ms of Start or Trip event.

Table 4.60 Residual current input signals selection

Name	Range	Step	Default	Description
I0 Input	0: Not in use 1: I01 2: I02	-	Not in use	Selection of residual current measurement input. In cases if the residual current is measured with separate CT the residual current circuit can be monitored also with the CTS function. This does not apply summing connection (Holmgren etc.) in case of phase current CT summed to I01 or I02 input use selection 0:Not in use.

Pick-up characteristics

Current dependent pick-up and activation of the CTS function is controlled by ISet and I0set setting parameters, which defines the minimum allowed measured current before action from the function. The function constantly calculates the ratio in between of the setting values and measured magnitude (Im) per all three phases and selected residual current input. Reset ratio of 97 % is inbuilt in the function and is always related to the settingvalue. The setting value is common for all measured phases and single-, dual- or all phases Im exceed of the Iset value will cause pick-up operation of the function.

Table 4.61 Pick-up characteristics setting

Name	Range	Step	Default	Description
Iset Highlimit	0.01 ... 40.00xIn	0.01xIn	1.20xIn	Pick-up threshold for phase current measurement. This setting limit defines the upper limit for the phase current pick-up element. If this condition is met it is considered as fault and the CTS is not activated
Iset Lowlimit	0.01 ... 40.00xIn	0.01xIn	0.10xIn	Pick-up threshold for phase current measurement. This setting limit defines the lower limit for the phase current pick-up element. If this condition is met it is considered as one trigger for the CTS activation.

Name	Range	Step	Default	Description
Iset Ratio	0.01 ... 100.00%	0.01%	10.00%	Pick-up ratio threshold for phase current min and max values. This condition has to be met in order CTS is activated.
I2/I1 ratio	0.01 ... 100.00%	0.01%	49.00%	Pick-up ratio threshold for Negative sequence / Positive sequence currents calculated from the phase currents. This condition has to be met in order CTS is activated. In full single phasing fault when one of the phases is completely lost the ratio shall be 50%. Setting of 49% allows 0.01 xIn to flow in one phase when the two other are 1.00 xIn
Isum difference	0.01 ... 40.00xIn	0.01xIn	0.10xIn	Pick-up ratio threshold for calculated residual phase current to measured residual current. If the measurement circuit is healthy the sum of these should be 0.

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active. From binary signals the activation of the pick-up is immediate when the monitored signal is activated.

Function blocking

In the blocking element the block signal is checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup current values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

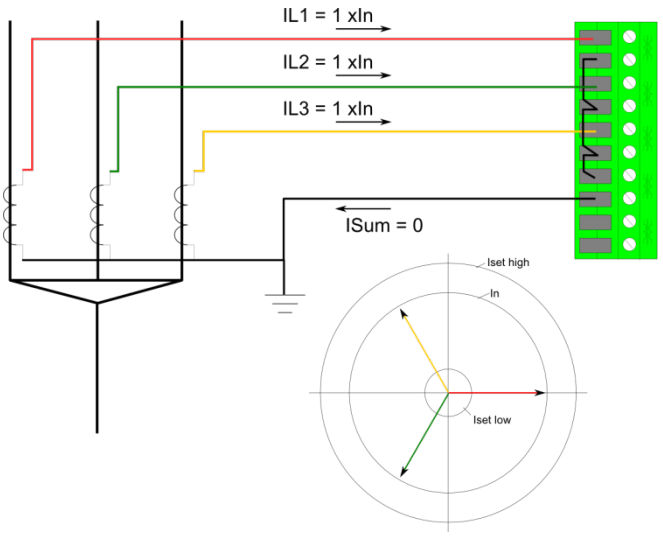
Operating time characteristics

This function supports definite time delay (DT). For detailed information on this delay type refer to chapter General properties of a protection function.

Typical CTS cases

In following figures are presented few typical cases of CTS situations and setting effects.

Figure 4.42 System in case when all is working properly and no fault is present.

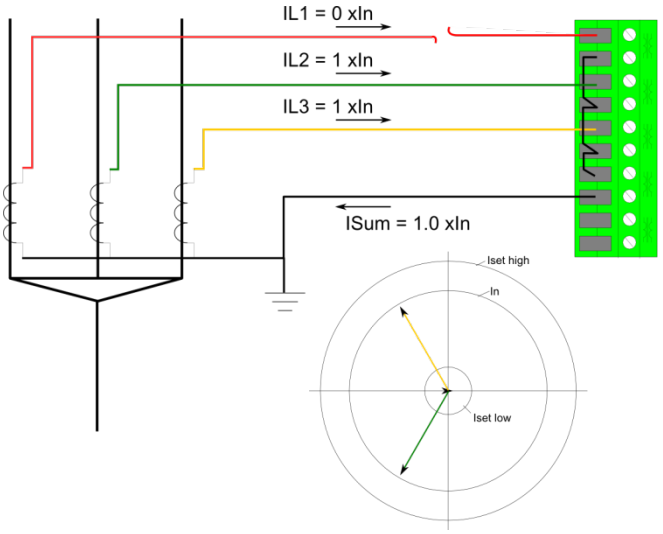


Settings:
Iset Highlimit = 1.20 xIn
Iset Lowlimit = 0.10 xIn
Iset ratio = 10.00 %
I1/I2 ratio = 49.00 %
I0input = Not in use

Measurements:
Imin = 1 xIn
Imax = 1 xIn
I1 = 1 xIn
I2= 0 xIn
Imin/Imax = 1
I2/I1 = 0

CTS conditions:
Iset Highlimit < = 1
Iset Lowlimit low < = 0
Iset Lowlimit high > = 1
Iratio < = 0
Iunbalance ratio > = 0

Figure 4.43 System in case when secondary circuit fault is found in phase L1 wiring.



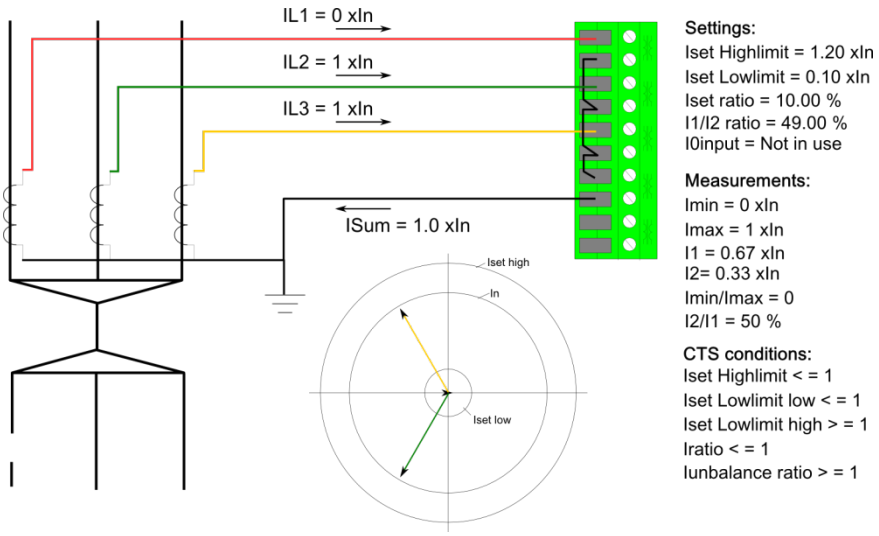
Settings:
Iset Highlimit = 1.20 xIn
Iset Lowlimit = 0.10 xIn
Iset ratio = 10.00 %
I1/I2 ratio = 49.00 %
I0input = Not in use

Measurements:
Imin = 0 xIn
Imax = 1 xIn
I1 = 0.67 xIn
I2= 0.33 xIn
Imin/Imax = 0
I2/I1 = 50 %

CTS conditions:
Iset Highlimit < = 1
Iset Lowlimit low < = 1
Iset Lowlimit high > = 1
Iratio < = 1
Iunbalance ratio > = 1

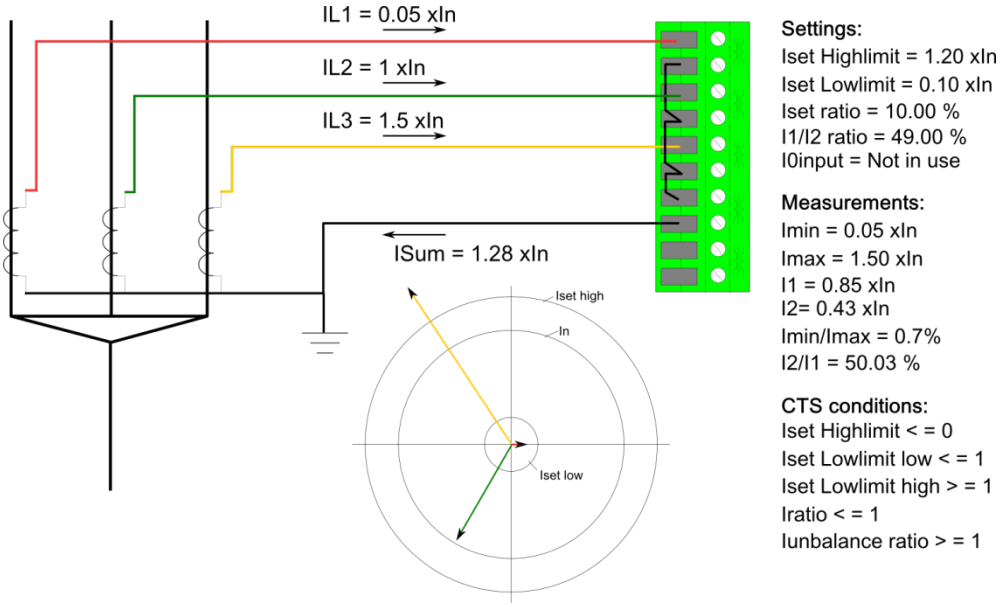
When fault is detected and all of the conditions are met the CTS timer will start counting. If the situation continues until the set time has been spent CTS will issue alarm.

Figure 4.44 System in case when primary circuit fault is found in phase L1 wiring.



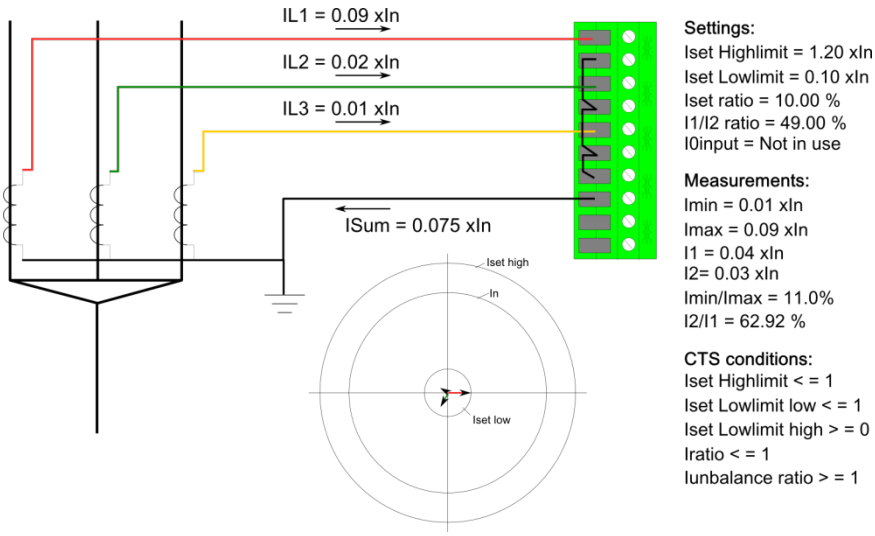
Distinction in between primary and secondary fault in this case is impossible. However the situation meets the CTS conditions and as well as in the secondary circuit fault the CTS will issue alarm if this state continues until the set time has been spent. This means that the CTS do not supervise only the secondary circuit but also the primary circuit.

Figure 4.45 System in case when there is no wiring fault and heavy unbalance.



If any of the phases is over the Iset Highlimit the operation of the CTS is not activated. This behavior is applied in short circuit and earth faults also if the fault current exceeds the Iset high setting.

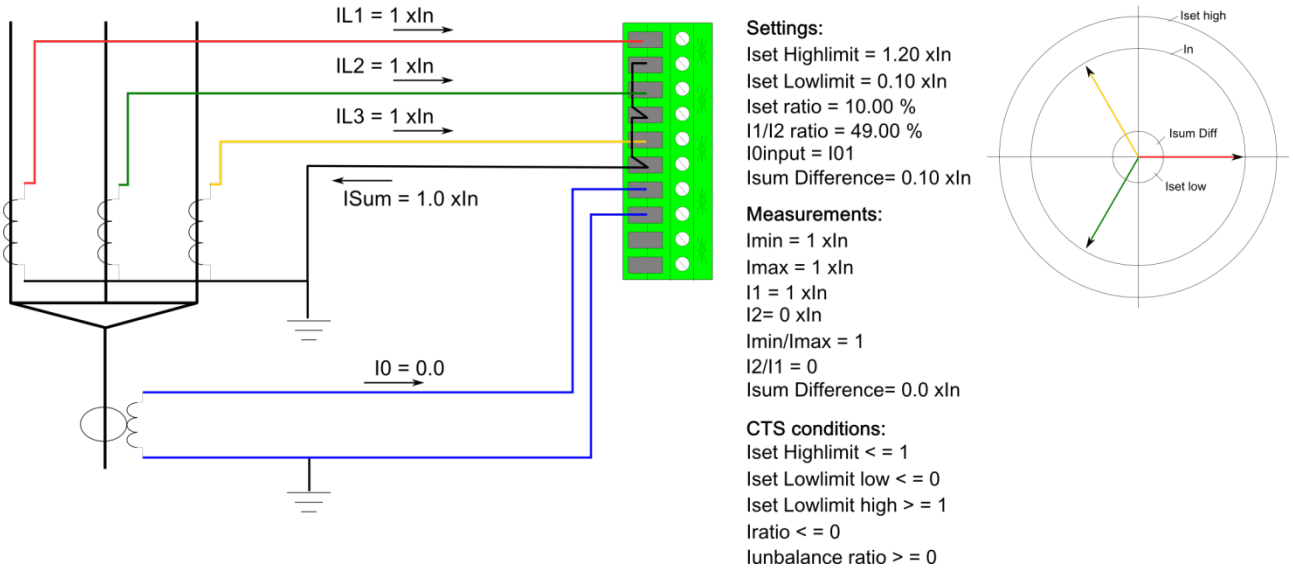
Figure 4.46 System in case of low current and heavy unbalance.



If all of the measured phases magnitudes are below the Iset Lowlimit setting the CTS is not activated even the unbalance and other conditions are met.

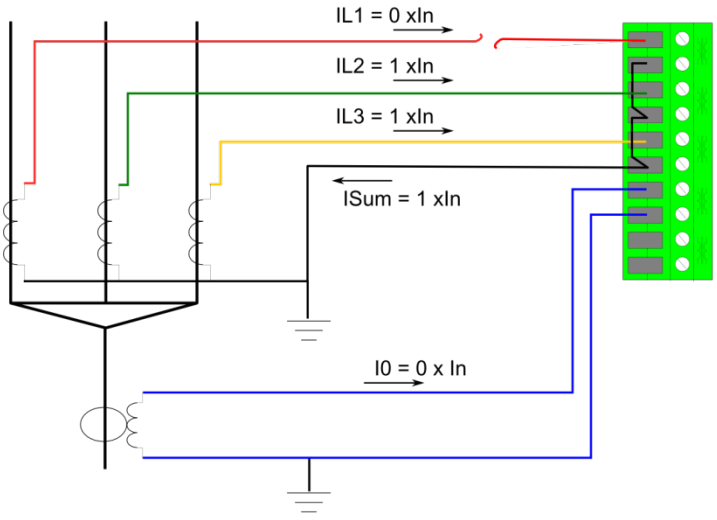
By adjusting the Iset Highlimit and Iset Lowlimit setting parameters according to the application normal behavior, the operation of the CTS can be set to very sensitive for broken circuit/conductor faults.

Figure 4.47 System in normal situation when measuring also the residual current.



When the residual condition is added the sum current and residual current are compared against each other and the wiring condition can be verified.

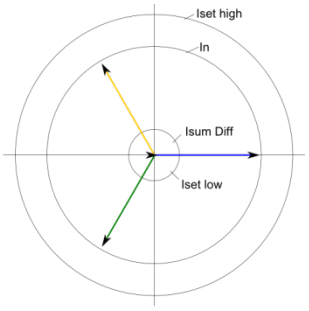
Figure 4.48 System in case when secondary phase current wiring is broken.



Settings:
Iset Highlimit = 1.20 xIn
Iset Lowlimit = 0.10 xIn
Iset ratio = 10.00 %
I1/I2 ratio = 49.00 %
I0input = I01
Isum Difference= 0.10 xIn

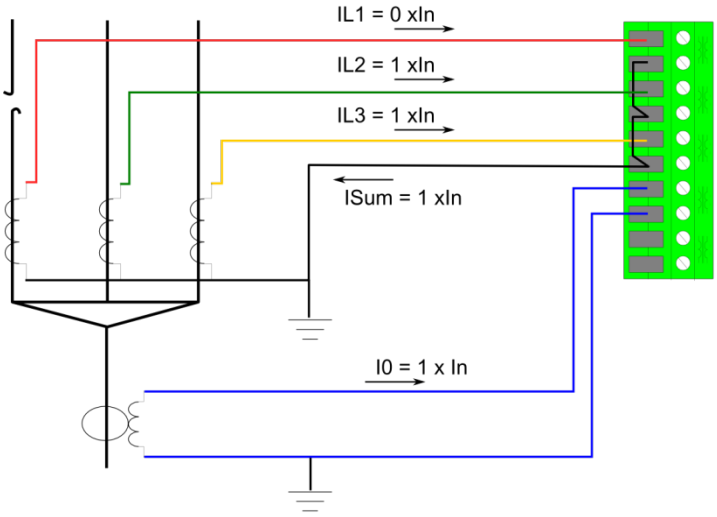
Measurements:
Imin = 1 xIn
Imax = 0 xIn
I1 = 0.67 xIn
I2= 0.33 xIn
Imin/Imax = 0
I2/I1 = 50 %
Isum Difference= 1.0 xIn

CTS conditions:
Iset Highlimit < = 1
Iset Lowlimit low < = 1
Iset Lowlimit high > = 1
Iratio < = 1
Iunbalance ratio > = 1
Isum Difference > = 1



When phase current wire is broken all of the conditions are met in the CTS and alarm shall be issued in case if the situation continues until the set alarming time is met.

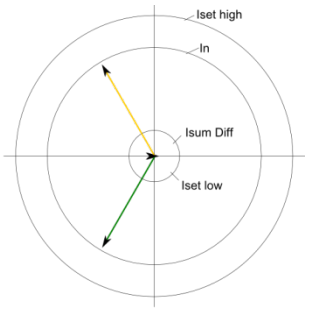
Figure 4.49 System in case when primary phase current wiring is broken.



Settings:
Iset Highlimit = 1.20 xIn
Iset Lowlimit = 0.10 xIn
Iset ratio = 10.00 %
I1/I2 ratio = 49.00 %
I0input = I01
Isum Difference= 0.10 xIn

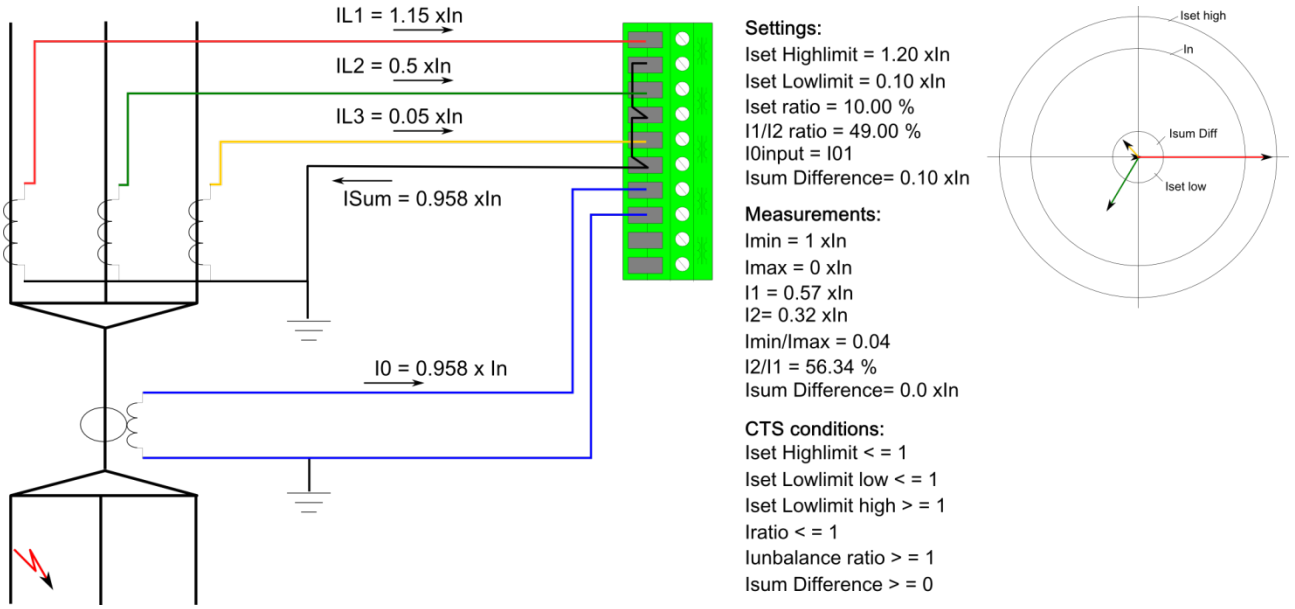
Measurements:
Imin = 0 xIn
Imax = 1 xIn
I1 = 0.67 xIn
I2= 0.33 xIn
Imin/Imax = 0
I2/I1 = 50 %
Isum Difference= 0.0 xIn

CTS conditions:
Iset Highlimit < = 1
Iset Lowlimit low < = 1
Iset Lowlimit high > = 1
Iratio < = 1
Iunbalance ratio > = 1
Isum Difference > = 0



In this case all other conditions are met except the residual difference which is now 0 x In and thus indicate primary side fault.

Figure 4.50 System in case of primary side high impedance earth fault.



In case of high impedance earth fault the CTS will not activate if the measurement conditions are met and the calculated and measured residual current difference is not reaching the limit. The setting Isum difference should be set according to the application to reach maximum security and sensitivity for the network earthing.

Events and registers

The CTS function generates events and registers from the status changes of the ALARM activated and blocked signals. To main event buffer is possible to select status “On” or “Off” messages.

Function includes 12 last registers where the triggering event of the function (ALARM activated or blocked) is recorded with time stamp and process data values.

Table 4.62 Event codes of the CTS function instance

Event Number	Event channel	Event block name	Event Code	Description
3328	52	CTS1	0	Alarm On
3329	52	CTS1	1	Alarm Off
3330	52	CTS1	2	Block On
3331	52	CTS1	3	Block Off
3456	54	CTS2	0	Alarm On
3457	54	CTS2	1	Alarm Off
3458	54	CTS2	2	Block On
3459	54	CTS2	3	Block Off

In the register of the CTS function recorded events are activated, blocked etc. “On” event process data. In the table below is presented the structure of CTS function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 4.63 Register content.

Date & Time	Event code	Trigger currents	Time to CTSact	Ftype	Used SG
dd.mm.yyyy hh:mm:ss.mss	3328-3459 Descr.	Phase and residual currents	Time remaining before CTS is active	Monitored current status code	1 - 8

Date & Time	Event code	Trigger currents	Time to CTSact	Ftype	Used SG
		sequence currents on trigger time			

4.3.7 Total harmonic distortion monitor (THD)

Total harmonic distortion monitor function (THD) is used for monitoring the current harmonic content. THD is a measurement of the harmonic distortion present and is defined as the ratio of the sum of powers of all harmonic components to the power of fundamental frequency.

Harmonics can be caused by different sources in the electric networks like electric machine drives, thyristor controls etc. Monitoring of the THD of the currents can be used to alarm in case if the harmonic content rises too high in cases if either the electric quality requirement exist in the protected unit or in cases if process generated harmonics needs to be monitored.

THD function measures constantly phase and residual current magnitudes and the harmonic content of the monitored signals up to 31.st harmonic component. When the THD function is activated the THD measurements are available for displays also. User has possibility to set also the alarming limits for each measured channels if required by the application.

THD of the measured signals can be selected either amplitude- or power ratio THD. The difference is in the calculation formula:

Power THD ratio is the sum of harmonic components squared divided by the fundamental component squared.

Figure 4.51 THD calculation formula

$$THD_P = \frac{I_{x2}^{\,2} + I_{x3}^{\,2} + I_{x4}^{\,2} \ldots I_{x31}^{\,2}}{I_{x1}^{\,2}}$$

, where
I = measured current,
x= measurement input,
n = harmonic number

Amplitude THD (percentage) is otherwise similar in difference of that the result is square root of the Power THD:

$$THD_A = \sqrt{\frac{I_{x2}^{\,2} + I_{x3}^{\,2} + I_{x4}^{\,2} \ldots I_{x31}^{\,2}}{I_{x1}^{\,2}}}$$

, where
I = measured current,
x= measurement input,
n = harmonic number

Both of these mentioned ways to calculate THD exist, while power THD is known by IEEE and IEC defines the amplitude ratio.

Blocking signal and setting group selection controls the operating characteristics of the function during normal operation if the alarming is selected to be active.

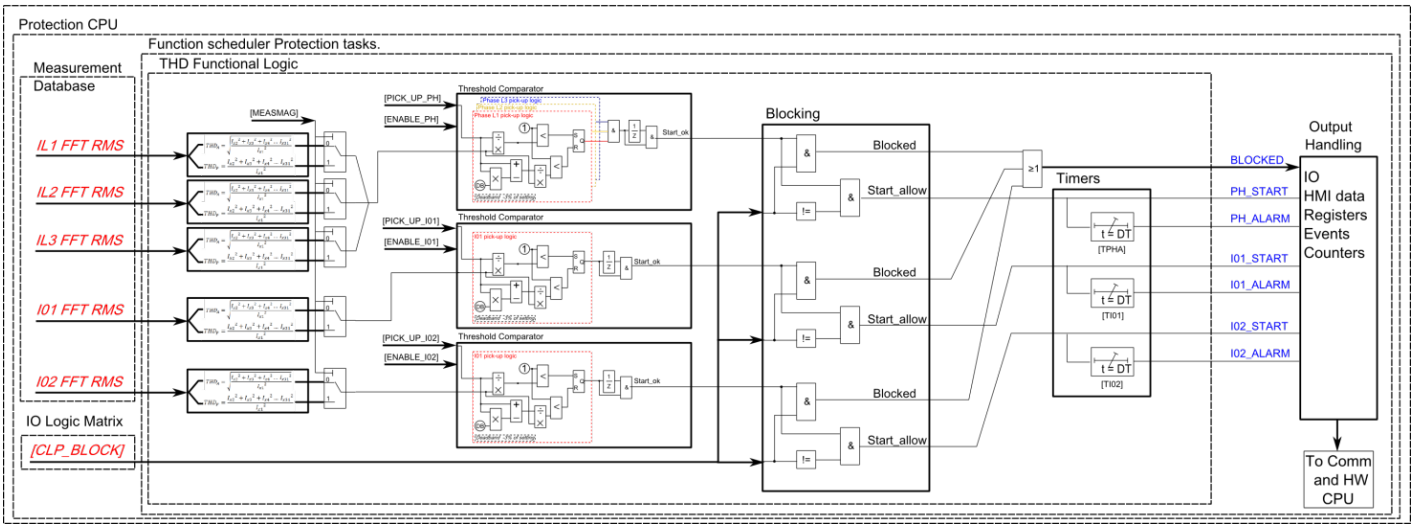
Outputs of the function are Start and Alarm act signals for phase current THD, I01 THD, I02 THD and Blocked signals. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function. THD function utilizes total of eight separate setting groups which can be selected from one common source.

The operational logic consists of input magnitude processing, threshold comparator, block signal check, time delay characteristics and output processing.

Inputs for the function are setting parameters and measured and pre-processed current magnitudes and binary input signals. Function outputs THD Alarm act and BLOCKED signals which can be used for direct IO controlling and for user logic programming. The function registers its operation into 12 last time-stamped registers and also generates general time stamped ON/OFF events to the common event buffer from each of the two output signals. Time stamp resolution is 1ms. Function provides also cumulative counters for THD Start and Alarm act and BLOCKED events.

In the following figure is presented the simplified function block diagram of the THD function.

Figure 4.52 Simplified function block diagram of the THD function.



Measured input values

Function block uses analog current measurement values. Function block always utilizes FFT measurement of whole harmonic specter of 32 components from each measured current channel which from the THD is calculated either as amplitude or power ratio THD. -20ms averaged value of the selected magnitude is used for pre-fault data registering.

Table 4.64 Analogic magnitudes used by the THD function.

Signal	Description	Time base
IL1FFT	Fundamental RMS measurement of phase L1/A current	5 ms
IL2FFT	Fundamental RMS measurement of phase L2/B current	5 ms
IL3FFT	Fundamental RMS measurement of phase L3/C current	5 ms
I01FFT	Fundamental RMS measurement of residual I01 current	5 ms
I02FFT	Fundamental RMS measurement of residual I02 current	5 ms

Selection of the THD calculation method is made with a setting parameter commonly for all of the measurement channels.

General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible change them with setting group switching.

Table 4.65 General settings of the function

Name	Description	Range	Step	Default
Measurement magnitude	Defines which available measured magnitude of THD is used by the function.	1:Amplitude 2:Powers	-	1:Amplitude
THD in side	Defines which current measurement module is used by the function.	1:Side1 2:Side2 3:Side3	-	1:Side1

Pick-up characteristics

Pick-up and activation of the THD function alarm is controlled by *IsetPh, IsetI01* and *IsetI02 pick-up* setting parameters, which defines the maximum allowed measured current THD before action from the function. In order to have alarm signals activated from the function, the corresponding pick-up element needs to be activated by the *Enable PH, Enable I01* and *Enable I02* setting parameters. Each pick-up element can be activated individually. The function constantly calculates the ratio in between of the setting values and measured magnitude (Im) per all three phases. Reset ratio of 97 % is inbuilt in the function and is always related to the settingvalue. The setting value is common for all measured phases and single-, dual- or all phases Im exceed of the Iset value will cause pick-up operation of the function.

Table 4.66 Pick-up characteristics setting

Name	Range	Step	Default	Description
Enable PH	On Off	-	Off	Enable of the THD alarm function from phase currents.
Enable I01	On Off	-	Off	Enable of the THD alarm function from residual current input I01.
Enable I02	On Off	-	Off	Enable of the THD alarm function from residual current input I02.
IsetPh	0.10 ... 200.00%	0.01%	20.00%	Pick-up setting for THD alarm element from the phase currents. The measured THD value has to be over this setting on at least one of the measured phases to activate the alarm signal.
IsetI01	0.10 ... 200.00%	0.01%	20.00%	Pick-up setting for THD alarm element from the residual current I01. The measured THD value has to be over this setting to activate the alarm signal.
IsetI02	0.10 ... 200.00%	0.01%	20.00%	Pick-up setting for THD alarm element from the residual current I02. The measured THD value has to be over this setting to activate the alarm signal.

The pick-up activation of the function is not directly equal to start-signal generation of the function. Start signal is allowed if blocking condition is not active.

Function blocking

In the blocking element the block signal is checked in the beginning of each program cycle. Blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If blocking signal is active when pick-up element activates a BLOCKED signal will be generated and the function shall not process the situation further. If START function has been activated before blocking signal it will reset and the release time characteristics are processed as in case of when pick-up signal is reset.

From blocking of the function a HMI display event as well as time stamped blocking event with information of the startup current values and fault type is issued.

Blocking signal can be tested also in the commissioning phase of the stage by software switch signal when relay common and global testing mode is activated.

User settable variables are binary signals from the system. Blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passedfor blocking to be active in time.

Operating time characteristics for activation and reset

The operating timers' behavior of the function can be set for activation and the cold load pick up situation monitoring and release.

In the following table are presented the setting parameters for the function time characteristics.

Table 4.67 Operating time characteristics setting parameters.

Name	Range	Step	Default	Description
Tpha	0.000...1800.000s	0.005s	10.000s	Delay time setting for the alarm timer from the phase currents measured THD.
TI01	0.000...1800.000s	0.005s	10.000s	Delay time setting for the alarm timer from the residual current I01 measured THD.
TI02	0.000...1800.000s	0.005s	10.000s	Delay time setting for the alarm timer from the residual current I02 measured THD.

Events and registers

The THD function generates events and registers from the status changes of the alarm function when it is activated. Recorded signals are Start and Alarm signals per monitoring element and common blocked signals. To main event buffer is possible to select status "On" or "Off" messages.

In the function is available 12 last registers where the triggering event of the function (THD start, alarm or blocked) is recorded with time stamp and process data values.

Table 4.68 Event codes of the THD function

Event Number	Event channel	Event block name	Event Code	Description
3520	55	THD1	0	THD Start Phase On
3521	55	THD1	1	THD Start Phase Off
3522	55	THD1	2	THD Start I01 On
3523	55	THD1	3	THD Start I01 Off
3524	55	THD1	4	THD Start I02 On
3525	55	THD1	5	THD Start I02 Off
3526	55	THD1	6	THD Alarm Phase On
3527	55	THD1	7	THD Alarm Phase Off
3528	55	THD1	8	THD Alarm I01 On
3529	55	THD1	9	THD Alarm I01 Off
3530	55	THD1	10	THD Alarm I02 On
3531	55	THD1	11	THD Alarm I02 Off
3532	55	THD1	12	Blocked On
3533	55	THD1	13	Blocked Off

In the register of the THD function is recorded activated, blocked etc. "On" event process data. In the table below is presented the structure of THD function register content. This information is available in 12 last recorded events for all provided instances separately.

Table 4.69 Register content.

Date & Time	Event code	IL1 THD	IL2 THD	IL3 THD	I01 THD	I02 THD	Ph Trem	I01 Trem	I02 Trem	Used SG
dd.mm.yyyy hh:mm:ss.mss	3521-3534 Descr.	Measured THD values on the trigger event.					Time left to Alarm on the trigger event			1 - 8

4.3.8 Voltage memory function

Certain protection functions such as, impedance or directional overcurrent, are using the current and voltage measured at the relay to determine if the electrical network fault appears to be inside protected area. The determination is made by comparing the angle between the operating quantity (zone/trip area) to actual measured quantity. The function will produce an output in case required terms are met.

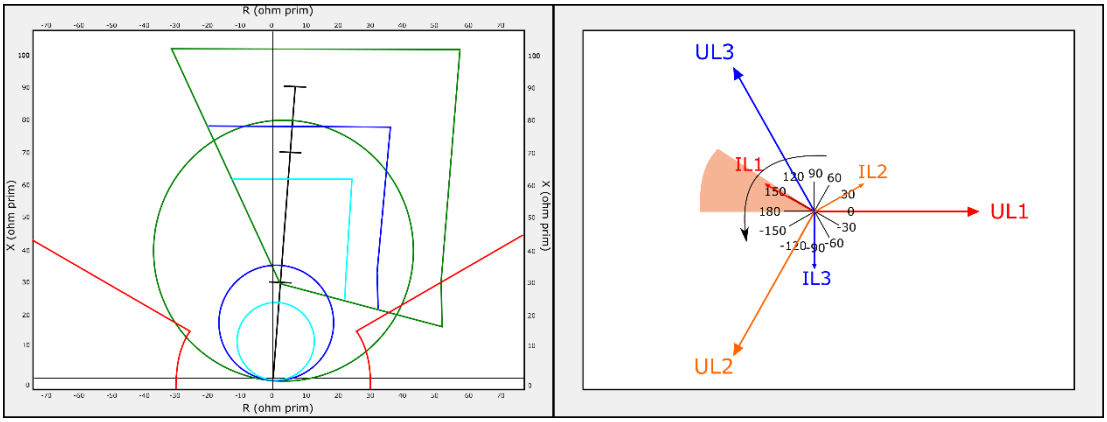
In close-in faults the system voltage on secondary side may fall under several volts or close to nothing. In such case when measured voltage is absent, the fault direction is not possible to be solved. As backup, un-directional protection can be used for tripping, but in such cases selectivity of network will reduce. To prevent this from happening, an angle memory for voltage can be used. Adjustable voltage level with pre-fault voltage angles can be used as a reference for fault direction/ distance, for duration that can be set manually. Due to configurable voltage memory, even time delayed backup tripping can be initiated.

Voltage memory activation and all related settings are found at *Measurements → Transformers → VT Module (3/4U) 1 → Voltage memory* (activated/disabled)

Activation of voltage memory depends of following criteria's:

1. All used line-to-line or line-to-neutral voltages need to be below set "VMEM activation voltage".
2. Least one phase current must be higher than set "Measured current condition 3I>". This setting limit is optional.

Figure 4.53 Distance protection characteristics and directional overcurrent.



When above mentioned criteria are met, voltage memory will activate. VMEM will use "VMEM activation voltage" as voltage amplitude even, when actual measured voltage has decreased lower or close to nothing. Used angle is captured a moment before the fault has occurred and voltage memory has been activated. When VMEM is activate, a specific output "Voltage memory on" is switched on. This signal can be found under device IO matrix.

Voltage memory blocking signal can be found among other stage related settings in "VT Module (3/4U) 1" -menu. In the blocking element the block signal is checked in the beginning of each program cycle.

Measured input values

Function block uses analog voltage and current measurement fundamental frequency RMS values.

Table 4.70 Analogic magnitudes used by the Voltage angle memory function.

Signal	Description	Time base
IL1RMS	Fundamental RMS measurement of phase L1/A current	5 ms
IL2RMS	Fundamental RMS measurement of phase L2/B current	5 ms
IL3RMS	Fundamental RMS measurement of phase L3/C current	5 ms
U_1RMS	Fundamental RMS measurement of voltage U_1/V	5 ms
U_2RMS	Fundamental RMS measurement of voltage U_2/V	5 ms
U_3RMS	Fundamental RMS measurement of voltage U_3/V	5 ms
U_4RMS	Fundamental RMS measurement of voltage U_4/V	5 ms

Voltage measurement mode 3LN and 3LL use three voltage inputs channels U_A, U_B and U_C. When voltage mode is set to 2LL only two channels U_A and U_B are being used. In this mode voltage memory is based on line-to-line voltages U12 and U23. In case 2LL+U0 mode is used, voltage memory is based on calculated phase-to-neutral voltages.

Pick-up characteristics

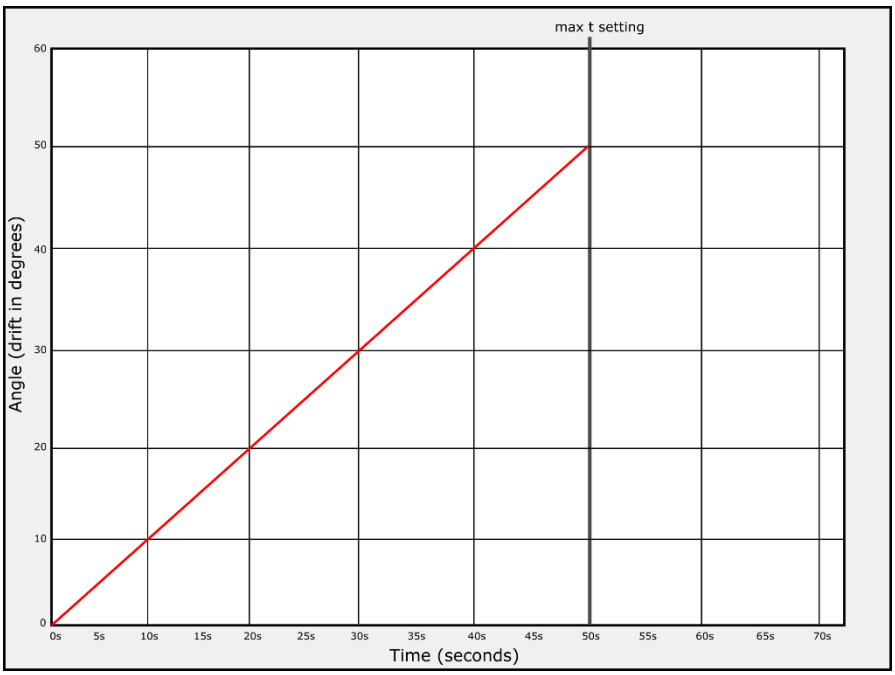
VMEM activation voltage and measured current condition 3I>

When voltage memory is enabled, it activated when all line voltages drop below “VMEM activation voltage” threshold limit. This limit is settable between 2...50VAC. In case “Measured current condition 3I>” is used, activation based on mere voltage is not enough. Then, also at least one of three phase currents need to raise above the set current pick-up setting. Voltage memory can be active for period of set “VMAX active time”

VMEM max active time

VMEM function supports definite time (DT) delay type. How long voltage memory should be used depends of the application. Normally during massive bolted faults, the fault should be cleared, and breaker opened as soon as it is possible. Therefore, normally a short operating time for voltage memory is applied. Typical delay for voltage memory is 0.5 to 1.0 seconds. When operating time passes and voltage memory is no longer used, directional overcurrent/distance protection goes to unidirectional mode to secure safe tripping. Longer operating times for VMEM are used in case backup protection is applied, for example in distance protection a zone(s) further away. VMEM max active time is settable between 0.02...50.00 seconds.

Figure 4.54 Voltage angle drift is approximately 1 degree in a second while voltage memory is in use.



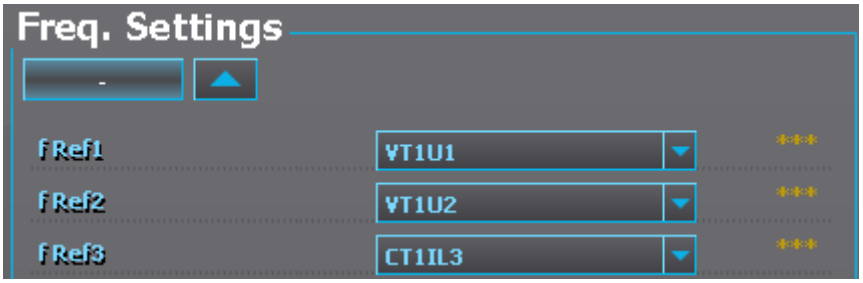
While voltage memory is active the voltages are absent and therefore angle measurement is not possible. Healthy state angles (before fault) are being used during fault. Due to this, a drift between assumed voltage angle and actual measured phase current angle is taking place. While voltage memory is used the angle of phase currents drifts for approximately 1 degree per each passing second.

Forced CT f tracking on VMEM

While fixed frequency tracking is used, all protection stage-based sampling (Except frequency protection) is based on set fixed frequency like 50/60Hz. In case frequency drops massively during fault and angle memory is used, it is also possible that frequency of the system starts to fluctuate. In such cases, if current sampling of used protection stages is based on 50/60Hz, there could be an error in current magnitude and angle measurement. To minimize errors, it is preferable that while voltages are gone, it is better to measure frequency, and to also perform protection-based sampling from the current.

In case “Forced CT f tracking” is on, while voltages are gone, the frequency from selected current based reference channel 3 (current from IL3) is used for current sampling. This eliminates possible measurement error in fixed frequency mode.

Figure 4.55 Frequency reference channels.



An example, 500A of current measured on primary side, while fixed frequency is set to 50Hz: In case the frequency would drop to 46Hz, the actual current measurement would be 460A. An error of 40A would be measured in the system.

Events

The VMEM function generates events from the status changes of various activities. To main event buffer is possible to select status “On” or “Off” messages.

Table 4.71 Event codes of the VMEM function.

Event Number	Event channel	Event block name	Event Code	Description
12160	190	M1VT1	0	Voltage memory enabled
12161	190	M1VT1	1	Voltage memory disabled
12162	190	M1VT1	2	Voltage low detected On
12163	190	M1VT1	3	Voltage low detected Off
12164	190	M1VT1	4	Current high detected On
12165	190	M1VT1	5	Current high detected Off
12166	190	M1VT1	6	Frequency tracked from CT On
12167	190	M1VT1	7	Frequency tracked from CT Off
12168	190	M1VT1	8	Using Voltage memory On
12169	190	M1VT1	9	Using Voltage memory Off
12170	190	M1VT1	10	Voltage memory blocked On
12171	190	M1VT1	11	Voltage memory blocked Off

5. Communication

5.1 Connections

5.1.1 General IO analog fault registers

At *Communication → General IO → Analog fault register* it is possible to set up to 12 channels to record the measured value at the time of protection function start or trip. These values can be read through possibly used communication protocol or locally from this same menu.

5.1.2 Real time measurements to communication

Realtime signals to communication enables reporting measurements to SCADA that are not normally available in the communication protocols mapping. Real time meas to comm reports the selected eight magnitudes. Recorded value can be either per unit value or primary value which is user settable.

Outputs of the function are selected measured values. Setting parameters are static inputs for the function which are changed only by user input in the setup phase of the function.

Measurable values

Function block uses analog current and voltage measurement values. From these values relay calculates the secondary and primary values of currents, voltages, powers, impedances and other values.

Up to 8 magnitudes can be set to be reported.

Table 5.1 Available measured values to be reported in realtime signals to comm function.

Currents	
Signals	Description
IL1ff, IL2ff, IL3ff, I01ff, I02ff	Fundamental frequency current measurement values of phase currents and residual currents
IL1TRMS, IL2TRMS, IL3TRMS, I01TRMS, I02TRMS	TRMS current measurement values of phase currents and residual currents
IL1,2,3 & I01/I02 2^{nd} h., 3^{rd} h., 4^{th} h., 5^{th} h., 7^{th} h., 9^{th} h., 11^{th} h., 13^{th} h., 15^{th} h., 17^{th} h., 19^{th} h.	Magnitudes of phase current components: Fundamental, 2^{nd} harmonic, 3^{rd} harmonic, 4^{th} harmonic, 5^{th} harmonic 7^{th}, harmonic 9^{th}, harmonic 11^{th}, harmonic 13^{th}, harmonic 15^{th}, harmonic 17^{th}, harmonic 19^{th} harmonic current.
I1,I2,I0Z	Positive sequence current, negative sequence current and zero sequence current
I0CalcMag	Residual current calculated from phase currents
IL1Ang, IL2Ang, IL3Ang, I01Ang, I02Ang, I0CalcAng I1Ang, I2Ang	Angles of each measured current
Voltages	
UL1Mag, UL2Mag, UL3Mag, UL12Mag, UL23Mag, UL31Mag, U0Mag, U0CalcMag	Magnitudes of phase voltages, phase-to-phase voltages and residual voltages.
U1 Pos.seq V mag, U2 Neg.seq V mag	Positive and negative sequence voltages.
UL1Ang, UL2Ang, UL3Ang, UL12Ang, UL23Ang, UL31Ang, U0Ang, U0CalcAng	Angles of phase voltages, phase-to-phase voltages and residual voltages.

Currents	
U1 Pos.seq V Ang, U2 Neg.seq V Ang	Positive and negative sequence angles.
Powers	
S3PH P3PH Q3PH	Three phase apparent, active and reactive power
SL1,SL2,SL3, PL1,PL2,PL3, QL1,QL2,QL3	Phase apparent, active and reactive powers
tanfi3PH tanfiL1 tanfiL2 tanfiL3	Tan (φ) of three phase powers and phase powers
cosfi3PH cosfiL1 cosfiL2 cosfiL3	Cos (φ) of three phase powers and phase powers
Impedances and admittances	
RL12, RL23, RL31 XL12, XL23, XL31 RL1, RL2, RL3 XL1, XL2, XL3 Z12, Z23, Z31 ZL1, ZL2, ZL3	Phase-to-phase/Phase-to-neutral resistances, reactances and impedances
Z12Ang, Z23Ang, Z31Ang, ZL1Ang, ZL2Ang, ZL3Ang	Phase-to-phase/Phase-to-neutral impedance angles
Rseq, Xseq, Zseq RseqAng, XseqAng, ZseqAng	Positive sequence resistance, reactance and impedance values and angles
GL1, GL2, GL3, G0 BL1, BL2, BL3, B0 YL1, YL2, YL3, Y0	Conductances, susceptances and admittances
YL1angle, YL2angle, YL3angle, Y0angle	Admittance angles
Others	
System f.	Used tracking frequency at the moment
Ref f1	Reference frequency 1
Ref f2	Reference frequency 1
M thermal T	Motor thermal temperature
F thermal T	Feeder thermal temperature
T thermal T	Transformer thermal temperature
RTD meas 1...16	RTD measurement channels 1...16
Ext RTD meas 1...8	External RTD measurement channels 1...8 (ADAM module)

Parameters

Table 5.2 Parameters of Realtime signals to comm

Name	Range	Step	Description
Measurement value recorder mode	0:Disabled	-	Activation of the function

Name	Range	Step	Description
	1:Activated		
Scale current values to primary	0:No 1:Yes	-	Selection between using secondary values or primary values
Slot 1...8 Magnitude selection	0:Currents; 1:Voltages; 2:Powers; 3:Imp.(ZRX).Adm.(YGB); 4:Others;	-	Selection of slots measured magnitude category
Slot 1...8 Magnitude (x)	Described in table above	-	Selection of the magnitude in the previously selected category

5.2 Protocols

5.2.1 NTP

NTP is short for Network Time Protocol. When NTP service is enabled in the device it can use an external time sources for synchronization of the device system time. NTP client service uses Ethernet connection to connect to NTP time server. NTP is enabled by setting the Primary time server (and Secondary time server) parameters to the address of the system NTP time source(s).

Table 5.3 NTP connection parameters

Parameter	Range	Description
Primary time server address	[0.0.0.0 ... 255.255.255.255]	Primary NTP server address. 0.0.0.0 = service not in use.
Secondary time server address	[0.0.0.0 ... 255.255.255.255]	Secondary/backup NTP server address. 0.0.0.0 = service not in use.
IP address	[0.0.0.0 ... 255.255.255.255]	The NTP Client IP address. **NOTE**: NTP Client IP has to be different than relay IP address.
Netmask	[0.0.0.0 ... 255.255.255.255]	NTP Client Netmask
Gateway	[0.0.0.0 ... 255.255.255.255]	NTP Client Gateway
NetworkStatus	Messages: Running IP error NM error GW error	Displays the status or possible errors of NTP settings. These are errors in the parameters mentioned above.
NTP quality for events	No sync Synchronized	Shows the status of the NTP time synchronization at the moment. If other time synchronization method is used (external serial), this indication isn't valid.

NOTE: a unique IP address needs to be reserved for NTP Client. Relay IP address cannot be used.

To set the time zone of the relay connect to relay and then *Commands → Set time zone*.

5.2.2 ModbusTCP and ModbusRTU

The device supports both Modbus TCP and Modbus RTU communication. Modbus TCP uses the Ethernet connection for communicating with Modbus TCP clients. Modbus RTU is a serial protocol which can be selected for the available serial ports.

Following Modbus function types are supported:

- Read Holding Register, 3
- Write Single Register, 6
- Write Multiple Registers, 16
- Read/Write Multiple Registers, 23

Following data can be accessed using both Modbus TCP and Modbus RTU

- Device measurements
- Device I/O
- Commands
- Events
- Time

Modbus map of the relay is found in the MVR utility software in *Tools* → *Modbus* map once the configuration file has been loaded. Please notice that holding registers start from 1. Some masters might start holding register numbering from 0 instead of 1 which will cause an offset of 1 between the relay and master.

Table 5.4 Modbus TCP parameters

Parameter	Range	Description
ModbusTCP enable	[Disabled, Enabled]	Enable setting for Modbus TCP on Ethernet port.
IP port	[0...65535]	IP port used by Modbus TCP. Standard and default port is 502.

Table 5.5 Modbus RTU parameters

Parameter	Range	Description
Slave address	[1...247]	Modbus RTU slave address for the unit.

Additionally, update interval of measurement updating is adjusted with the following parameters.

Table 5.6 Modbus measurement update interval setting parameters

Parameter	Range	Step	Description
Current meas update interval	500...10000ms	5ms	Measurement update interval of all current related measurements.
Voltage meas update interval	500...10000ms	5ms	Measurement update interval of all voltage related measurements.
Power meas update interval	500...10000ms	5ms	Measurement update interval of all power related measurements.
Impedance meas update interval	500...10000ms	5ms	Measurement update interval of all impedance related measurements.

These parameters can be found in menu *Measurement* → *Measurement* update. These parameters do not affect to the operation time of protection functions. These parameters only affect to the frequency of measurement reporting to Modbus.

5.2.3 ModbusIO

ModbusIO can be selected for communication on available serial ports. ModbusIO is actually a ModbusRTU master implementation dedicated for communication with serial ModbusRTU slaves such as RTD inputs modules. Up to 3 ModbusRTU slaves can be connected to the same bus polled by the ModbusIO implementation. These are named IO Module A ... IO Module C. Each of the modules can be configured using parameters in the following table.

Parameter	Range	Description
IO Module[A,B,C] address	[0...247]	Modbus unit address for the IO Module. 0 = not in use.
Module[A,B,C] type	[ADAM-4018+]	Type selection for module
Channels in use	[Ch0...Ch7]	Channel selection for the module.

For each of the 8 channels of the IO module connected thermocouple can be selected.

T.C. type	[+-20mA,Type J, Type K, Type T, Type E, Type R, Type S]	Thermocouple type setting.

5.2.4 IEC 61850

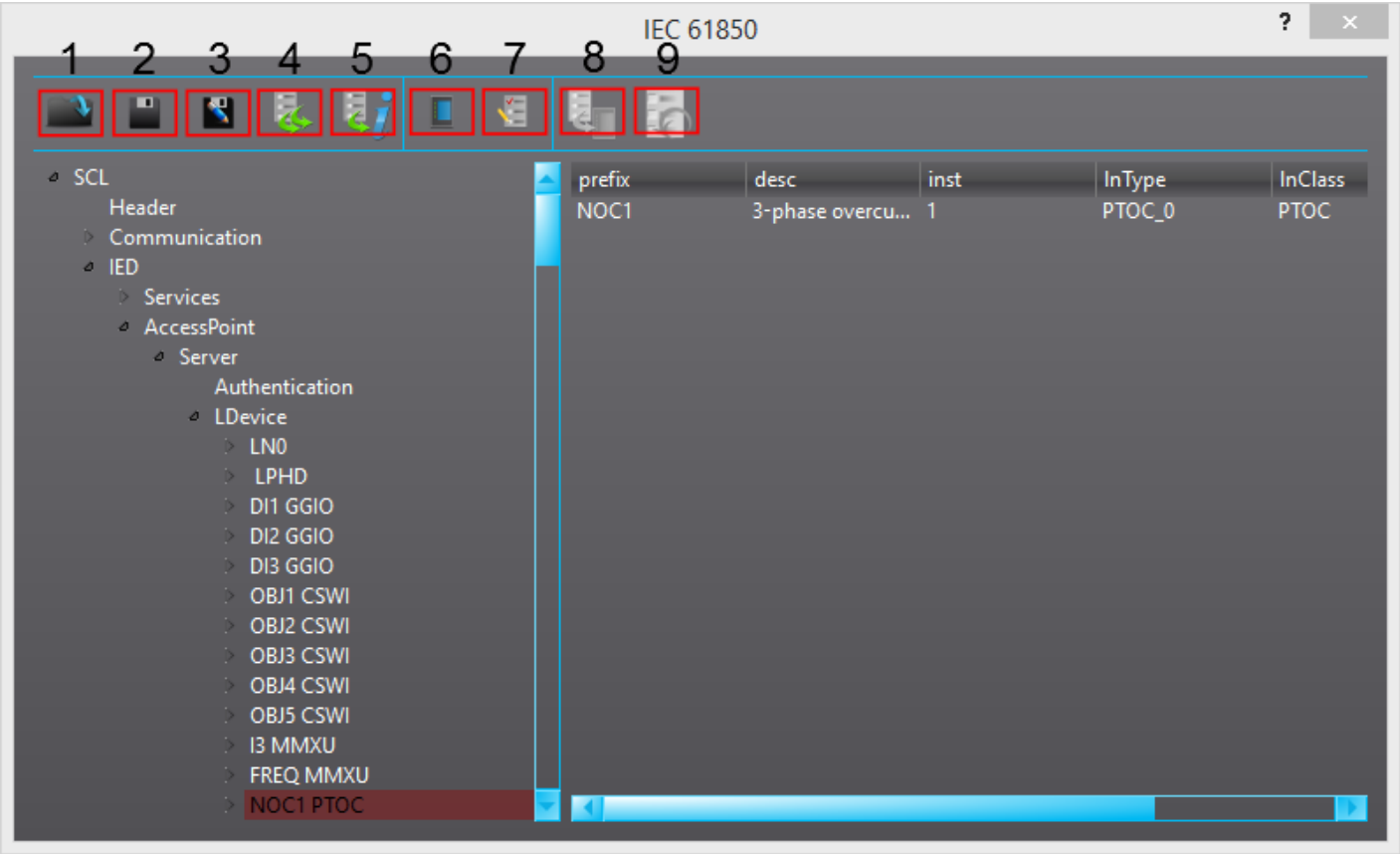
IEC 61850 is included in function packages B, C, D & E

Device models with IEC 61850 support, can have the IEC 61850 protocol enabled by the user. IEC61850 edition1 is used by MVR-200 series IEDs. IEC 61850 in the MVRs support the following services:

- Dataset, pre-defined datasets can be edited with IEC 61850 editor tool in the MVR utility software.
- Report control block, both buffered and un-buffered reporting is supported.
- Control, 'direct-with-normal-security' control sequences are supported.
- Disturbance recording file transfer
- GOOSE
- Time synchronization

Currently used 61850 setup of the device can be viewed in the IEC61850 tool (*Tools → IEC61850*). For a list of available Logical Nodes in the implementation browse the 61850 tree. See following picture:

Figure 5.1 IEC 61850 tool buttons.

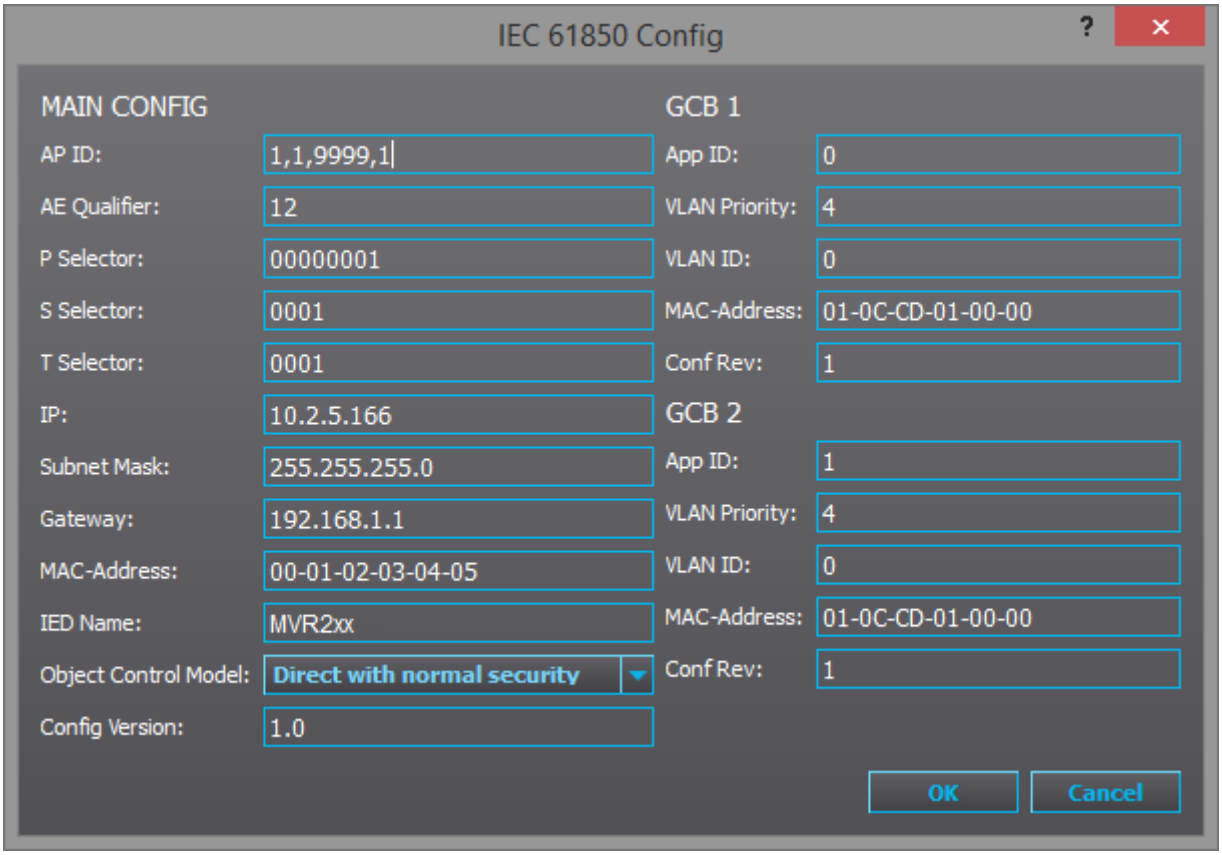


The available functions in the IEC 61850 tool are:

1. Open an existing CID-file from the PC hard drive
2. Save the CID file into the aqs currently open (save the aqs file as well [*File* → *Save*] to keep the changes)
3. Save the CID file into the hard drive for later use.
4. Exports current CID file without private tags
5. Exports dataset info into a txt file that can be viewed in table format in tools like Excel
6. Opens main configurations window
7. Opens data set editing window
8. Send the CID configuration to the relay (requires a connection to the relay)
9. Retrieves the default CID file from the relay.

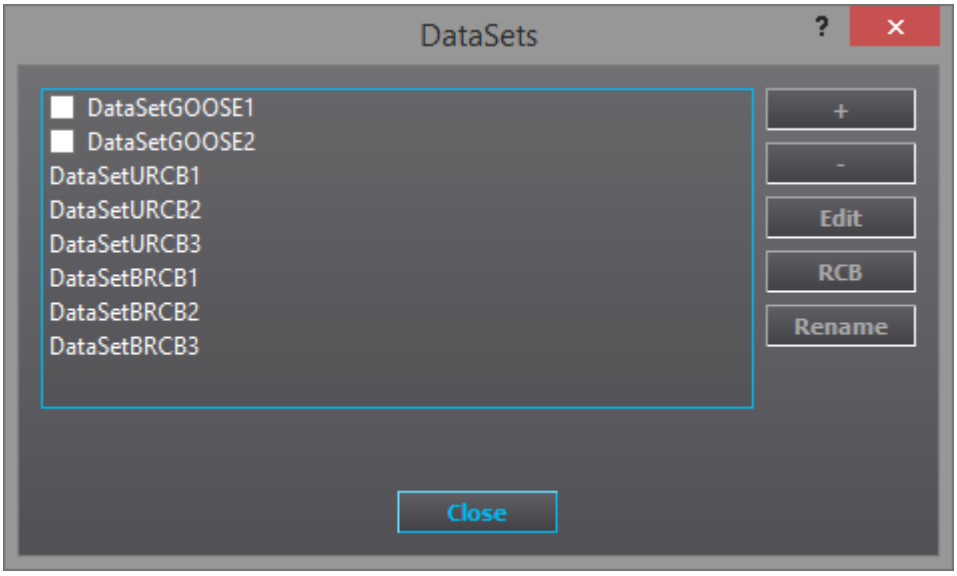
The main configurations dialog is opened by pressing 6th button. Important parameters are here the IED Name and the IP settings. Also if GOOSE publisher service is to be used, the parameters for GCB1 and GCB2 should be set. See following picture:

Figure 5.2 Main configuration window for basic settings and goose publishing.



The pre-defined, editable, datasets can be opened by pressing the 7th button. It is possible to add and remove datasets with +/- buttons. When a dataset has been added it has to be assigned to an RCB with RCB-button (opens a new window). It is possible to assign to Un-buffered URCB's or Buffered reporting BRCB's. All of these datasets can be edited. By un-checking both of the GOOSE publisher datasets GOOSE publisher service will be disabled. See following picture.

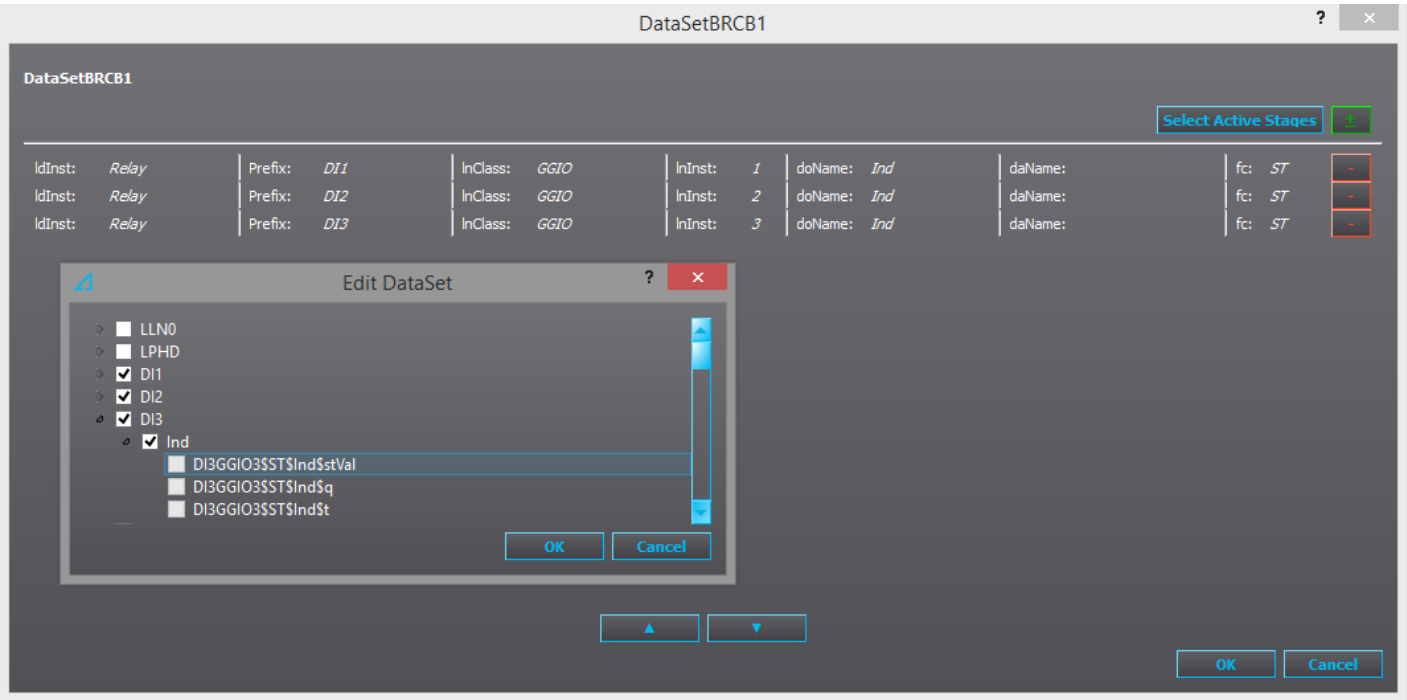
Figure 5.3 DataSets window for adding/removing and editing datasets.



By marking a dataset and pressing the Edit button the dataset edit dialog is opened. See following picture. In the edit dialog all currently configured entries of the dataset are visible. If the red '-'-button is pressed in the end of an entry row the entry will be removed from the dataset. If the green '±'-button is pressed a new dialog is opened were it is possible to edit contents of the dataset. New entries can be added and old edited. It is recommended that for URCB and BRCB datasets

that data is selected on the doName, data object level, (see example below). In this way all available information like; status, quality and time is always sent in the report. Data can also be selected on daName, data attribute level, selecting each individual data. This approach may be preferred for the GOOSE datasets.

Figure 5.4 Data can be also chosen in data attribute level.



For more information on IEC 61850 support, see the conformance statement documents.

IEC61850 general parameters visible in the MVR utility software and local HMI are described in the table below.

Parameter	Range	Description
IEC61850 enable	[Disabled, Enabled]	Enable setting for IEC 61850 protocol.
IP port	[0...65535]	IP port used by IEC 61850 protocol. Standard and default port is 102.
Measurements dead-band	[0.01...10.00]	Measurement data reporting dead-band setting.
GOOSE subscriber enable	[Disabled, Enabled]	Enable setting for GOOSE subscriber.

5.2.5 GOOSE

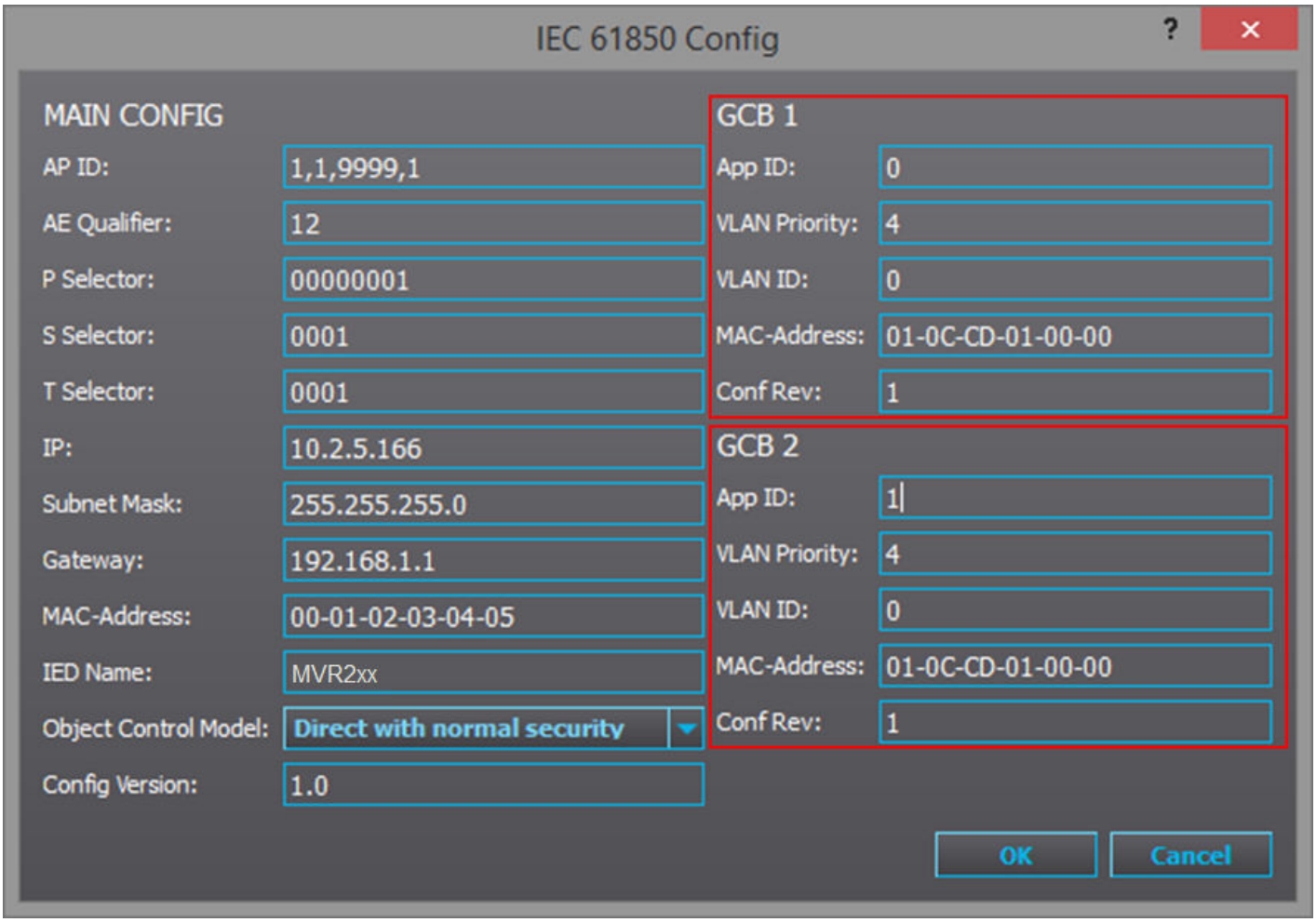
Both GOOSE publisher and subscriber are supported by the implementation. GOOSE subscriber is enabled by parameter setting (*Communication → Protocols → IEC61850 → GOOSE subscriber enable*) and GOOSE inputs are configured using HMI or the MVR utility software. For each of the Goose inputs there is also an input quality signal which can also be used in the internal logic. If the input quality is low, (=0), then the quality is good. Input quality can be bad for reasons like GOOSE timeout and configuration error. Logical input signal states and quality can be viewed in the device under Device IO menu. For each GOOSE input following parameters are available.

Parameter	Range	Description
In use	[No, Yes]	Setting to take input in to use.
AppId	[0...4294967295]	Application ID which will be matched with the publishers GOOSE control block.
ConfRev	[0...4294967295]	Configuration revision which will be matched with the publishers GOOSE control block.
DataIdx	[0...99]	Data index of the value in the matched published frame which will be the state of this input.
NextIdx is quality	[No, Yes]	If the “next” received input is the quality bit of this GOOSE Input choose yes.

Goose publisher configuration is done using the IEC61850 editor started from the MVR utility software tools menu. For GOOSE publishing service to start the GCB’s and GOOSE datasets must be setup. GOOSE Control Blocks are visible by pressing 6th button in the IEC61850 tool. See picture below. On the right side in the dialog the GCB’s are setup. The important parameters are App ID which should be unique for the system. Also confRev parameter is checked by the receiving part. If VLAN switches are used to build sub-networks the VLAN Priority and VLAN ID parameters must be set to match with the system specification.

Figure 5.5 Settings for both available GOOSE Publishing datasets.





GOOSE datasets defines the data which will be sent by the GOOSE publisher. Only binary data and quality information for the binary signals can be sent by the GOOSE publisher. The binary signals will be mapped to GOOSE input signals on the receiving side together with the quality information for that binary signal. The quality information in the incoming frame will be ORed with GOOSE reception timeout supervision information so that quality information for each GOOSE input can be used in relay logic.

5.2.6 IEC 103

IEC 103 is short for international standard IEC 60870-5-103. A secondary station (slave) is implemented. The IEC 103 protocol can be selected for the available serial ports of the device. A master or primary station can communicate with the DEIF device and receive information by polling from the slave device. Disturbance recordings transfer is not supported.

NOTE: IEC103 map of the relay is found in the MVR utility software in *Tools → IEC103* map once the configuration file has been loaded.

IEC 103 parameters can be found in the following table.

Parameter	**Range**	**Description**
Slave address	[1...254]	IEC 103 slave address for the unit.
Measurement interval	[0...60000]ms	Interval setting for the measurements update.

5.2.7 DNP3

DNP3 is a protocol standard which is controlled by the DNP Users Group at www.dnp.org. The implementation of a DNP3 slave is compliant with DNP3 Subset Definition Level 2, but contains also functionality of higher levels. For detailed information see the DNP3 Device Profile document.

DNP3 parameters can be found in following table.

Parameter	Range	Description
Slave address	[1...65519]	DNP3 slave address for the unit.
Master address	[1...65519]	DNP3 address setting for allowed master.
Link layer timeout	[0...60000]ms	Timeout of link layer
Link layer retries	[1...20]	Number of link layer retries
Application layer timeout	[0...60000]ms	Application layer timeout
Application layer confirmation	[0=No,1=Yes]	Application layer confirmation enable.
Time sync request interval	[0...60000]ms	Request interval for synchronization.

5.2.8 IEC 101/104

Standards IEC 60870-5-101 & IEC 60870-5-104 are closely related. Both are derived from IEC 60870-5 standard. On the physical layer IEC 101 uses serial communication but IEC 104 uses Ethernet communication.

The IEC 101/104 implementation works as a slave in unbalanced mode.

For more detailed information see the IEC101 Profile Checklist document.

IEC101/104 parameters can be found in following table.

Parameter	Range	Description
Link layer address	[1...65535]	Link layer address
Link layer address size	[1...2]	Link layer address size

Parameter	Range	Description
ASDU address	[1...65535]	ASDU address
ASDU address size	[1...2]	ASDU address size
IO address size	[1...2]	IO address size
IEC104 server enable	[0=No,1=Yes]	IEC104 enable
IEC104 client IP		Client IP address

5.2.9 SPA protocol

IED can act as a SPA-slave. SPA can be selected as the communication protocol into COM B port (in CPU module). If serial RS232 & serial fiber module is available in the device SPA protocol can be activated for these channels (COM E or F). See the chapter for construction and installation to see the connections for these modules.

SPAs data transfer rate is 9600bps but it can be also set to 19200bps or 38400bps. As a slave the relay will send data on demand or by sequenced polling. Available data can be measurements, circuit breaker states, function starts/trips etc. Full SPA signal map can be found in the MVR utility software from *Tools → SPA map*. Please note that aqs file should be downloaded from relay first.

The SPA EVENT addresses can be found in *Tools → Events and logs → Event list*. This also requires to open an aqs configuration file of the relay first.

NOTE: SPA map of the relay is found in the MVR utility software in *Tools → SPA map* once the configuration file has been loaded.

6. Hardware

6.1 Overview

This chapter contains detailed hardware performance information. See the **Data sheet** for the hardware technical data.

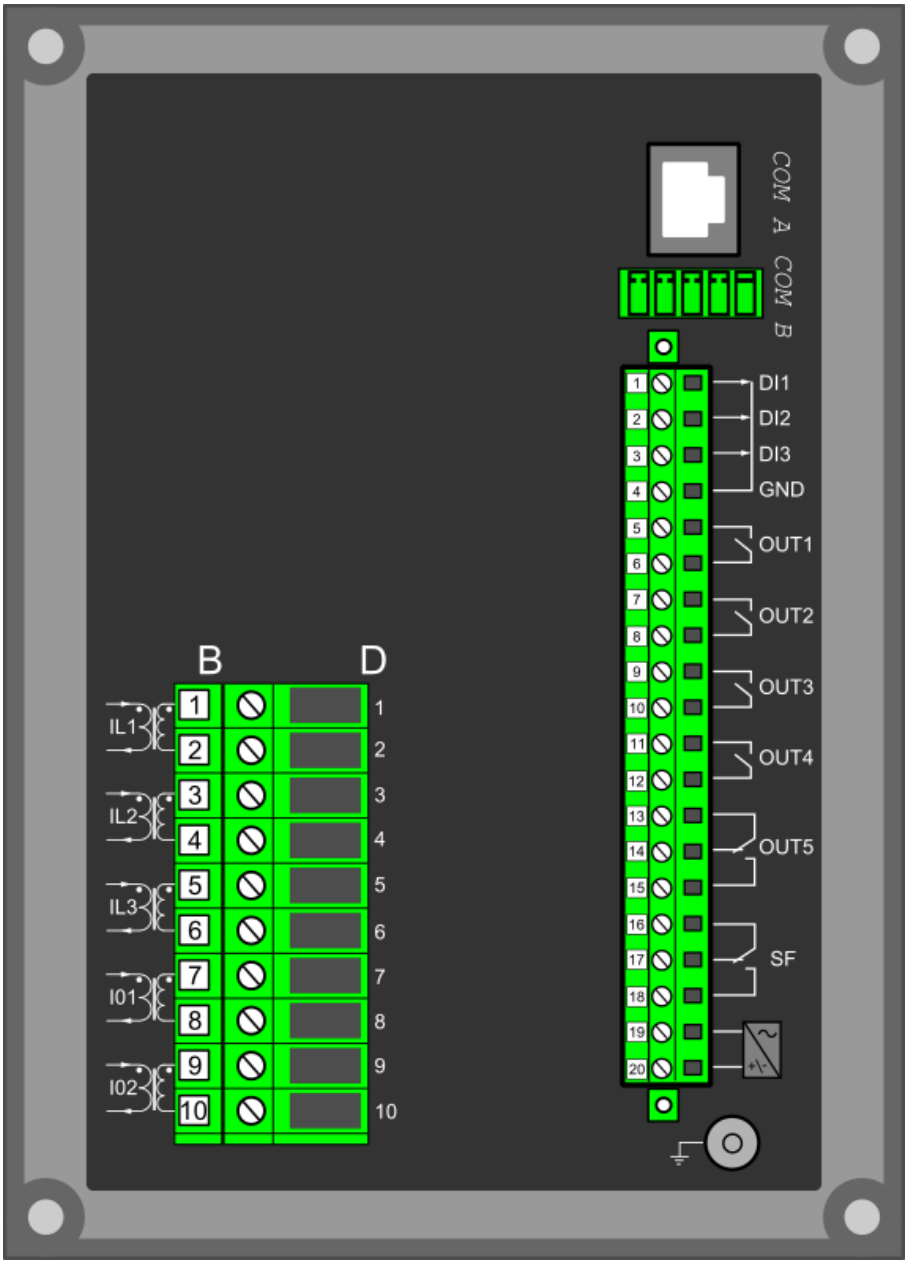
6.2 Application options

6.2.1 MVR-F201

Construction and Installation

Even though MVR-F201 is a member of modular and scalable MVR-2xx series it does not have optional modules and the construction and content of the relay's hardware is fixed. The relay includes CPU, IO, Power supply module and one five channel current measurement module.

Figure 6.1 Connections and modules in MVR-F201 protection relay.

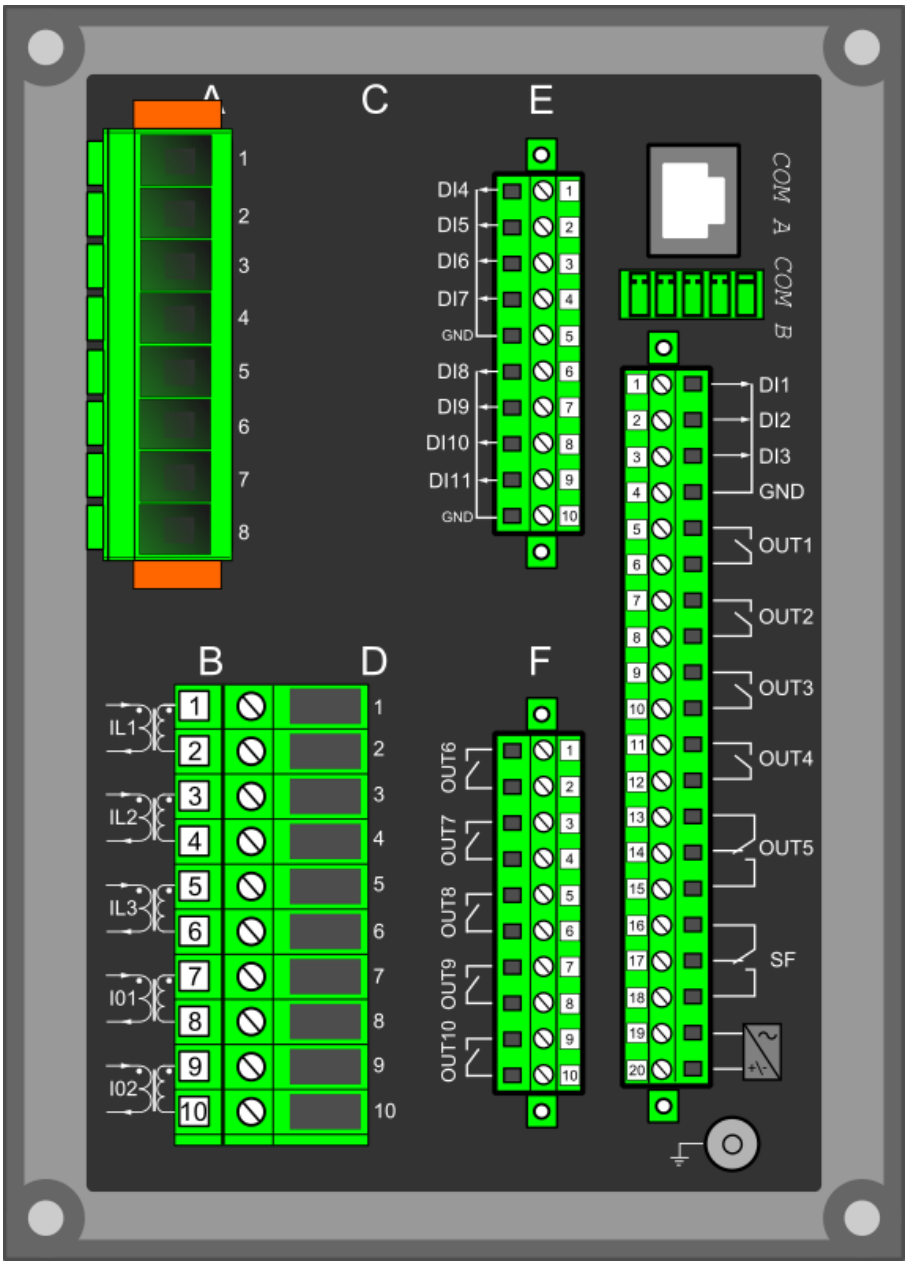


6.2.2 MVR-F205

Construction and installation

Even though MVR-F205 is a member of modular and scalable MVR-2xx series it does not have optional modules and the construction and content of the relays hardware are fixed. The relay includes CPU, IO, Power supply module, one five channel current measurement module, one four channel voltage measurement module, one 8DI module and one 5DO module.

Figure 6.2 Modular construction of MVR-F205 Feeder Protection IED



6.2.3 MVR-F210 and MVR-M210

Construction and installation

MVR-X210 IED is a member of modular and scalable MVR-2xx series and includes four configurable modular add-on card slots. As a standard configuration the IED includes CPU, IO and Power supply module. Non-optioned model (MVR-X210-XXXXXXX-*AAAA*) and fully optioned model (MVR-X210-XXXXXXX-*BBBC*) of the MVR-X210 IED is presented in the figure below.

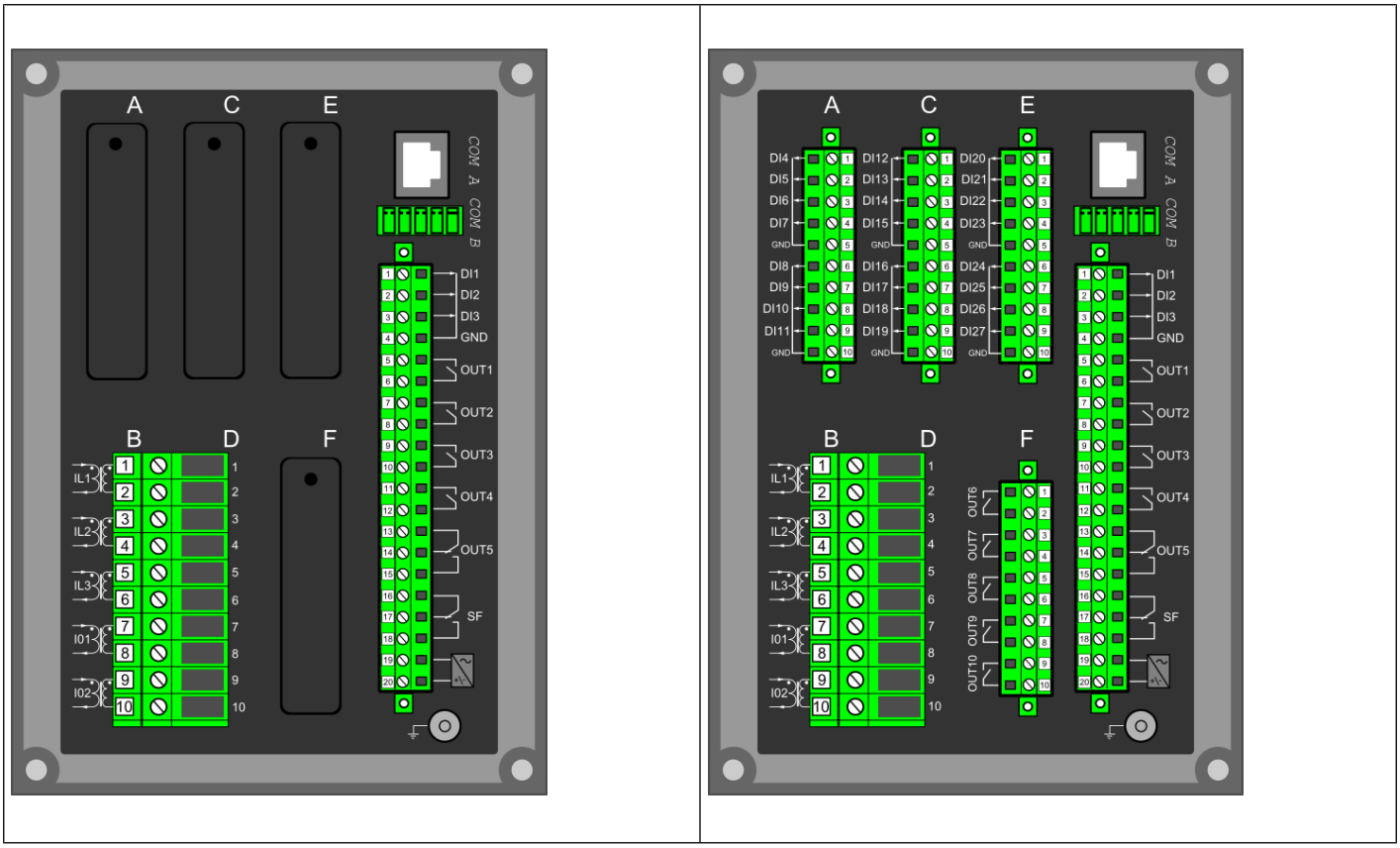


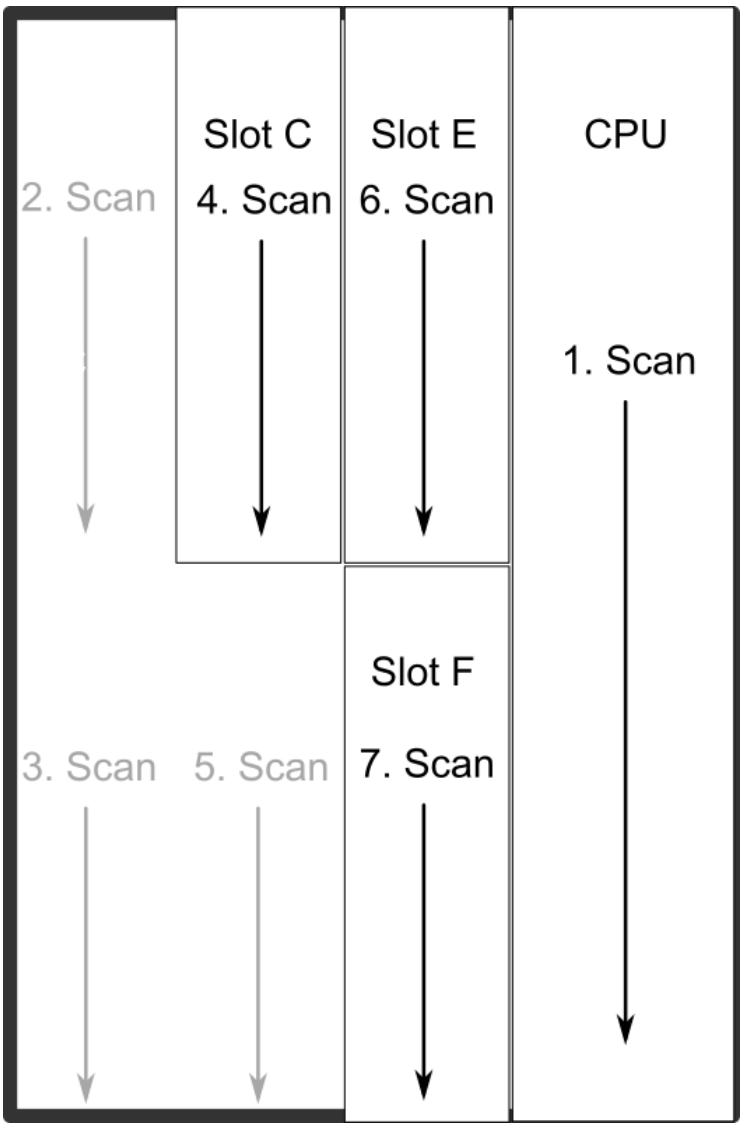
Figure 6.3 Modular construction of MVR-X210 IED

MVR-X210 modular structure allows scalable solutions for different application requirements. Into any of the non-standard configured slot A, C, E and F any available add-on module can be ordered which can be binary IO module, integrated Arc – protection or any special module provided. Only differentiating factor in the device scalability is considering slot E which supports also communication options.

In case add-on module is inserted to the IED the start-up scan will search of the modules according to the type designation code, if the module location or content is differing from the expected the IED will not take additional modules into account and will issue a configuration error. For a field upgrade this means that the add-on module has to be ordered with the corresponding unlocking code in order the device to be operating correctly after upgrading the hardware configuration. This means also that the module location cannot be changed without updating the device configuration data, for this case also unlocking code is needed.

When IO module is inserted to the IED the module location shall affect to the naming of the IO. The scanning order in the start-up sequence is CPU-module IO, slot A, C, E and F. This means that the binary input channels DI1, DI2 and DI3 and the binary output channels OUT1, OUT2, OUT3, OUT4 and OUT5 are always located in the CPU-module. If more IO is installed the location of each type of card will have effect on the found IO naming. In following figure is presented the principle of the start-up hardware scan of the IED.

Figure 6.4 Hardware scanning and IO naming principle in MVR-X210 IED



1. Scan: Start-up system, detect and self-test CPU-module, voltages, comm. and IO. Find and assign DI1, DI2, DI3, OUT1, OUT2, OUT3, OUT4 and OUT5.
2. Scan: Scan Slot A, if empty go to next slot. If found 8DI module then reserve to this slot DI4, DI5, DI6, DI7, DI8, DI9, DI10 and DI11. If found DO5 module then reserve to this slot OUT6, OUT7, OUT8, OUT9 and OUT10. Amount of IO is added If the type designation code allows and if not match then issue alarm as also if module is expected to be found and is not there, alarm will be issued.
3. Scan: Scan Slot B, in case of MVR-X210 should be always empty. If not empty, then issue alarm.
4. Scan: Scan Slot C, if empty go to next slot. If found 8DI module then reserve to this slot running number regard if Slot A was empty or had other than Dix module then DI4, DI5, DI6, DI7, DI8, DI9, DI10 and DI11 or if Slot A has also DI8 module then DI12, DI13, DI14, DI15, DI16, DI17, DI18 and DI19. If found DO5 module then reserve to this slot OUT6, OUT7, OUT8, OUT9 and OUT10 or OUT11, OUT12, OUT13, OUT14 and OUT15 with similar basis than for the inputs.
5. Scan: Find CTM module 5 channels (fixed for MVR-X210).
6. Scan: Similar operation to Scan 4.
7. Scan: Similar operation to Scan 4.

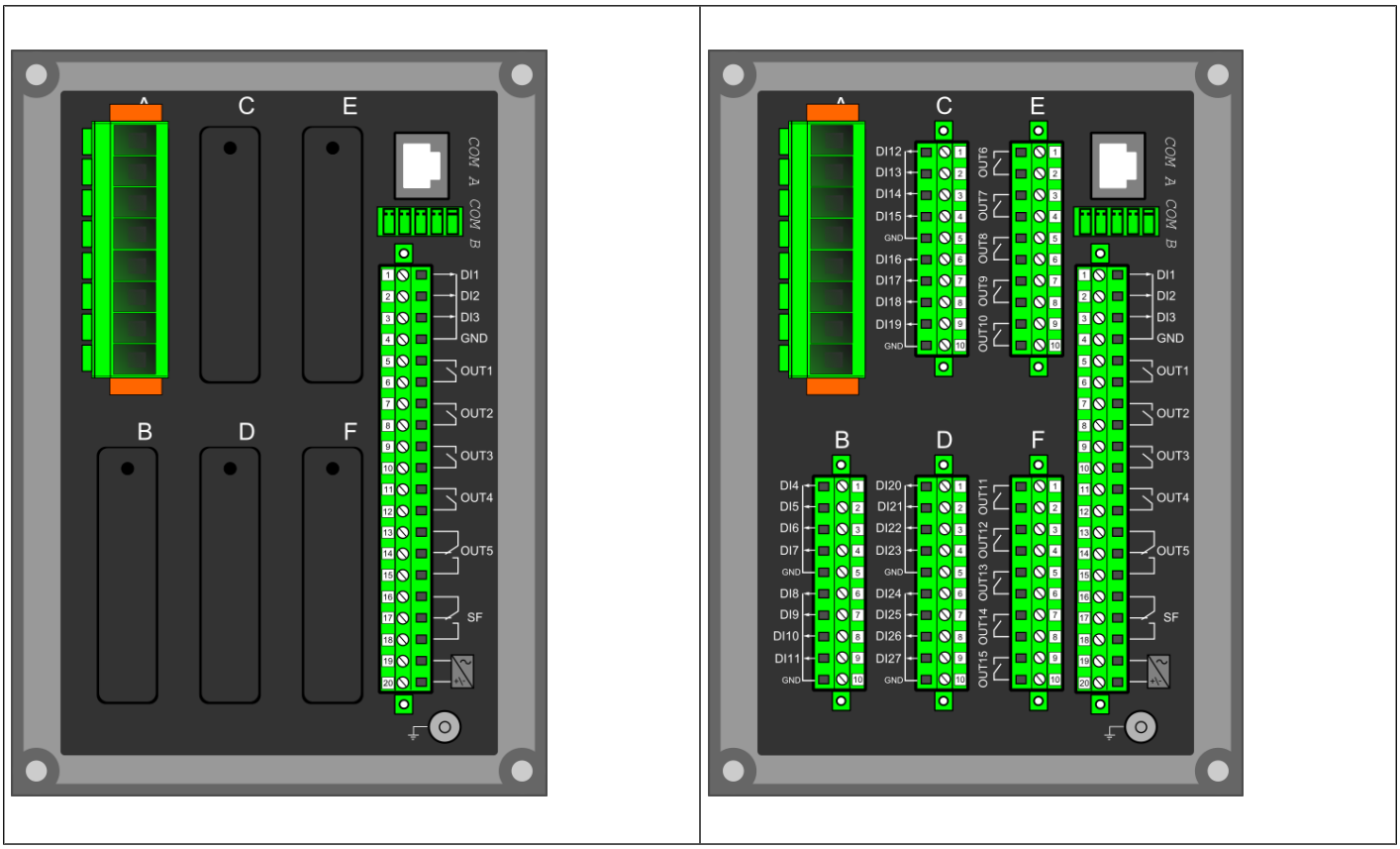
In the previous example only IO add-on cards were described if installed into the option module slots. If the slot has any other module than IO they are treated similarly. For example, in case of added communication port the upper port of the communication module shall be in minimum of Comm. port 3 etc. since in the CPU-module already exist Comm. ports 1 and 2. After communication port is detected it is added into the communication space in the IED and corresponding settings are enabled for the IED.

In the example case of MVR-X210-XX-BBBC number of available binary input channels is DI1...DI27, from which DI1-DI3 are in the CPU module, DI4-DI11 are in Slot A, DI12-DI19 are in Slot C, DI20-DI27 are in Slot E. Available binary output channels are DO1...DO10, of which DO1-DO5 are in the CPU module and DO6-DO10 are in slot F. If the configuration should differ from this example the same principle is always applied into the IED.

6.2.4 MVR-V211

Construction and installation

MVR-X211 IED is a member of modular and scalable MVR-2xx series and includes three configurable modular add-on card slots. As a standard configuration the IED includes CPU, IO and Power supply module. Non-optioned model (MVR-X211-XXXXXXX-*AAAA*) and fully optioned model (MVR-X211-XXXXXXX-*BBBCC*) of the MVR-X211 IED are presented in the picture below.

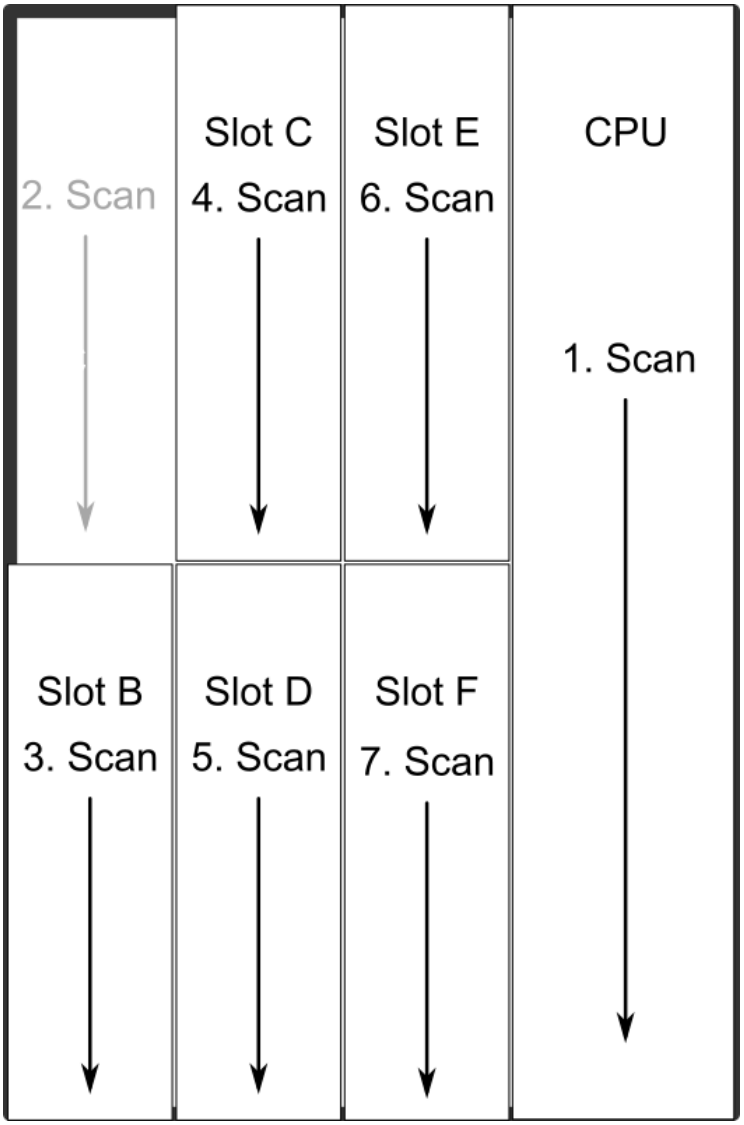


MVR-X211 modular structure allows scalable solutions for different application requirements. In any of the non-standard configured slot B, C, D, E and F can be ordered with any available add-on module which can be binary IO module or any special module provided. Only differentiating factor in the device scalability is considering the “F” slot which supports also communication options.

In case add-on module is inserted to the IED the start-up scan will search of the modules according to the type designation code, if the module location or content is differing from the expected the IED will not take additional modules into account and will issue a configuration error. For a field upgrade this means that the add-on module has to be ordered with the corresponding unlocking code in order the device to be operating correctly after upgrading the hardware configuration. This means also that the module location cannot be changed without updating the device configuration data, for this case also unlocking code is needed.

When IO module is inserted to the IED the module location shall effect to the naming of the IO. The scanning order in the start-up sequence is CPU-module IO, slot C, slot E and slot F. This means that the binary input channels DI1, DI2 and DI3 and also the binary output channels OUT1, OUT2, OUT3, OUT4 and OUT5 are always located in the CPU-module. If more IO is installed the location of each type of card will have effect on the found IO naming. In following figure is presented the principle of the start-up hardware scan of the IED.

Figure 6.5 Hardware scanning and IO naming principle in MVR-X211 IED



1. Scan: Start-up system, detect and self-test CPU-module, voltages, comm. and IO. Find and assign DI1, DI2, DI3, OUT1, OUT2, OUT3, OUT4 and OUT5.
2. Scan: Find VTM module 4 channels (fixed for MVR-X211).
3. Scan: Scan Slot B, if empty go to next slot. If found 8DI module then reserve to this slot DI4,DI5,DI6,DI7,DI8, ,DI9,DI10 and DI11. If found DO5 module then reserve to this slot OUT6, OUT7, OUT8, OUT9 and OUT10. Amount of IO is added If the type designation code allows and if not match then issue alarm as also if module is expected to be found and is not there alarm will be issued.
4. Scan: Scan Slot C, if empty go to next slot. If found 8DI module then reserve to this slot running number regard if Slot B was empty or had other than Dix module then DI4, DI5, DI6, DI7, DI8, DI9, DI10 and DI11 or if Slot B has also DI8 module then DI12, DI13, DI14, DI15, DI16, DI17, DI18 and DI19. If found DO5 module then reserve to this slot OUT6, OUT7, OUT8, OUT9 and OUT10 or OUT11, OUT12, OUT13, OUT14 and OUT15 with similar basis than for the inputs
5. Scan: Similar operation to Scan 4.
6. Scan: Similar operation to Scan 4.
7. Scan: Similar operation to Scan 4.

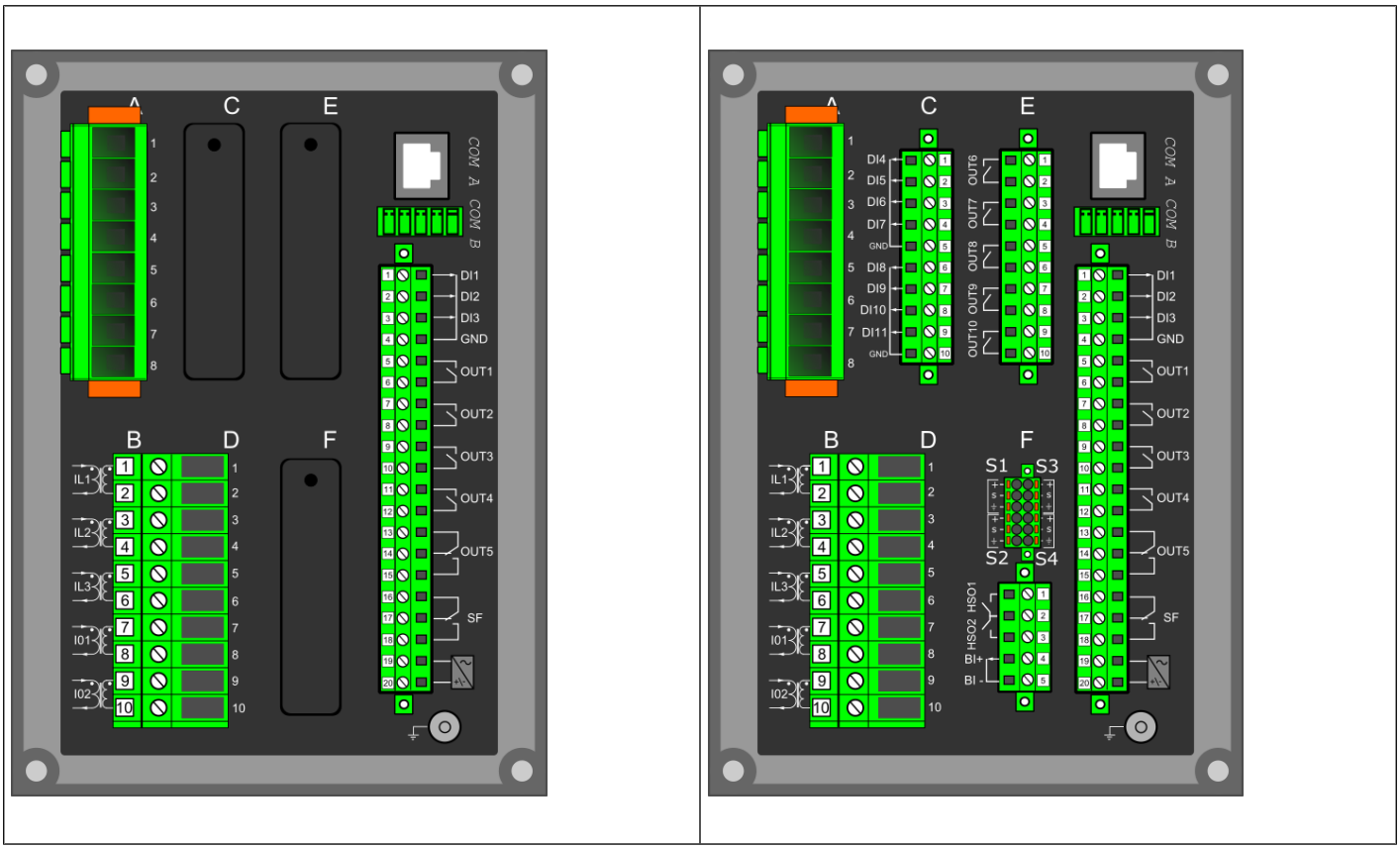
In the previous example only IO add-on cards were described if installed into the option module slots. If the slot has other type of module than IO they are treated similarly. For example, in case of added communication port the upper port of the communication module shall be in minimum of Comm. port 3 etc. since in the CPU-module already exist Comm. ports 1 and 2. After communication port is detected it is added into the communication space in the IED and corresponding settings are enabled for the IED.

In the example case of MVR-X211-XXXXXXX-*BBBCC* number of available binary input channels is DI1...DI27, of which DI1-DI3 are in the CPU module, DI4-DI11 are in Slot B, DI12-DI19 are in Slot C and DI20-DI27 are in Slot D. Available binary output channels are DO1...D15, of which DO1-5 are in the CPU module, DO6-10 are in Slot E and DO11-15 are in slot F. If the configuration should differ from this example the same principle is always applied into the IED.

6.2.5 MVR-F215, MVR-M215, MVR-G215, MVR-T215

Construction and installation

MVR-X215 IED is a member of modular and scalable MVR-2xx series and includes three configurable modular add-on card slots. As a standard configuration the IED includes CPU, IO and Power supply module. Non-optioned model (MVR-X215-XXXXXXX-*AAA*) and fully optioned model (MVR-X215-XXXXXXX-*BCD*) of the MVR-X215 IED are presented in the image below.

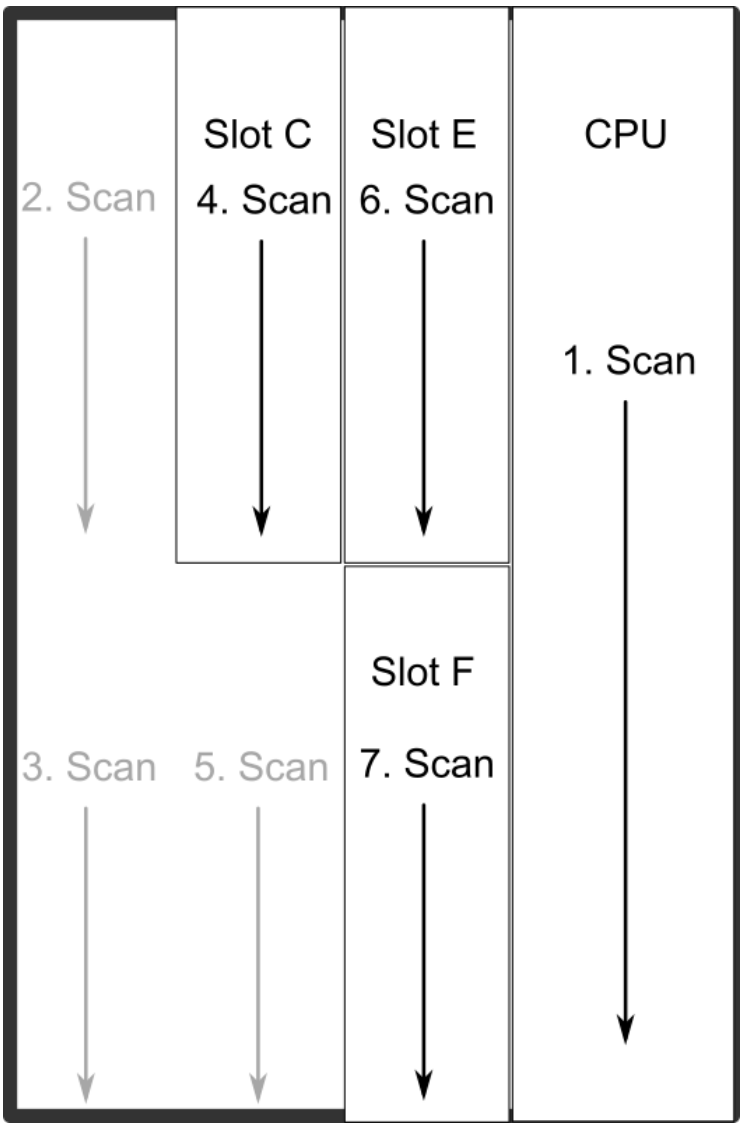


MVR-X215 modular structure allows scalable solutions for different application requirements. In any of the non-standard configured slot C, E and F any available add-on module which can be binary IO module, integrated Arc –protection or any special module provided can be ordered. Only differentiating factor in the device scalability is considering the F slot which supports also communication options.

In case add-on module is inserted to the IED the start-up scan will search of the modules according to the type designation code, if the module location or content is differing from the expected the IED will not take additional modules into account and will issue a configuration error. For a field upgrade this means that the add-on module has to be ordered with the corresponding unlocking code in order the device to be operating correctly after upgrading the hardware configuration. This means also that the module location cannot be changed without updating the device configuration data, for this case also unlocking code is needed.

When IO module is inserted to the IED the module location shall affect the naming of the IO. The scanning order in the start-up sequence is CPU-module IO, slot C, E and F. This means that the binary input channels DI1, DI2 and DI3 and also the binary output channels OUT1, OUT2, OUT3, OUT4 and OUT5 are always located in the CPU-module. If more IO is installed the location of each type of card will have effect on the found IO naming. In following figure, the principle of the start-up hardware scan of the IED is presented.

Figure 6.6 Hardware scanning and IO naming principle in MVR-X215 IED



1. Scan: Start-up system, detect and self-test CPU-module, voltages, comm. and IO. Find and assign DI1, DI2, DI3, OUT1, OUT2, OUT3, OUT4 and OUT5.
2. Scan: Find VTM module 4 channels (fixed for MVR-X215).
3. Scan: Scan Slot B, in case of MVR-X215 should be always empty. If not empty, then issue alarm.
4. Scan: Scan Slot C, if empty go to next slot. If found 8DI module then reserve to this slot DI4, DI5, DI6, DI7, DI8, DI9, DI10 and DI11. If found DO5 module then reserve to this slot OUT6, OUT7, OUT8, OUT9 and OUT10. Amount of IO is added If the type designation code allows and if not match then issue alarm as also if module is expected to be found and it is not there alarm will be issued.
5. Scan: Find CTM module 5 channels (fixed for MVR-X215).
6. Scan: Scan Slot E, if empty go to next slot. If found 8DI module then reserve to this slot running number regard if Slot C was empty or had other than Dix module then DI4, DI5, DI6, DI7, DI8, DI9, DI10 and DI11 or if Slot C has also DI8 module then DI12, DI13, DI14, DI15, DI16, DI17, DI18 and DI19. If found DO5 module then reserve to this slot OUT6, OUT7, OUT8, OUT9 and OUT10 or OUT11, OUT12, OUT13, OUT14 and OUT15 with similar basis as for the inputs.

   If found arc protection module, reserve sensor channels S1, S2, S3, S4, high speed outputs HSO1, HSO2 and binary input channel ArcBI to this slot.
7. Scan: Similar operation to Scan 6.

In the previous example only IO add-on cards were described if installed into the option module slots. If the slot has a different type of module than IO they are treated similarly. For example, in case of added communication port the upper port of the communication module shall be in minimum of Comm. port 3 etc. since in the CPU-module already exist Comm.

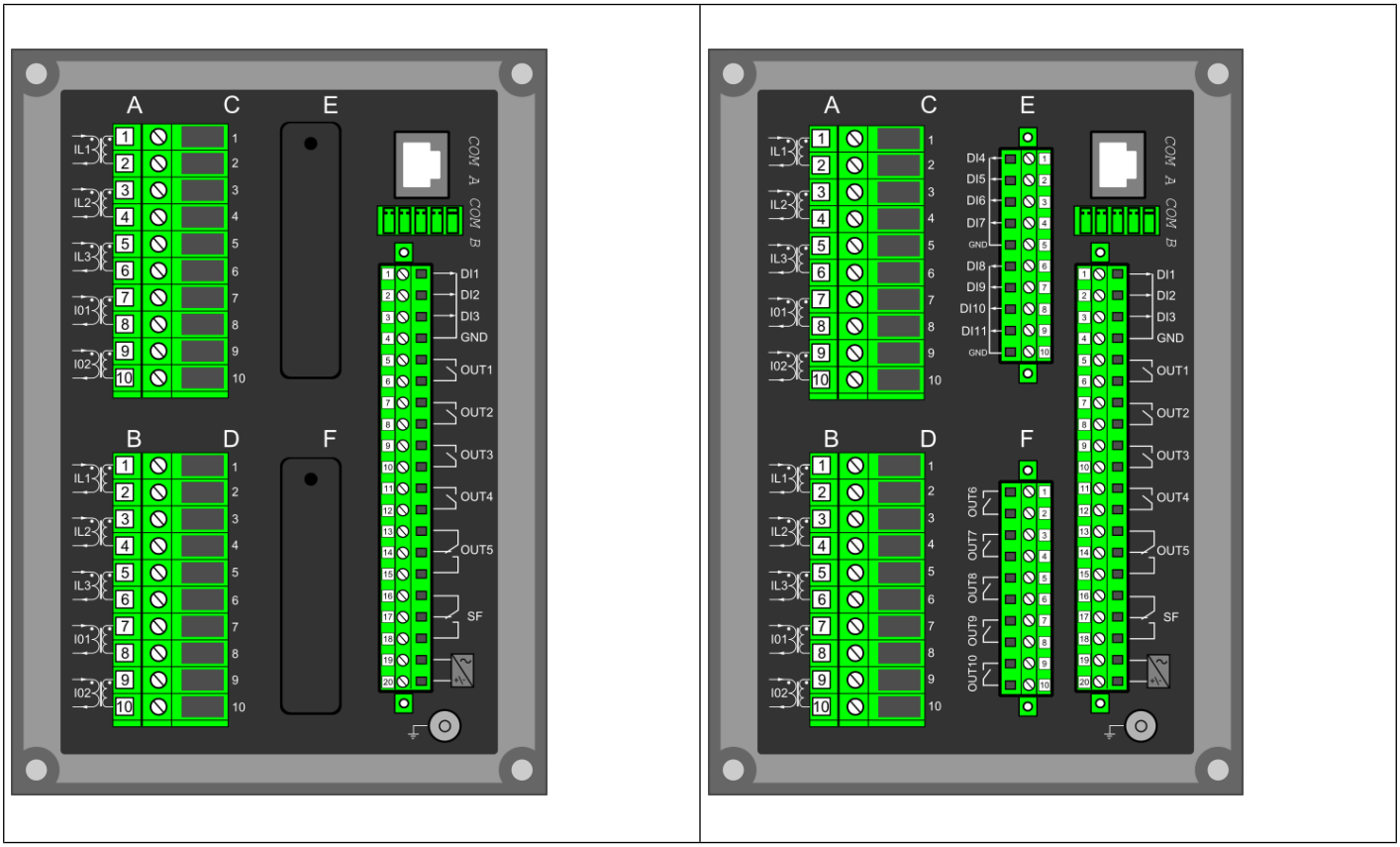
ports 1 and 2. After communication port is detected it is added into the communication space in the IED and corresponding settings are enabled for the IED.

In the example case of MVR-X215-XXXXXXX-*BCD* number of available binary input channels is DI1...DI11, of which DI1-DI3 are in the CPU module and DI4-DI11 are in Slot C. Available binary output channels are DO1...DO10, of which DO1-DO5 are in the CPU module and DO6-DO10 are in slot E. If the configuration should differ from this example the same principle is always applied into the IED. Slot F has an arc protection module installed, which has sensor modules S1,S2,S3 and S4, one binary input ArcBI and high speed outputs HSO1 and HSO2.

6.2.6 MVR-T216

Construction and installation

MVR-X216 IED is a member of modular and scalable MVR-2xx series and includes four configurable modular add-on card slots. As a standard configuration in the IED are included CPU, IO and Power supply module. In the figure below is presented non-optioned model (MVR-X216-XXXXXXX-*AA*) and fully optioned model (MVR-X216-XXXXXXX-*BC*) of the MVR-X216 IED.



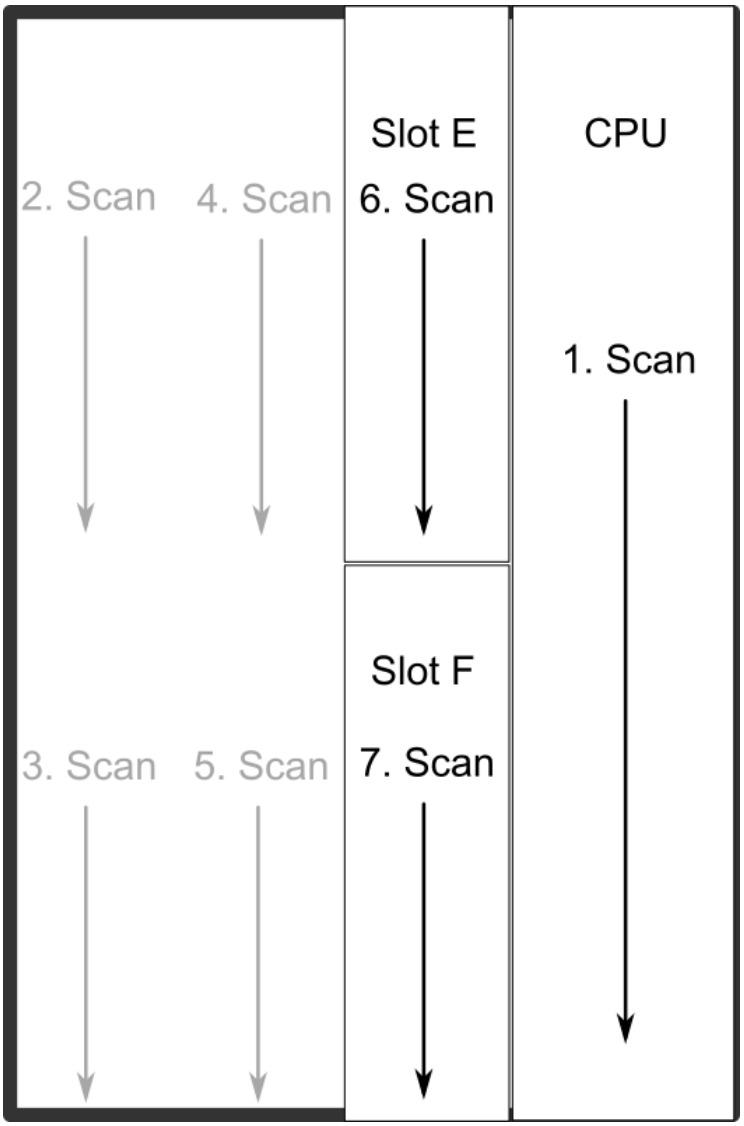
MVR-X216 modular structure allows scalable solutions for different application requirements. In any of the non-standard configured slots E and F can be ordered with any available add-on module which can be binary IO module, integrated Arc – protection or any special module provided. Only differentiating factor in the device scalability is considering the E slot which supports also communication options.

In case add-on module is inserted to the IED the start-up scan will search of the modules according to the type designation code, if the module location or content is differing from the expected the IED will not take additional modules into account and will issue a configuration error. For a field upgrade this means that the add-on module has to be ordered with the corresponding unlocking code in order the device to be operating correctly after upgrading the hardware configuration. This means also that the module location cannot be changed without updating the device configuration data, for this case also unlocking code is needed.

When IO module is inserted to the IED the module location shall affect to the naming of the IO. The scanning order in the start-up sequence is CPU-module IO, slot A, slot C, slot E and slot F. This means that the binary input channels DI1, DI2 and

DI3 and also the binary output channels OUT1, OUT2, OUT3, OUT4 and OUT5 are always located in the CPU-module. If more IO is installed the location of each type of card will have effect on the found IO naming. In following figure is presented the principle of the start-up hardware scan of the IED.

Figure 6.7 Hardware scanning and IO naming principle in MVR-216 IED



1. Scan: Start-up system, detect and self-test CPU-module, voltages, comm. and IO. Find and assign DI1, DI2, DI3, OUT1, OUT2, OUT3, OUT4 and OUT5.
2. Scan: Scan Slot A&B, in case of X216 should be always empty. Otherwise error is issued.
3. Scan Slot B, in case of X216 should be always empty. Otherwise error is issued.
4. Scan: Scan Slot C, find CTM module (5 channels).
5. Scan: Scan Slot D, find CTM module (5 channels).
6. Scan: Scan slot E, if empty go to next slot. If found 8DI module then reserve to this slot DI4, DI5, DI6, DI7, DI8, DI9, DI10 and DI11. If found DO5 module then reserve to this slot OUT6, OUT7, OUT8, OUT9 and OUT10. Amount of IO is added If the type designation code allows and if not match then issue alarm as also if module is expected to be found and is not there alarm will be issued.
7. Scan: Scan Slot F, if empty go to next slot. If found 8DI module then reserve to this slot running number regard if Slot E was empty or had other than Dix module then DI4, DI5, DI6, DI7, DI8, DI9, DI10 and DI11 or if Slot A has also DI8 module then DI12, DI13, DI14, DI15, DI16, DI17, DI18 and DI19. If found DO5 module then reserve to this slot OUT6, OUT7, OUT8, OUT9 and OUT10 or OUT11, OUT12, OUT13, OUT14 and OUT15 with similar basis than for the inputs.

In the previous example only IO add-on cards were described if installed into the option module slots. If the slot has other type of module than IO they are treated similarly. For example, in case of added communication port the upper port of the

communication module shall be in minimum of Comm. port 3 etc. since in the CPU-module already exist Comm. ports 1 and 2. After communication port is detected it is added into the communication space in the IED and corresponding settings are enabled for the IED.

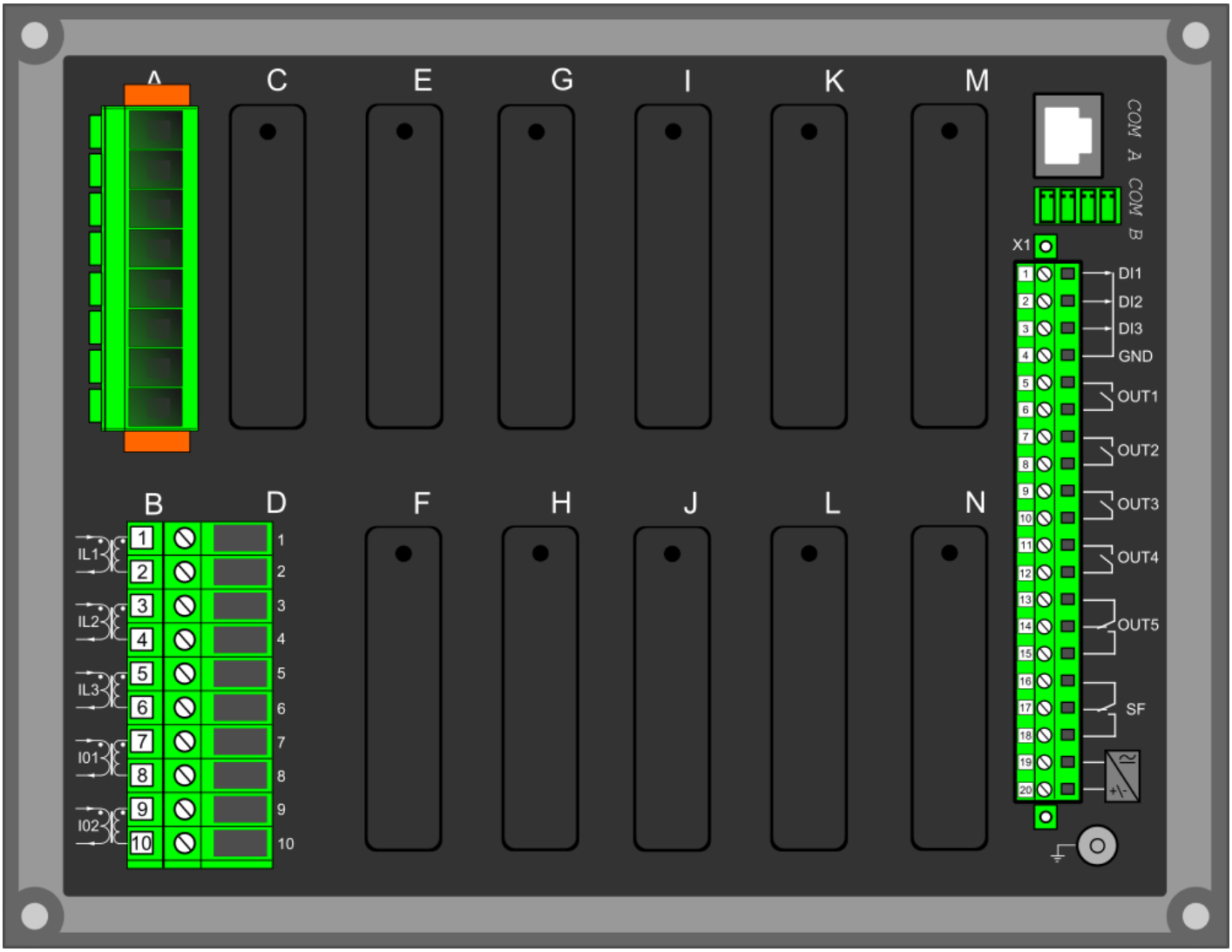
In the example case of MVR-X216-XXXXXXX-*BC* number of available binary input channels is DI1...DI11, of which DI1-DI3 are in the CPU module, DI4-DI11 are in Slot E. Available binary output channels are DO1...DO10, of which DO1-DO5 are in the CPU module and DO6-DO10 are in slot F. If the configuration should differ from this example the same principle is always applied into the IED.

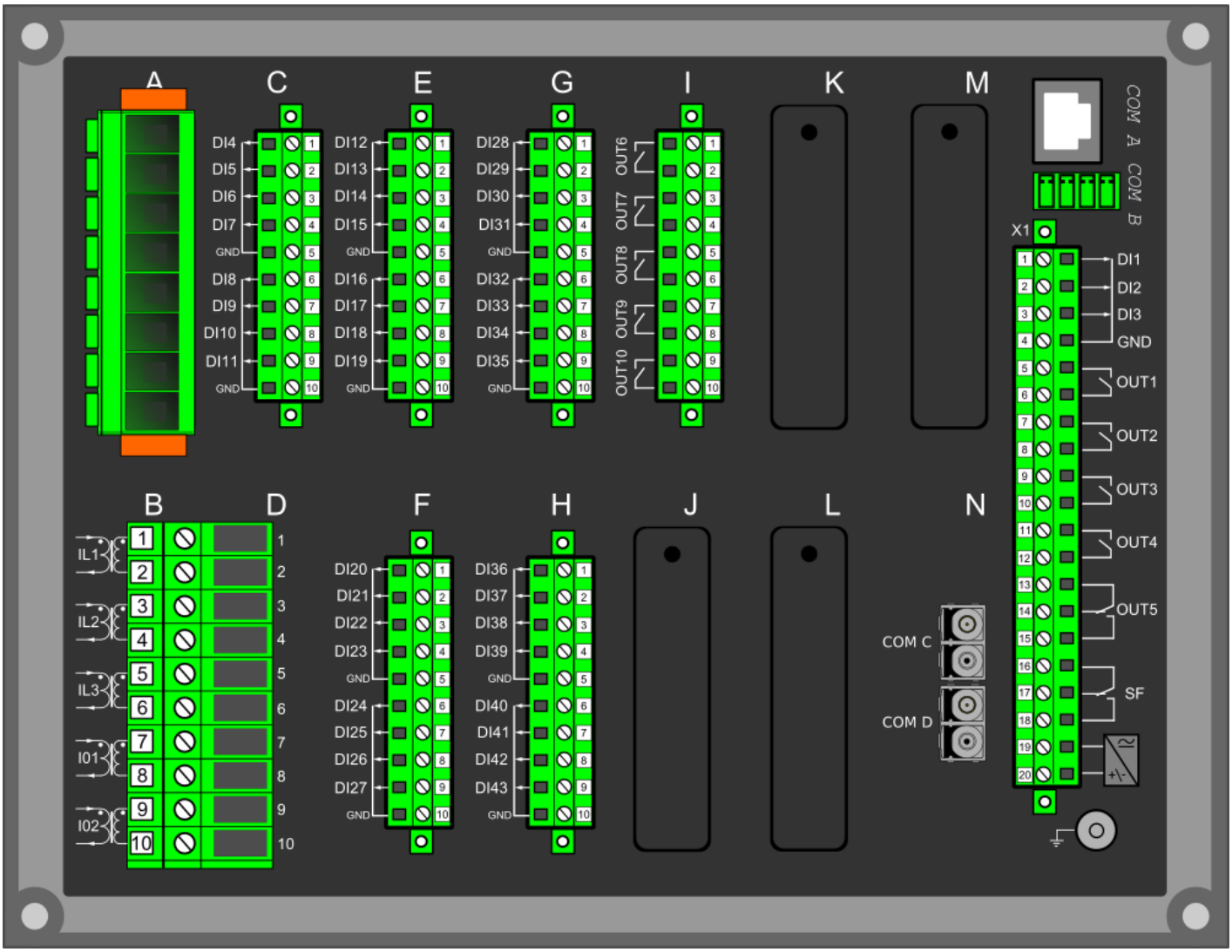
6.2.7 MVR-F255 and MVR-M255

Construction and installation

MVR-X255 IED is a member of modular and scalable MVR-2xx series and includes 11 configurable modular add-on card slots. As a standard configuration the IED includes combined CPU, IO and Power supply module, and separate voltage –and current measurement modules. In the figure below is presented non-optioned model (MVR-X255-XXXXXXX-*AAAAAAAAAAA*) and partially optioned model (MVR-X255-XXXXXXX-*BBBBBCAAAAJ*) of the MVR-X255 IED.

Figure 6.8 Modular construction of MVR-X255 IED



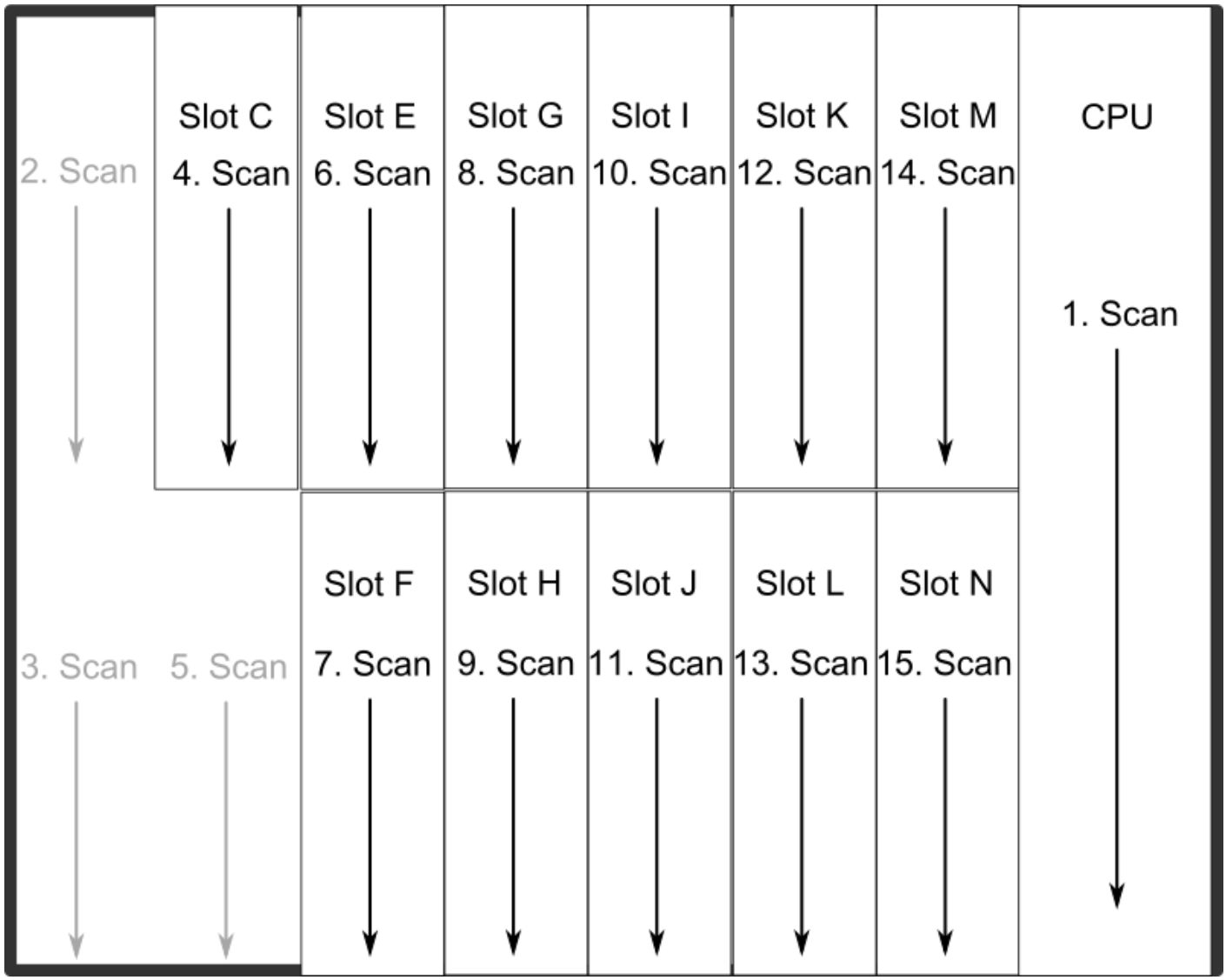


MVR-X255 modular structure allows scalable solutions for different application requirements. In any of the non-standard configured slots from C to N can be ordered with any available add-on module which can be binary IO module, integrated Arc –protection or any special module provided. Only differentiating factor in the device scalability is considering the M and N slots which support also communication options.

In case add-on module is inserted to the IED the start-up scan will search of the modules according to the type designation code, if the module location or content is differing from the expected the IED will not take additional modules into account and will issue a configuration error. For a field upgrade this means that the add-on module has to be ordered with the corresponding unlocking code in order the device to be operating correctly after upgrading the hardware configuration. This means also that the module location cannot be changed without updating the device configuration data, for this case also unlocking code is needed.

When IO module is inserted to the IED the module location shall affect to the naming of the IO. The scanning order in the start-up sequence is CPU-module IO, slot C, slot E, slot F and so on. This means that the binary input channels DI1, DI2 and DI3 and also the binary output channels OUT1, OUT2, OUT3, OUT4 and OUT5 are always located in the CPU-module. If more IO is installed the location of each type of card will have effect on the found IO naming. In following figure is presented the principle of the start-up hardware scan of the IED.

Figure 6.9 Hardware scanning and IO naming principle in MVR-X215 IED



1. Scan: Start-up system, detect and self-test CPU-module, voltages, comm. and IO. Find and assign DI1, DI2, DI3, OUT1, OUT2, OUT3, OUT4 and OUT5.
2. Scan: Find VTM module 4 channels (fixed for MVR-X215).
3. Scan: Scan Slot B, in case of MVR-X215 should be always empty. If not empty then issue alarm.
4. Scan: Scan Slot C, if is empty goes to next slot. If found 8DI module then reserve to this slot DI4,DI5,DI6,DI7,DI8, ,DI9,DI10 and DI11. If found DO5 module then reserve to this slot OUT6, OUT7, OUT8, OUT9 and OUT10. Amount of IO is added If the type designation code allows and if not match then issue alarm as also if module is expected to be found and is not there alarm will be issued.
5. Scan: Find CTM module 5 channels (fixed for MVR-X215).
6. Scan: Scan Slot E, if is empty goes to next slot. If found 8DI module then reserve to this slot running number regard if Slot C was empty or had other than DIx module then DI4, DI5, DI6, DI7, DI8, DI9, DI10 and DI11 or if Slot C has also DI8 module then DI12, DI13, DI14, DI15, DI16, DI17, DI18 and DI19. If found DO5 module then reserve to this slot OUT6, OUT7, OUT8, OUT9 and OUT10 or OUT11, OUT12, OUT13, OUT14 and OUT15 with similar basis than for the inputs.

   If found arc protection module, reserve sensor channels S1, S2, S3, S4, high speed outputs HSO1, HSO2 and binary input channel ArcBI to this slot.

7-15 Scan: Similar operation to Scan 6.

In the previous example only IO add-on cards were described if installed into the option module slots. If the slot has other type of module than IO they are treated similarly. For example, in case of added communication port the upper port of the

communication module shall be in minimum of Comm. port 3 etc. since in the CPU-module already exist Comm. ports 1 and 2. After communication port is detected it is added into the communication space in the IED and corresponding settings are enabled for the IED.

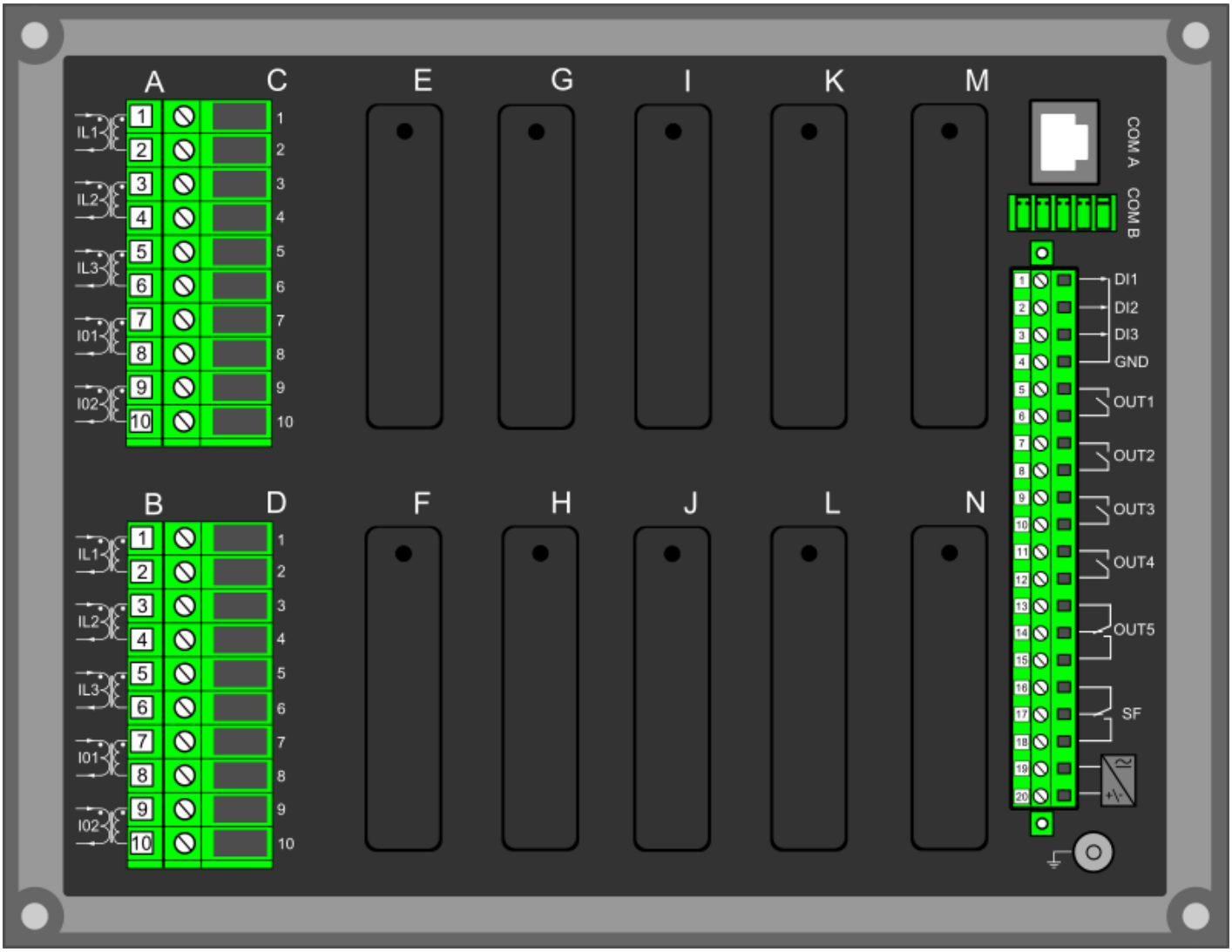
In the example case of MVR-X255-XXXXXXX-*BBBBBCAAAAJ* number of available binary input channels is DI1...DI43, of which DI1-DI3 are in the CPU module and DI4-DI11 are in Slot C etc. All available binary output channels are DO1...DO10, of which DO1-DO5 are in the CPU module and DO6-DO10 are in slot I. If the configuration should differ from this example the same principle is always applied into the IED. Slot N has “double fiber ethernet” module installed.

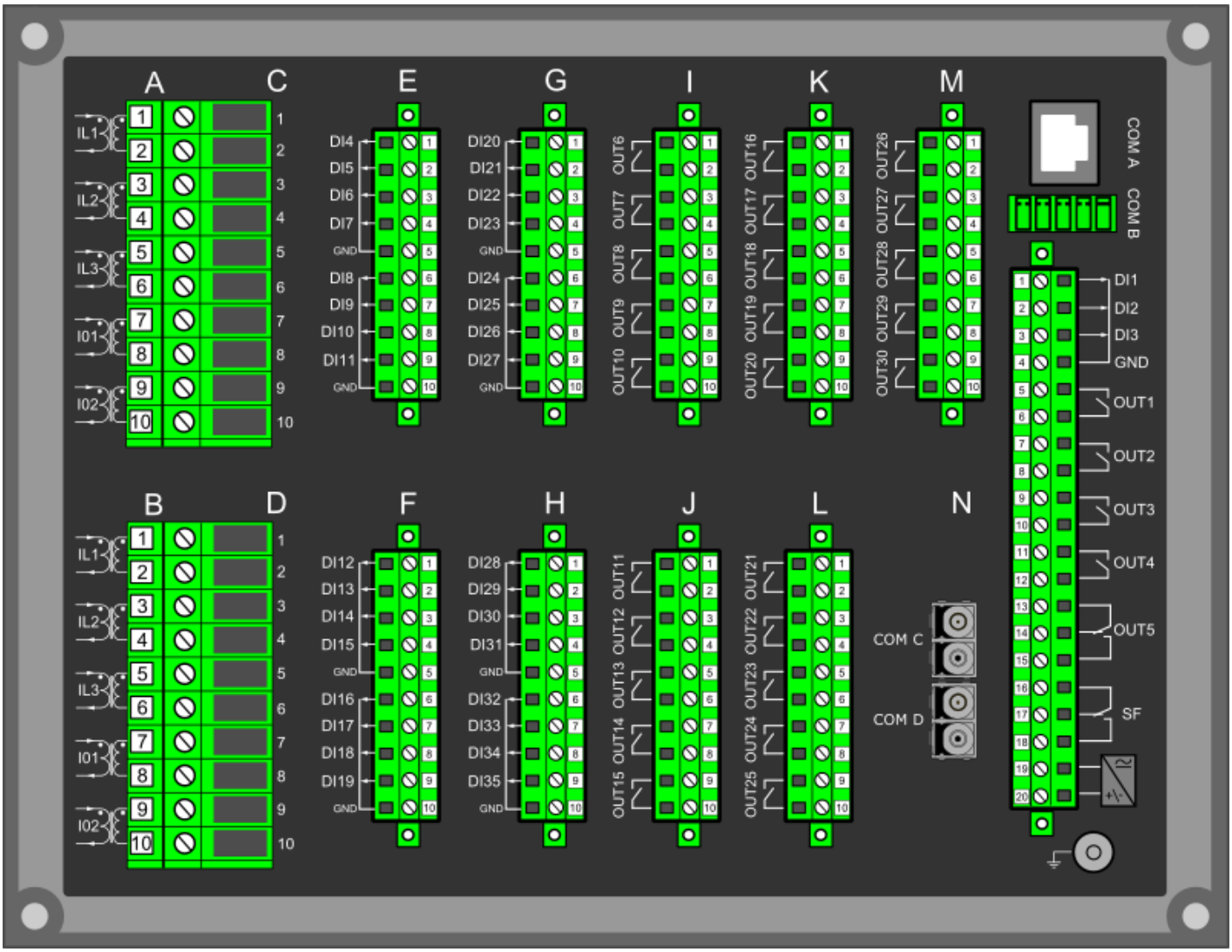
6.2.8 MVR-T256

Construction and installation

MVR-X25x IEDs are members of modular and scalable MVR-2xx series and includes 10 configurable modular add-on card slots. As a standard configuration the IEDs includes combined CPU, IO and Power supply module, and separate current measurement modules. In the figure below is presented a non-optioned model MVR-X256-XXXXXXX-*AAAAAAAAAA* and fully optioned model MVR-X256-XXXXXXX-*BBBBCCCCCJ*.

Figure 6.10 Modular construction of MVR-X256 IEDs



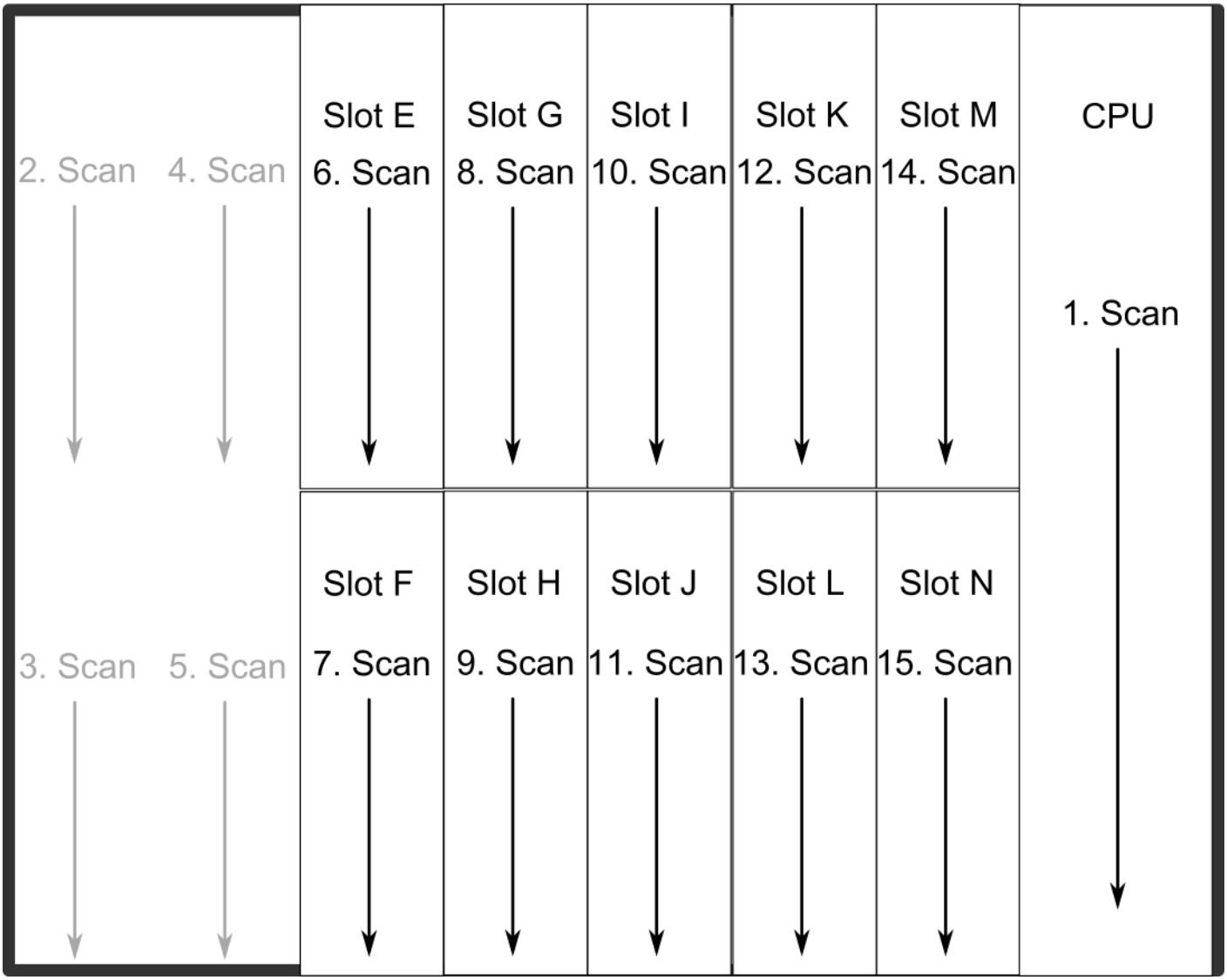


MVR-256 modular structure allows scalable solutions for different application requirements. In any of the non-standard configured slots from E to N can be ordered with any available add-on module which can be binary IO module, integrated Arc –protection or any special module provided. Only differentiating factor in the device scalability is considering the M and N slots which do supports also communication options.

In case add-on module is inserted to the IED the start-up scan will search of the modules according to the type designation code, if the module location or content is differing from the expected the IED will not take additional modules into account and will issue a configuration error. For a field upgrade this means that the add-on module has to be ordered with the corresponding unlocking code in order the device to be operating correctly after upgrading the hardware configuration. This means also that the module location cannot be changed without updating the device configuration data, for this case also unlocking code is needed.

When IO module is inserted to the IED the module location shall effect to the naming of the IO. The scanning order in the start-up sequence is CPU-module IO, slot E, slot F and so on. This means that the binary input channels DI1, DI2 and DI3 and also the binary output channels OUT1, OUT2, OUT3, OUT4 and OUT5 are always located in the CPU-module. If more IO is installed the location of each type of card will have effect on the found IO naming. In following figure is presented the principle of the start-up hardware scan of the IED.

Figure 6.11 Hardware scanning and IO naming principle in MVR-X256 IED



1. Scan: Start-up system, detect and self-test CPU-module, voltages, comm. and IO. Find and assign DI1, DI2, DI3, OUT1, OUT2, OUT3, OUT4 and OUT5.
2. Scan: Scan Slot A, in case of MVR-X256 should be always empty. If not empty, issue alarm.
3. Scan: Scan Slot B, in case of MVR-X256 should be always empty. If not empty, issue alarm.
4. Scan: Scan slot C, find CTM module with 5 channels (fixed for MVR-X256).
5. Scan: Scan slot D, find CTM module with 5 channels (fixed for MVR-X256).
6. Scan: Scan Slot E, if empty go to next slot. If found 8DI module then reserve to this slot DI4, DI5, DI6, DI7, DI8, DI9, DI10 and DI11. If found DO5 module then reserve to this slot OUT6, OUT7, OUT8, OUT9 and OUT10. Amount of IO is added If the type designation code allows and if not match then issue alarm as also if module is expected to be found and it is not there, alarm will be issued.
7. Scan: Scan Slot F, if is empty goes to next slot. If found 8DI module then reserve to this slot running number regard if Slot E was empty or had other than DIx module then DI4, DI5, DI6, DI7, DI8, DI9, DI10 and DI11 or if Slot C has also DI8 module then DI12, DI13, DI14, DI15, DI16, DI17, DI18 and DI19. If found DO5 module then reserve to this slot OUT6, OUT7, OUT8, OUT9 and OUT10 or OUT11, OUT12, OUT13, OUT14 and OUT15 with similar basis than for the inputs.

   If found arc protection module, reserve sensor channels S1, S2, S3, S4, high speed outputs HSO1, HSO2 and binary input channel ArcBI to this slot.

5-15 Scan: Similar operation to Scan 7.

In the previous example only IO add-on cards were described if installed into the option module slots. If the slot has other type of module than IO they are treated similarly. For example, in case of added communication port the upper port of the communication module shall be in minimum of Comm. port 3 etc. since in the CPU-module already exist Comm. ports 1 and 2. After communication port is detected it is added into the communication space in the IED and corresponding settings are enabled for the IED.

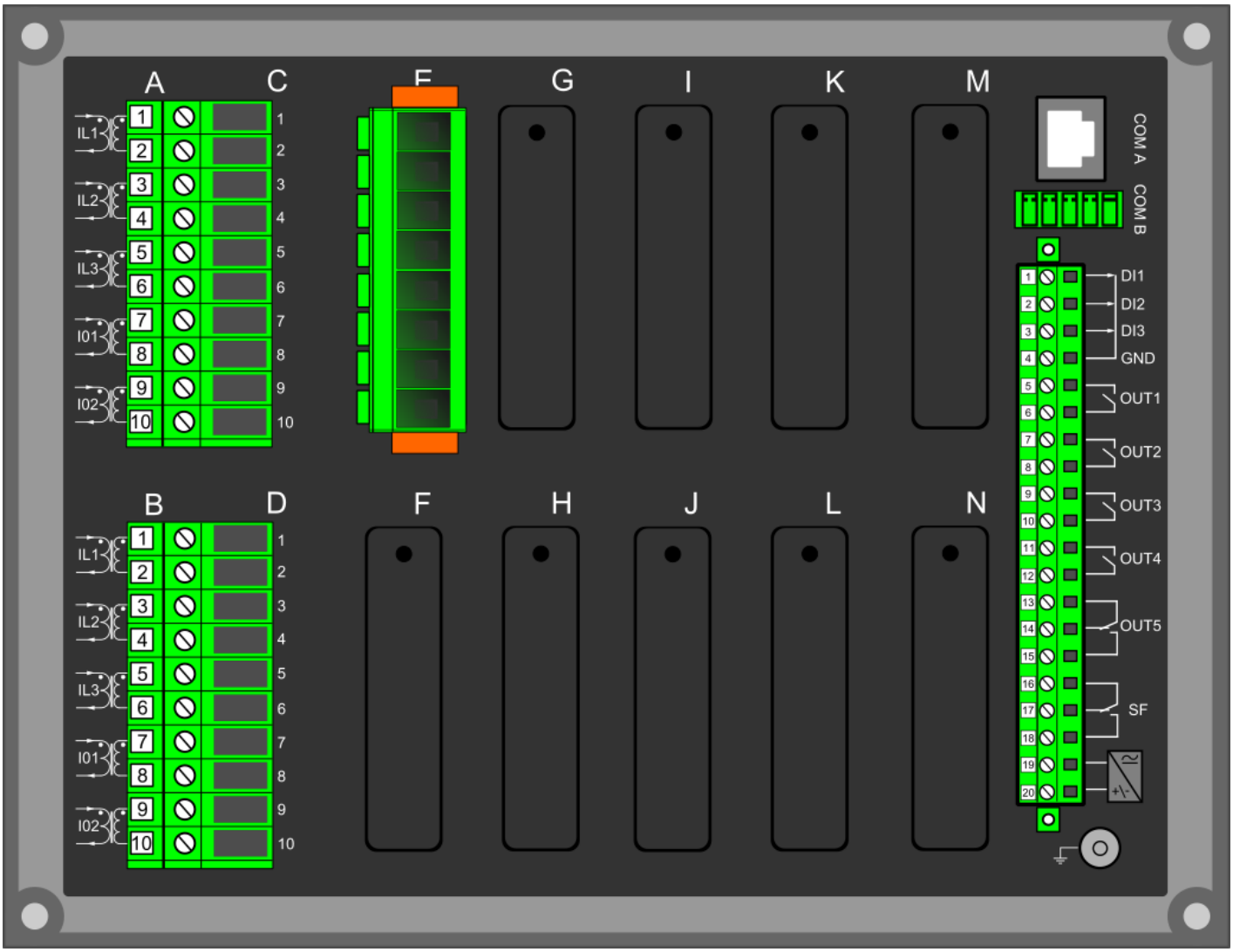
In the fully optioned example case of MVR-256-XXXXXXX-*BBBBCCCCCJ* number of available binary input channels is DI1...DI35, of which DI1-DI3 are in the CPU module and DI4-DI35 are in four separate DI option slots E, F, G and H. Amount of available binary output channels are DO1...DO30, of which DO1-DO5 are in the CPU module and DO6-DO30 are in slots I, J, K, L and M. If the configuration should differ from this example the same principle is always applied into the IED. Slot N has a double (LC) fiber Ethernet communication option card installed in it.

6.2.9 MVR-M257, MVR-G257 and MVR-T257

Construction and installation

MVR-X257 IEDs are members of modular and scalable MVR-2xx series and includes 9 configurable modular add-on card slots. As a standard configuration the IEDs includes combined CPU, IO and Power supply module, and separate current measurement modules. MVR-X257 IED also has an additional voltage measurement module. In the figure below is presented a non-optioned model MVR-257-XXXXXXX-*AAAAAAAAA* of the MVR-X257 IED family.

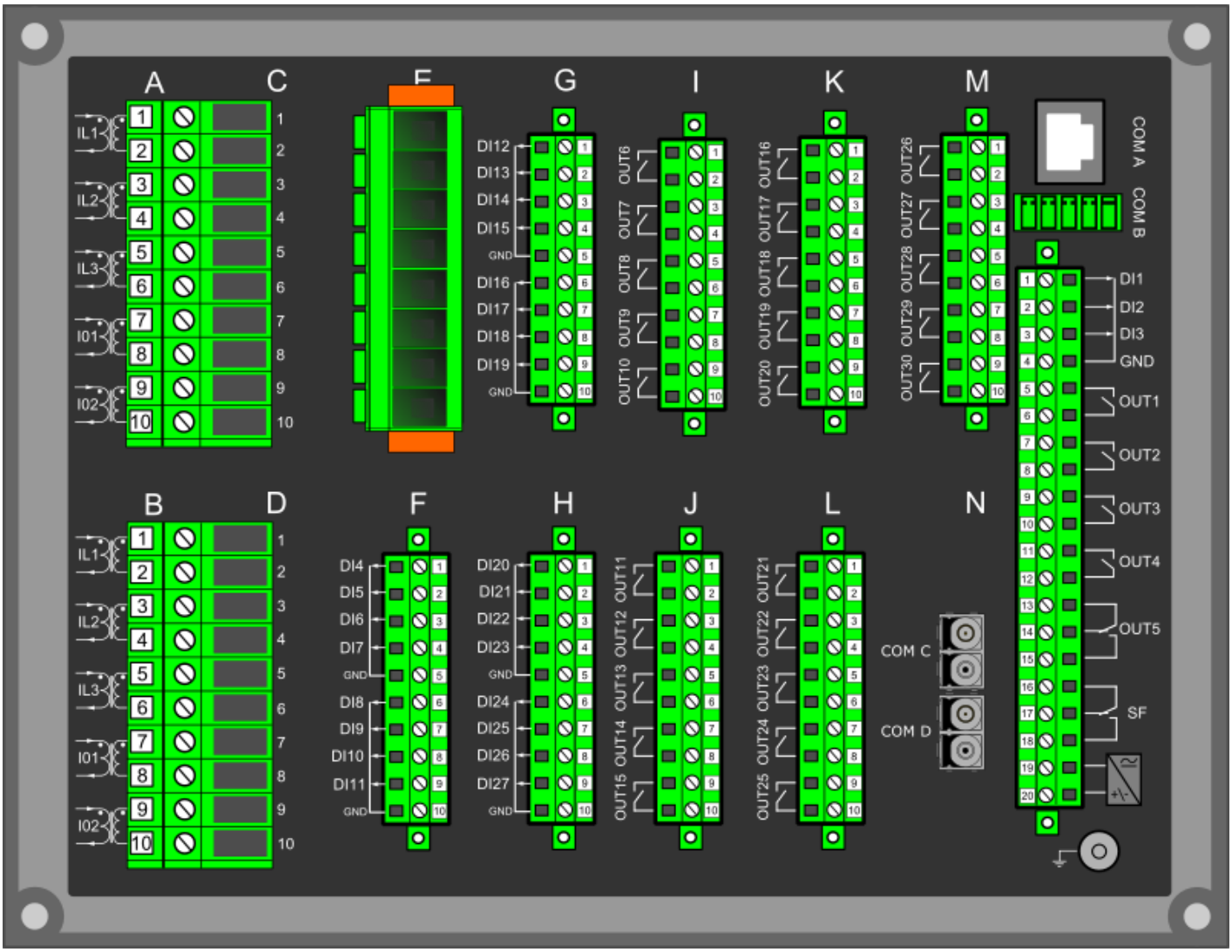
Figure 6.12 Modular construction of and MVR-X257 IEDs



MVR-X257 modular structure allows scalable solutions for different application requirements. In any of the non-standard configured slots from F to N can be ordered with any available add-on module which can be binary IO module, integrated

Arc –protection or any special module provided. Only differentiating factor in the device scalability is considering the M and N slots which also support communication options. In the figure below is presented a fully optioned model MVR-X257-XXXXXXX-**BBBCCCCCJ** of the MVR-X257 IED family.

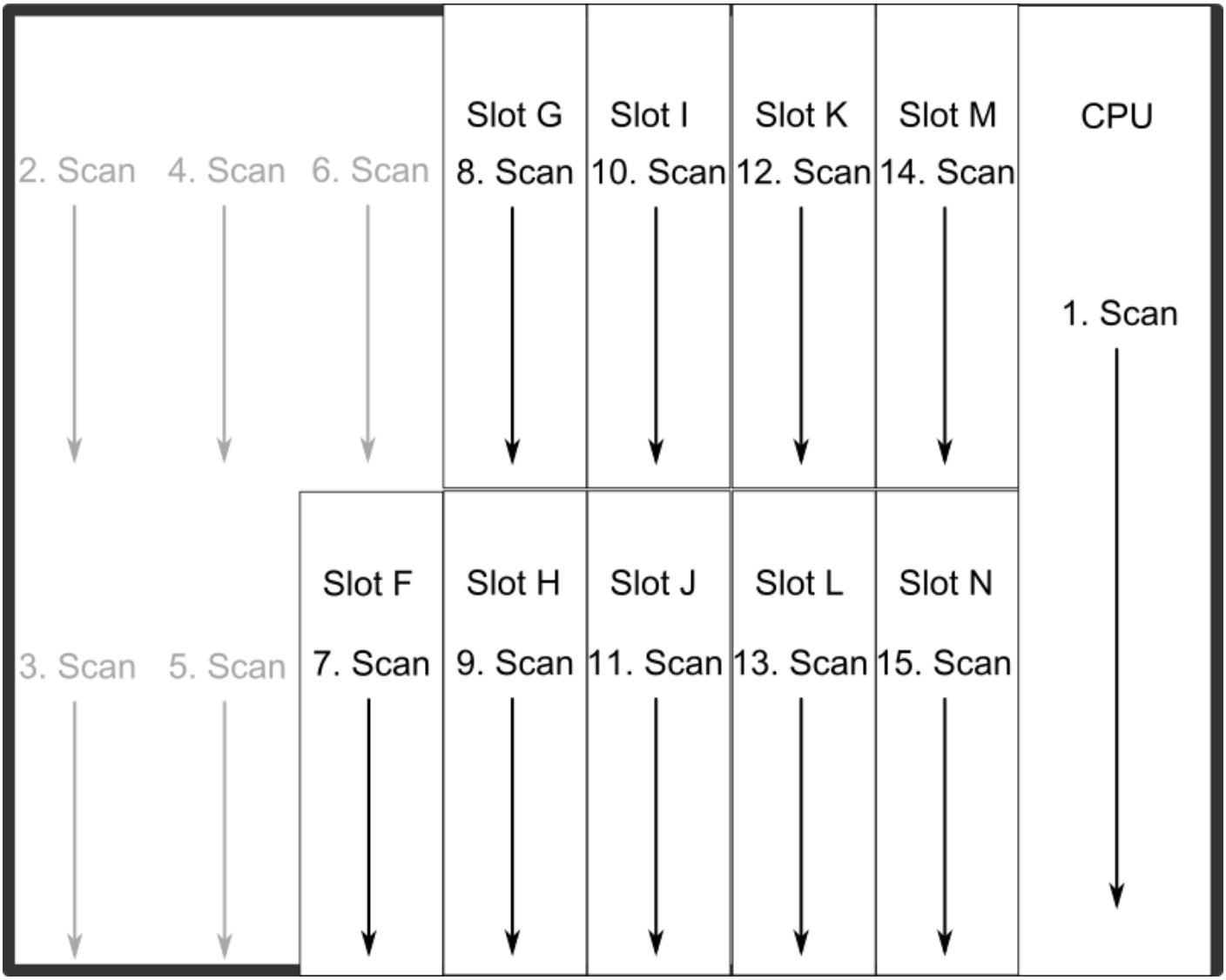
Figure 6.13 Fully optioned MVR-X257 IEDs



In case add-on module is inserted to the IED the start-up scan will search of the modules according to the type designation code, if the module location or content is differing from the expected the IED will not take additional modules into account and will issue a configuration error. For a field upgrade this means that the add-on module must be ordered with the corresponding unlocking code in order the device to be operating correctly after upgrading the hardware configuration. This means also that the module location cannot be changed without updating the device configuration data, for this case also unlocking code is needed.

When IO module is inserted to the IED the module location shall affect to the naming of the IO. The scanning order in the start-up sequence is CPU-module IO, slot E, slot F and so on. This means that the binary input channels DI1, DI2 and DI3 and the binary output channels OUT1, OUT2, OUT3, OUT4 and OUT5 are always located in the CPU-module. If more IO is installed the location of each type of card will have effect on the found IO naming. In following figure is presented the principle of the start-up hardware scan of the IED.

Figure 6.14 Hardware scanning and IO naming principle in MVR-X257 IED



1. Scan: Start-up system, detect and self-test CPU-module, voltages, comm. and IO. Find and assign DI1, DI2, DI3, OUT1, OUT2, OUT3, OUT4 and OUT5.
2. Scan: Scan Slot A, in case of MVR-X257 should be always empty. If not empty, then issue alarm.
3. Scan: Scan Slot B, in case of MVR-X257 should be always empty. If not empty, then issue alarm.
4. Scan: Scan Slot C, find CTM module with 5 channels.
5. Scan: Scan Slot D, find CTM module with 5 channels.
6. Scan: Scan Slot E, find VTM module with 4 channels.
7. Scan: Scan Slot F, if empty go to next slot. If found 8DI module then reserve to this slot DI4, DI5, DI6, DI7, DI8, DI9, DI10 and DI11. If found DO5 module then reserve to this slot OUT6, OUT7, OUT8, OUT9 and OUT10. Amount of IO is added If the type designation code allows and if not match then issue alarm as also if module is expected to be found and it is not there alarm will be issued.
8. Scan: Scan Slot G, if is empty goes to next slot. If found 8DI module then reserve to this slot running number regard if Slot F was empty or had other than DIx module then DI4, DI5, DI6, DI7, DI8, DI9, DI10 and DI11 or if Slot C has also DI8 module then DI12, DI13, DI14, DI15, DI16, DI17, DI18 and DI19. If found DO5 module then reserve to this slot OUT6, OUT7, OUT8, OUT9 and OUT10 or OUT11, OUT12, OUT13, OUT14 and OUT15 with similar basis than as for the inputs.

   If found arc protection module, reserve sensor channels S1, S2, S3, S4, high speed outputs HSO1, HSO2 and binary input channel ArcBI to this slot.

8-15 Scan: Similar operation to Scan 8.

In the previous example only IO add-on cards were described if installed into the option module slots. If the slot has other type of module than IO they are treated similarly. For example, in case of added communication port the upper port of the communication module shall be in minimum of Comm. port 3 etc. since in the CPU-module already exist Comm. ports 1 and 2. After communication port is detected it is added into the communication space in the IED and corresponding settings are enabled for the IED.

In the fully optioned example case of MVR-X257-XXXXXXX-*BBBCCCCCJ* number of available binary input channels amount is DI1...DI27, from which DI1-DI3 are in the CPU module and DI4-DI27 are in three separate DI option slots F, G and H. All available binary output channels are DO1...DO30, of which DO1-DO5 are in the CPU module and DO6-DO30 are in slots I, J, K, L & M. If the configuration should differ from this example the same principle is always applied into the IED. Slot N has a double (LC) fiber Ethernet communication option card installed.

6.3 Measurement

6.3.1 Power and energy measurement

Table 6.1 Power and energy measurement accuracy

Power measurement P, Q, S	Frequency range 6...75 Hz
Inaccuracy	0.3 % <1.2 x In or 3 VA of secondary 1.0 % >1.2 x In or 3 VA of secondary
Energy measurement	Frequency range 6...75 Hz
Energy and power metering inaccuracy	IEC 62053-22 class 0.55 S (50/60Hz) as standard IEC 62053-22 class 0.25 S (50/60Hz) option available (See order code for details)

6.4 Option cards

6.4.1 Hardware options

The following hardware options are available for the MVR 200:

Table 6.2 Available hardware options

Option	Description
Option B	8 digital outputs
Option C	5 relay outputs
Option I	4 analogue outputs 1 analogue input
Option J	100 Mb/s fibre Ethernet
Option L	Serial RS232 and fiber, Plastic - Plastic (PP)*
Option M	Serial RS232 and fiber, Plastic - Glass (PG)*
Option N	Serial RS232 and fiber, Glass - Plastic (GP)*
Option O	Serial RS232 and fiber, Glass - Glass (GG)*

NOTE * Only one communication module per relay, to be placed in the last slot.

- MVR- 21x series: Slot F
- MVR- 25x series: Slot N

NOTE See the **Data sheet** for more information about the hardware options.