AQ-T257

Transformer protection IED

Instruction manual

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Disclaimer

Please read these instructions carefully before using the equipment or taking any other actions with respect to the equipment. Only trained and qualified persons are allowed to perform installation, operation, service or maintenance of the equipment. Such qualified persons have the responsibility to take all appropriate measures, including e.g. use of authentication, encryption, anti-virus programs, safe switching programs etc. necessary to ensure a safe and secure environment and usability of the equipment. The warranty granted to the equipment remains in force only provided that the instructions contained in this document have been strictly complied with.

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1. Manual revision notes

1.1. Version 2 revision notes

Revision	2.00
Date	6.6.2019
Changes	- New more consistent look. - Improved descriptions generally in many chapters. - Improved readability of a lot of drawings and images. - Updated protection functions included in every IED manual. - Every protection IED type now has connection drawing, application example drawing with function block diagram and application example with wiring. - Added current measurement side selection description to functions with such feature. - Added General-menu description.
Revision	2.01
Date	6.11.2019
Changes	- Added description for LED test and button test. - Added display sleep timer description. - Complete rewrite of every chapter. - Improvements to many drawings and formula images. - Order codes revised. - Added double ST 100 Mbps Ethernet communication module and Double RJ45 10/100 Mbps Ethernet communication module descriptions

1.2. Version 1 revision notes

Revision	1.00
Date	13.4.2016
Changes	- The first revision for AQ-T256, T257 and T259 IEDs.
Revision	1.01
Date	10.2.2017
Changes	- Order code updated - Added programmable stage description
Revision	1.02
Date	9.1.2018
Changes	- Measurement value recorder description - ZCT connection added to current measurement description - Internal harmonics blocking to I>,I0> function descriptions - Non-standard delay curves added - Event lists revised on several functions - RTD&mA card description improvements - Ring-lug CT card option description added - New U> and U< function measurement modes documented - Order code revised
Revision	1.03
Date	14.8.2018
Changes	- Added mA output option card description and ordercode - Added HMI display technical data

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

3. General

The AQ-T257 transformer protection IED is a member of the AQ-200 product line. The hardware and software are modular: the hardware modules are assembled and configured according to the application's I/O requirements and the software determines the available functions. This manual describes the specific application of the AQ-T257 transformer protection IED. For other AQ-200 series products please consult the respective device manuals.

4. IED user interface

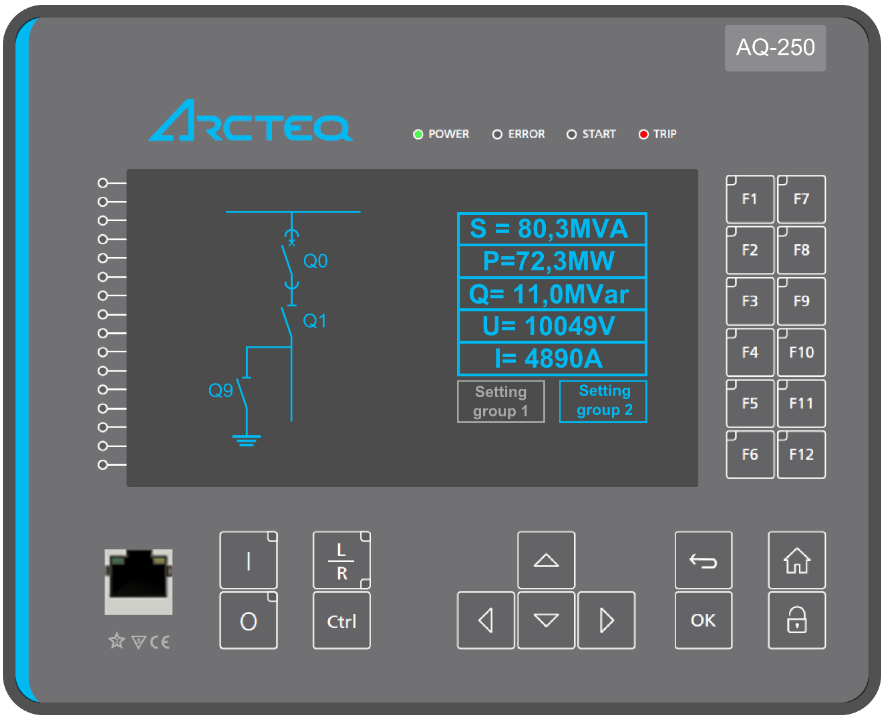
4.1. Panel structure

The user interface section of an AQ-200 series device is divided into two user interface sections: one for the hardware and the other for the software. You can access the software interface either through the front panel or through the AQtivate freeware software suite.

4.1.1. Local panel structure

The front panel of AQ-250 series devices have multiple LEDs, control buttons and a local RJ-45 Ethernet port for configuration. Each unit is also equipped with an RS-485 serial interface and an RJ-45 Ethernet interface on the back of the device. See the image and list below.

Figure. 4.1.1. - 1. Local panel structure.



- Four (4) freely configurable LEDs: "Power", "Error", "Start" and "Trip".
- Sixteen (16) freely configurable LEDs with programmable legend texts.
- Three (3) object control buttons: Choose the controllable object with the Ctrl button and the control breaker with the **I** and the **O** buttons.
- The **L/R** button switches between the local and the remote control modes.
- Eight (8) buttons for IED local programming: the four navigation arrows, the **Back** and the **OK** buttons, the **Home** and the password activation buttons).
- Twelve (12) freely configurable function buttons (F1…F12).
- One (1) RJ-45 Ethernet port for IED configuration.

The view in the screen is freely configurable with the buttons: you can change the setting groups or control the relay's general logic. The status of the object (circuit breaker, disconnector) can be displayed on the screen. All measured and calculated values regardless of the magnitude catecory (current, voltage, power, energy, frequency, etc.) can be shown on the screen.

Holding the **I** (object control) button down for five seconds brings up the button test menu. It displays all the physical buttons on the front panel. Pressing any of the listed buttons marks them as tested. When all buttons are marked as having been tested, you can press the **Back** button to close the button test menu.

4.2. Configuring user levels and their passwords

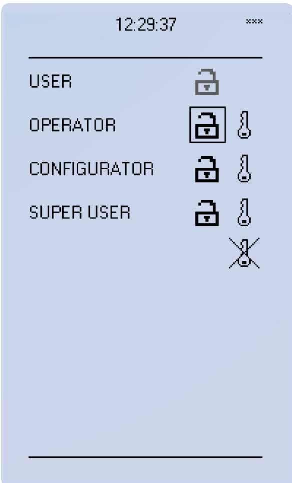
As a factory default, no user level is locked with a password in an IED. In order to activate the different user levels, click the **Lock** button in the device's HMI and set the desired passwords for the different user levels.

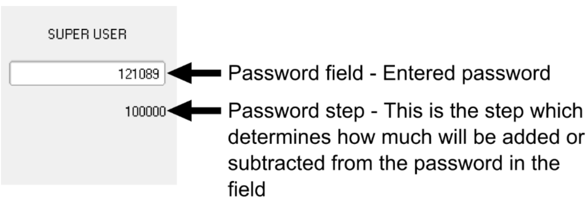
NOTE!

Passwords can only be set locally in an HMI.

A number of stars are displayed in the upper right corner of the HMI; these indicate the current user level. The different user levels and their star indicators are as follows (also, see the image below for the HMI view):

- Super user (***)
- Configurator (**)
- Operator (*)
- User (-)





You can set a new password for a user level by selecting the key icon next to the user level's name. After this you can lock the user level by pressing the **Return** key while the lock is selected. If you need to change the password, you can select the key icon again and give a new password. Please note that in order to do this the user level whose password is being changed must be unlocked.

As mentioned above, the access level of the different user levels is indicated by the number of stars. The required access level to change a parameter is indicated with a star (*) symbol if such is required. As a general rule the access levels are divided as follows:

- *User:* Can view any menus and settings but cannot change any settings, nor operate breakers or other equipment.
- *Operator:* Can view any menus and settings but cannot change any settings BUT can operate breakers and other equipment.
- *Configurator:* Can change most settings such as basic protection pick-up levels or time delays, breaker control functions, signal descriptions etc. and can operate breakers and other equipment.

- *Super user:* Can change any setting and can operate breakers and other equipment.

NOTE!

Any user level with a password automatically locks itself after half an hour (30 minutes) of inactivity.

5. Functions

5.1. Functions included in AQ-T257

The AQ-T257 transformer protection relay includes the following functions as well as the number of stages in those functions.

Table. 5.1. - 1. Protection functions of AQ-T257.

Name	IEC	ANSI	Description
NOC (4)	I> I>> I>>> I>>>>	50/51	Non-directional overcurrent protection
NEF (4)	I0> I0>> I0>>> I0>>>>	50N/51N	Non-directional earth fault protection
DOC (4)	Idir> Idir>> Idir>>> Idir>>>>	67	Directional overcurrent protection
DEF (4)	I0dir> I0dir>> I0dir>>> I0dir>>>>	67N	Directional earth fault protection
CUB (4)	I2> I2>> I2>>> I2>>>>	46/46R/46L	Negative sequence overcurrent/ phase current reversal/ current unbalance protection
HOC (4)	Ih> Ih>> Ih>>> Ih>>>>	50H/51H/68H	Harmonic overcurrent protection The detection and blocking or tripping based on a selectable harmonic. The phase currents and the residual currents have separate stages.
CBFP (1)	CBFP	50BF/52BF	Circuit breaker failure protection
DIF (1)	Idb>/Idi>	87G/87T	Transformer differential protection
REF (2)	I0d>	87N	Low-/high-impedance restricted earth fault/cable end differential protection
TOLT (1)	TT>	49T	Transformer thermal overload protection
TRF	-	-	Transformer status monitoring
RTD (1)	-	-	Resistance temperature detectors
OV (4)	U> U>> U>>> U>>>>	59	Overvoltage protection
UV (4)	U< U<< U<<< U<<<<	27	Undervoltage protections
VUB (4)	U1/U2>/< U1/U2>>/<< U1/U2>>>/<<< U1/U2>>>>/<<<<	47/27PN/59PN	Sequence voltage protection
NOV (4)	U0> U0>> U0>>> U0>>>>	59N	Neutral overvoltage protection

PQS (1)	P, Q, S >/<	32	Power protection
FRQV (8)	f> f>> f>>> f>>>> f< f<< f<<< f<<<<	81O/81U	Overfrequency and underfrequency protection
ROCOF (1)	df/dt>/< (1…8)	81R	Rate of change of frequency protection
PGS (1)	PGx >/<	99	Programmable stage
ARC (1)	IArc>/I0Arc>	50Arc/50NArc	Arc fault protection (optional)

Table. 5.1. - 2. Control functions of AQ-T257.

Name	IEC	ANSI	Description
SGS	-	-	Setting group selection
OBJ	-	-	Object control and monitoring
SYN	ΔV/Δa/Δf	25	Synchrocheck
VRG	-	-	Voltage regulator (included in Function package B)

Table. 5.1. - 3. Monitoring functions of AQ-T257.

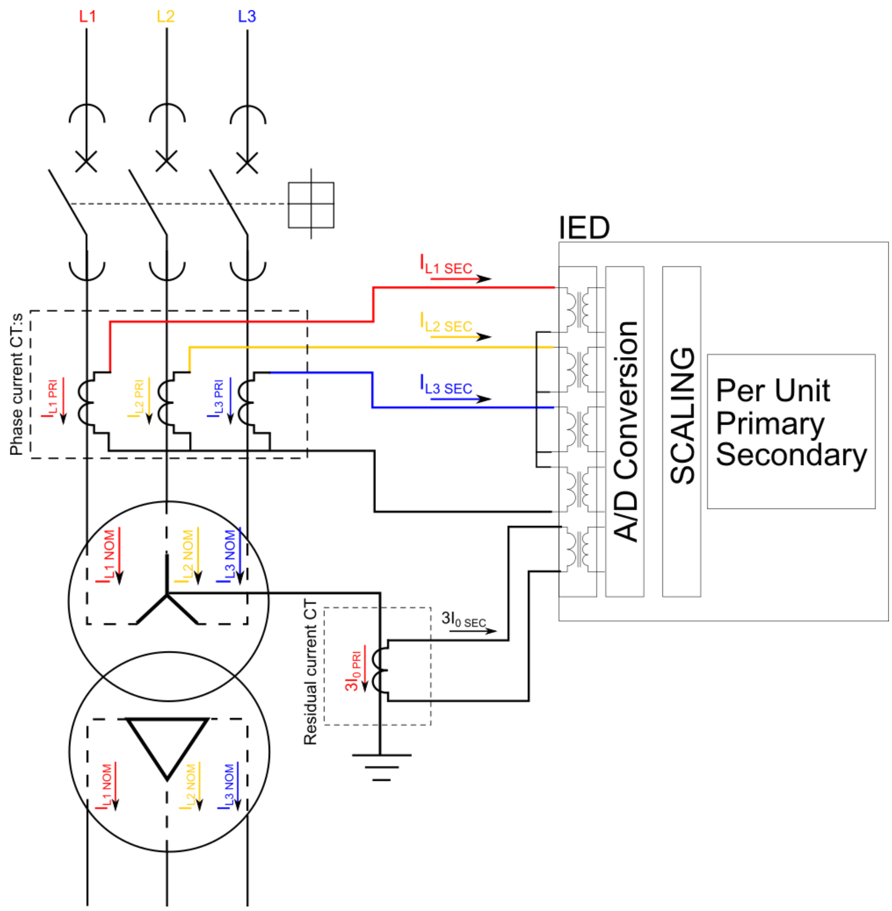
Name	IEC	ANSI	Description
CTS	-	-	Current transformer supervision
VTS	-	60	Voltage transformer supervision
DR	-	-	Disturbance recorder
MR	-	-	Measurement recorder
CBW	-	-	Circuit breaker wear monitor
THD	-	-	Total harmonic distortion
VREC	-	-	Measurement value recorder

5.2. Measurements

5.2.1. Current measurement and scaling in differential applications

The current measurement module (CT module, or CTM) is used for measuring the currents from current transformers. The measured values are processed into the measurement database and they are used by measurement and protection functions. It is essential to understand the concept of current measurements to be able to get correct measurements.

Figure. 5.2.1. - 2. Current measurement terminology



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

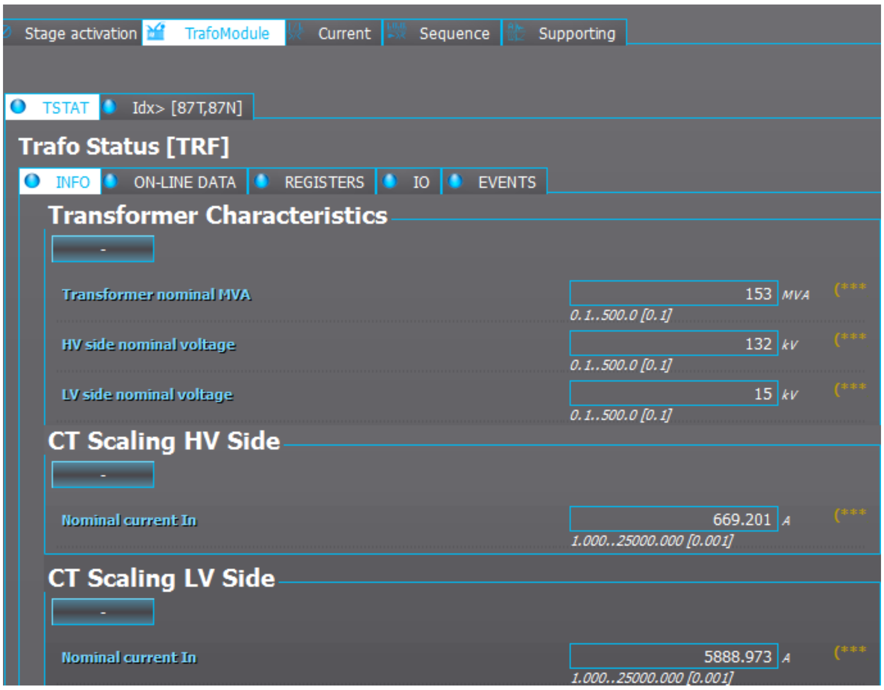
SEC: The secondary current, i.e. the current which the current transformer transforms according to its ratios. This current is measured by the protection relay.

NOM: The nominal primary current of the protected transformer. The nominal current on the HV side differs from that on the LV side according to the transformer voltage ratio. The nominal current is calculated based on the transformer's MVA and the nominal voltage on each winding.

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

The relay calculates the scaling factors based on the set values of the CT primary, the CT secondary and the nominal current. The relay measures the secondary current, the current output from the current transformer installed into application's primary circuit. The rated primary and secondary currents of the CT need to be set for the relay to "know" the primary and per-unit values. In power transformers, the protected unit's nominal current in both windings is calculated based on the given nominal power (MVA) and the nominal voltage. The settings can only give the apparatus nominal in p.u. when the nominal current is known. Also, knowing what the transformer's nominal current is makes the unit protection much easier and more straightforward. In modern protection devices this scaling calculation is done internally after the current transformer's primary current, secondary current and machine nominal current are set.

Figure. 5.2.1. - 3. Nominal current calculation in differential protection relays.



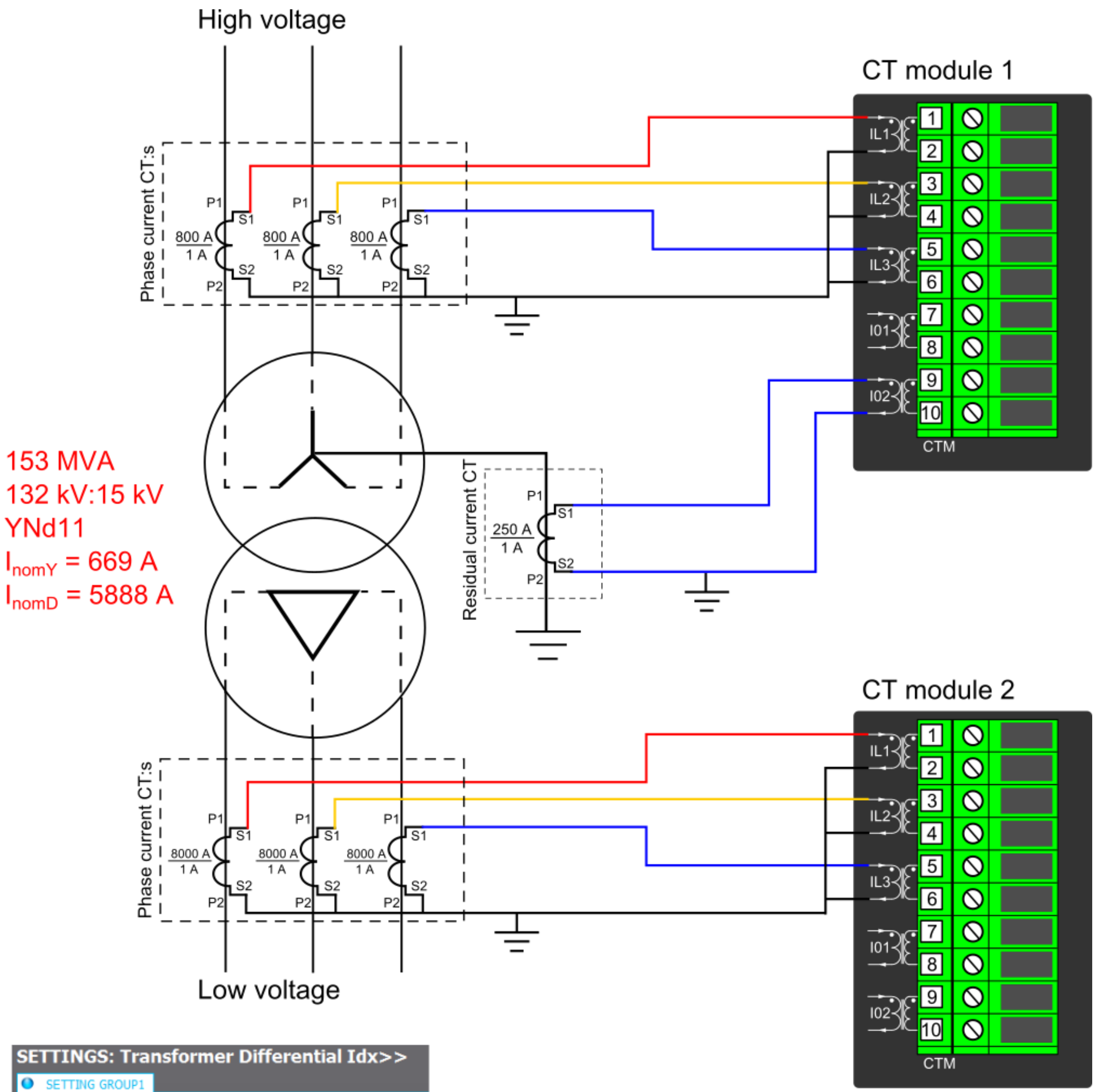
Normally, the primary current ratings for phase current transformers are ten amperes to thousands of amperes and their decimal multiples, while the secondary current ratings are 1 A and 5 A. Other, non-standard ratings can be directly connected as the scaling settings are flexible and have large ranges. For example, the ring core current transformer ratings may vary. 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.

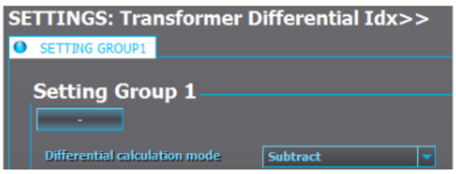
The following chapter is an example on how to set the scaling of the relay measurements for the selected current transformer and nominal load.

Example of CT scaling (application 1)

The following figure presents how CTs are connected to the relay's measurement inputs. It also shows the CT ratings and the transformer nominal current. Note that S1 is always connected to an odd connector regardless of the CT direction. The CT direction is selected in the settings of the transformer differential protection function.

Figure. 5.2.1. - 4. Connections (application 1).





Because of the direction of the CTs and because the CTs' P1/S1 side is always wired to the modules's odd inputs, the "Differential calculation mode" setting has to be set to "Subtract" (*Protection → TrafoModule → Idx> [87T,87N] → Settings*). This way the direction of the measured currents are checked correctly from the relay's perspective.

The following table presents the initial data of the connection as well as the ratings.

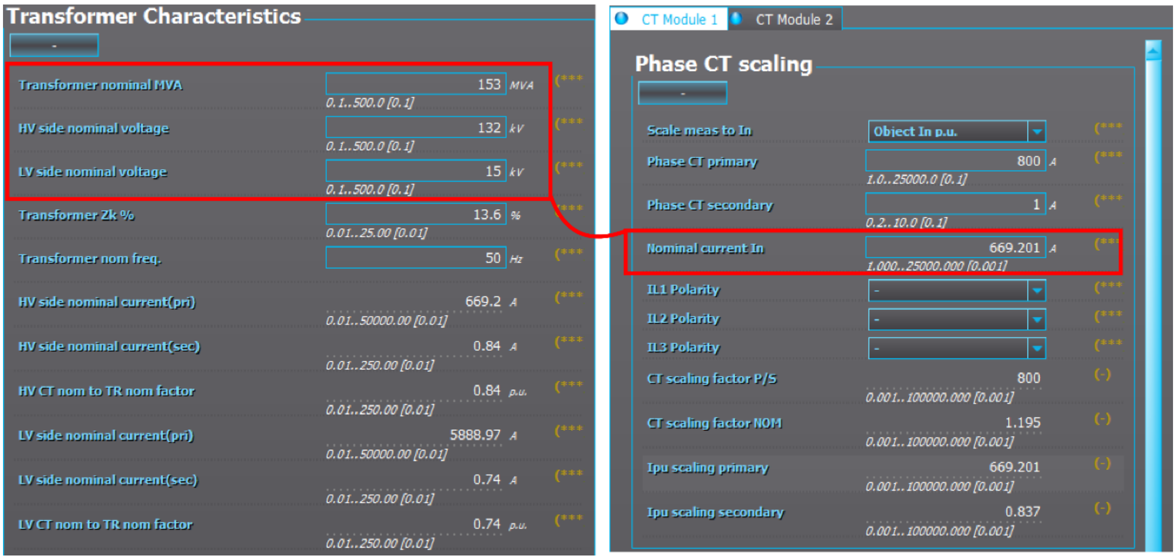
Table. 5.2.1. - 4. Initial data.

High-voltage side CT - CT primary: 800 A - CT secondary: 1 A High-voltage side nominal current 669 A	Ring core CT in Input I02 - 3I0CT primary: 250 A - 3I0CT secondary: 1 A	Low-voltage side CT - CT primary: 8000 A - CT secondary: 1 A Low-voltage side nominal current 5888 A

- both CTs are pointing through the transformer (HV-S2 and LV-S2 are pointing in the same direction)

The nominal current for both the HV and LV sides of the protected transformer are calculated based on the values set in the *Transformer characteristics* menu (*Protection → TrafoModule → TSTAT → INFO*). The ratio between the CT modules 1 and 2 can be set in their respective tabs at *Measurement → Transformers*. The per-unit scaling ("Scale meas. to In") is automatically set to "Object in p.u." in all machine protection relays and it cannot be changed.

Figure. 5.2.1. - 5. Phase CT scaling to machine nominal.



As seen in the image above, AQtivate calculates both the HV side nominal current (669.2 A) and the LV side nominal current (5 888.97 A). The nominal current calculations are done according to the following formulas:

$$\text{HV side nominal current (pri)} = \frac{trafo_{nom}/3}{U_{HV}/\sqrt{3}} = \frac{153\,000\,000/3}{132\,000/\sqrt{3}} \approx 669.201\ \text{A}$$

$$\text{LV side nominal current (pri)} = \frac{trafo_{nom}/3}{U_{LV}/\sqrt{3}} = \frac{153\,000\,000/3}{15\,000/\sqrt{3}} \approx 5888.97\ \text{A}$$

The HV and LV side nominal current can also be calculated in per unit values as follows:

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

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

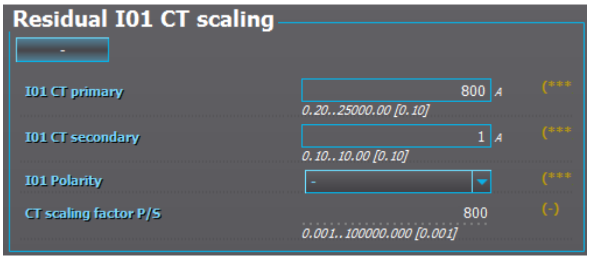
The secondary nominal current (in amperes) is the result of multiplying the per unit value with the phase CT secondary side current. This current can be used when the unit is commissioned and when the directions of CTs are checked. See the example calculation below:

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

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

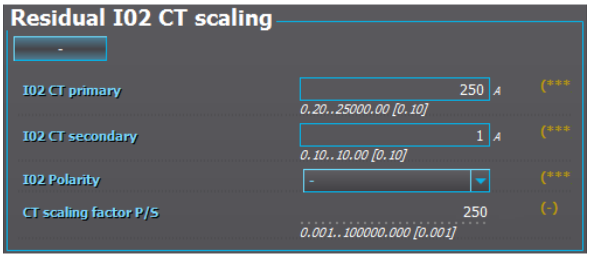
In case the phase current CTs are connected to the module via a Holmgren (summing) connection, the use of coarse residual current measurement settings is required: the "I01 CT" settings are set according to the phase current CTs' ratings (800/5 A).

Figure. 5.2.1. - 6. Residual I01 CT scaling (coarse).



The residual current CT is connected to the first CTM directly, which requires the use of sensitive residual current measurement settings: the "Residual I02 CT scaling" settings are set according to the residual current CT's ratings (250/1 A).

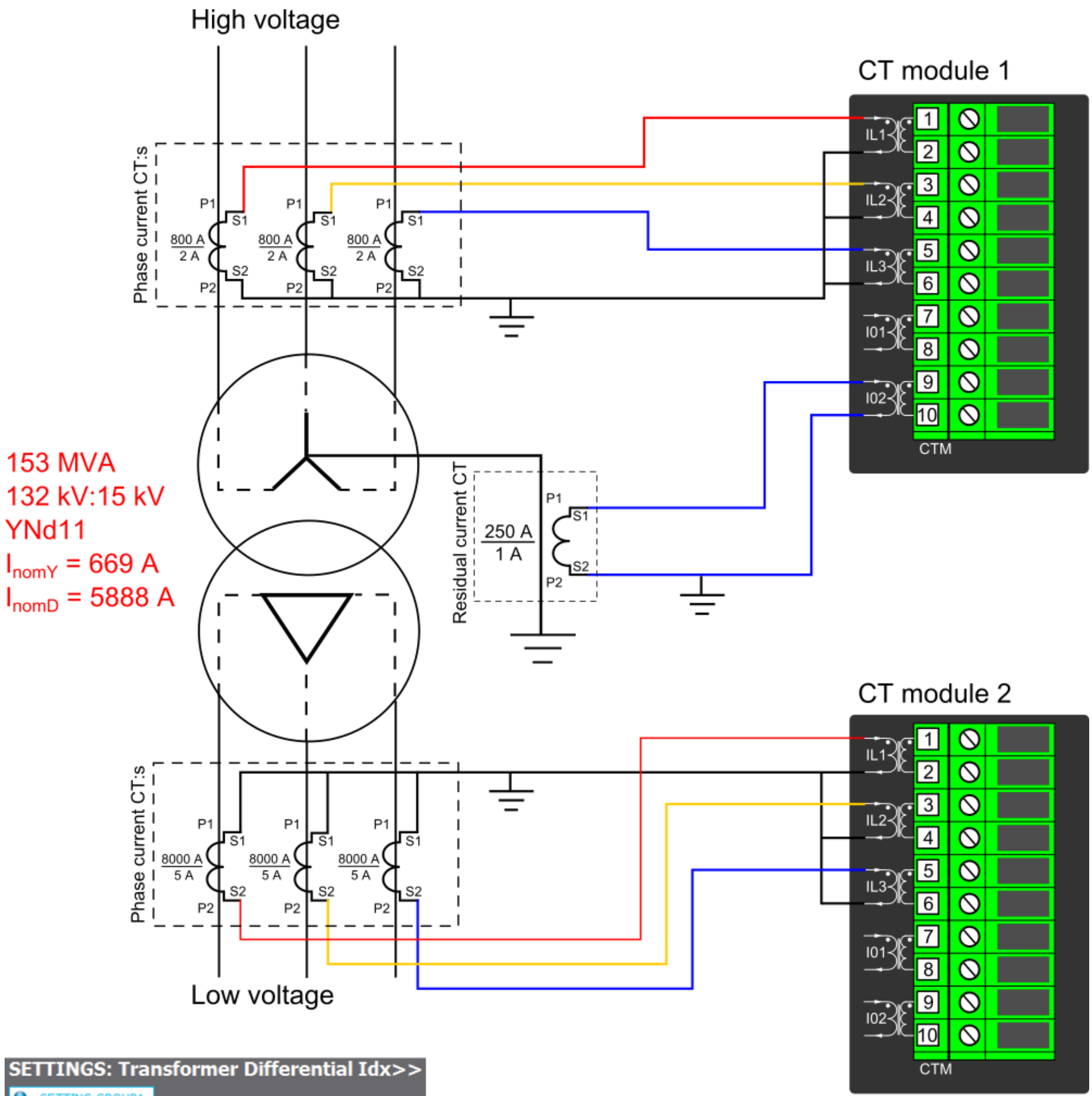
Figure. 5.2.1. - 7. Residual I02 CT scaling (sensitive).

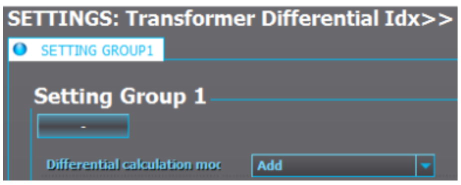


Example of CT scaling (application 2)

The following figure presents how the CTs are connected to the relay's measurement inputs. It also shows the CT ratings and the transformer nominal current. Note that S1 is always connected to an odd connector regardless of the CT direction. The CT direction is selected in the settings of the transformer differential protection function.

Figure. 5.2.1. - 8. Connections (application 2).





Because of the direction of the CTs and because the CTs' P1/S1 side is always wired to the modules's odd inputs, the "Differential calculation mode" has to be set to "Add" (*Protection → TrafoModule → Idx> [87T,87N] → Settings*). The difference with the first application is that here the CTs point towards the protected object instead of pointing through it.

The following table presents the initial data of the connection as well as the ratings.

Table. 5.2.1. - 5. Initial data.

Machine nominal power: 153 MVA
Machine high voltage side nominal amplitude: 132 kV
Machine low voltage side nominal amplitude: 15 kV

High voltage side CT - CT primary: 800 A - CT secondary: 2 A **High-voltage side nominal current** 669 A	**Residual current CT in Input I02** - 3I0CT primary: 250 A - 3I0CT secondary: 1 A	Low voltage side CT - CT primary: 8000 A - CT secondary: 5 A **Low-voltage side nominal current** 5 888 A
- both CTs are pointing towards the protected object (HV-S2 and LV-S2 are pointing at each other)		

The nominal currents on both the HV and the LV sides are the same as in Application 1. However, the CTs' secondary current levels have been changed to 2 A (on the HV side) and to 5 A (on the LV side). The nominal currents are still calculated the same way:

$$\text{HV side nominal current (pri)} = \frac{trafo_{nom}/3}{U_{HV}/\sqrt{3}} = \frac{153\,000\,000/3}{132\,000/\sqrt{3}} \approx 669.201\ \text{A}$$

$$\text{LV side nominal current (pri)} = \frac{trafo_{nom}/3}{U_{LV}/\sqrt{3}} = \frac{153\,000\,000/3}{15\,000/\sqrt{3}} \approx 5888.97\ \text{A}$$

The HV and LV side nominal current can also be calculated in per unit values as follows:

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

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

The secondary nominal current (in amperes) is the result of multiplying the per unit value with the phase CT secondary side current. This current can be used when the unit is commissioned and when the directions of CTs are checked. In Application 2 it is necessary to inject higher amplitudes to the CTs via the secondary injection tool in order to reach the nominal currents. See the example calculation below:

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

$$\text{LV side nominal current (sec)}$$
$$= LV\ CT\ nom\ to\ TR\ nom\ factor \times Phase\ CT\ secondary = 0.74\ \text{p.u.} \times 5\ \text{A} = 3.70\ \text{A}$$

Settings

Table. 5.2.1. - 6. 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.	The selection of the reference used in the relay's per-unit system scaling. Either the set phase current CT primary or the protected object's nominal current. (NOT APPLICBLE IN MACHINE PROTECTION!)
Phase CT primary	1…5000.0 A	0.1 A	100.0 A	The rated primary current of the current transformer.
Phase CT secondary	0.2…10.0 A	0.1 A	5.0 A	The rated secondary current of the current transformer.

Nominal current In	1…5000 A	0.01 A	100.00 A	The nominal current of the protected object. This setting is only visible if the option "Object In p.u." has been selected in the "Scale meas. to In" setting.
IL1 Polarity	0: - 1: Invert	-	0: -	The selection of the first current measurement channel's (IL1) polarity (direction). The default setting is for the positive current to flow from connector 1 to connector 2, with the secondary currents' starpoint pointing towards the line.
IL2 Polarity	0: - 1: Invert	-	0: -	The selection of the second current measurement channel's (IL2) polarity (direction). The default setting is for the positive current to flow from connector 3 to connector 4, with the secondary currents' starpoint pointing towards the line.
IL3 Polarity	0: - 1: Invert	-	0: -	The selection of the third current measurement channel's (IL3) polarity (direction). The default setting is for the positive current to flow from connector 5 to connector 6, with the secondary currents' starpoint pointing towards the line.
CT scaling factor P/S	-	-	-	A relay feedback value; the calculated scaling factor that is the ratio between the primary current and the secondary current.
CT scaling factor NOM	-	-	-	A relay feedback value; the calculated scaling factor that is the ratio between the set primary current and the set nominal current.
Ipu scaling primary	-	-	-	A relay feedback value; the scaling factor for the primary current's per-unit value.
Ipu scaling secondary	-	-	-	A relay feedback value; the scaling factor for the secondary current's per-unit value.

Table. 5.2.1. - 7. Settings of the Residual I01 CT scaling.

Name	Range	Step	Default	Description
I01 CT primary	1…5000.0 A	0.1 A	100.0 A	The rated primary current of the current transformer.
I01 CT secondary	0.2…10.0 A	0.1 A	5.0 A	The rated secondary current of the current transformer.
I01 Polarity	0: - 1: Invert	-	0: -	The selection of the coarse residual measurement channel's (I01) polarity (direction). The default setting is for the positive current to flow from connector 7 to connector 8.
CT scaling factor P/S	-	-	-	A relay feedback value; the calculated scaling factor that is the ratio between the primary current and the secondary current.

Table. 5.2.1. - 8. Settings of the Residual I02 CT scaling.

Name	Range	Step	Default	Description
I02 CT primary	1…5000.0 A	0.1 A	100.0 A	The rated primary current of the current transformer.
I02 CT secondary	0.1…10.0 A	0.1 A	5.0 A	The rated secondary current of the current transformer.
I02 Polarity	0: - 1: Invert	-	0: -	The selection of the sensitive residual measurement channel's (I02) polarity (direction). The default setting is for the positive current to flow from connector 9 to connector 10.
CT scaling factor P/S	-	-	-	A relay feedback value; the calculated scaling factor that is the ratio between the primary current and the secondary current.

Measurements

The following measurements are available in the measured current channels.

Table. 5.2.1. - 9. Per-unit phase current measurements.

Name	Range	Step	Description
Phase current ILx ("Pha.curr.ILx")	0.00…1250.0 × In	0.01 × In	The fundamental frequency RMS current measurement (in p.u.) from each of the phase current channels.
Phase current ILx TRMS ("Pha.curr.ILx TRMS")	0.00…1250.0 × In	0.01 × In	The TRMS current (inc. harmonics up to 31st) measurement (in p.u.) from each of the phase current channels.
Peak-to-peak current ILx ("P-P curr.ILx")	0.00…500.0 × In	0.01 × In	The peak-to-peak current measurement (in p.u.) from each of the phase current channels.

Table. 5.2.1. - 10. Primary phase current measurements.

Name	Range	Step	Description
Primary phase current ILx ("Pri.Pha.curr.ILx")	0.00…1 000 000.0 A	0.01 A	The primary fundamental frequency RMS current measurement from each of the phase current channels.
Primary phase current ILx TRMS ("Pha.curr.ILx TRMS Pri")	0.00…1 000 000.0 A	0.01 A	The primary TRMS current (inc. harmonics up to 31st) measurement from each of the phase current channels.

Table. 5.2.1. - 11. Secondary phase current measurements.

Name	Range	Step	Description
Secondary phase current ILx "Sec.Pha.curr.ILx")	0.00…300.0 A	0.01 A	The primary fundamental frequency RMS current measurement from each of the phase current channels.
Secondary phase current ILx TRMS ("Pha.curr.ILx TRMS Sec")	0.00…300.0 A	0.01 A	The primary TRMS current (inc. harmonics up to 31st) measurement from each of the phase current channels.

Table. 5.2.1. - 12. Phase current angle measurements.

Name	Range	Step	Description
Phase angle ILx ("Pha.angle ILx")	0.00…360.00 deg	0.01 deg	The phase angle measurement from each of the three phase current inputs.

Table. 5.2.1. - 13. Per-unit residual current measurements.

Name	Range	Step	Description
Residual current I0x ("Res.curr.I0x")	0.00…1250.0 × In	0.01 × In	The fundamental frequency RMS current measurement (in p.u.) from the residual current channel I01 or I02.
Calculated I0 ("calc.I0")	0.00…1250.0 × In	0.01 × In	The fundamental frequency RMS current measurement (in p.u.) from the calculated I0 current channel.
Phase current I0x TRMS ("Res.curr.I0x TRMS")	0.00…1250.0 × In	0.01 × In	The TRMS current (inc. harmonics up to 31st) measurement (in p.u.) from the residual current channel I01 or I02.
Peak-to-peak current I0x ("P-P curr.I0x")	0.00…500.0 × In	0.01 × In	The peak-to-peak current measurement (in p.u.) from the residual current channel I01 or I02.

Table. 5.2.1. - 14. Primary residual current measurements.

Name	Range	Step	Description
Primary residual current I01 ("Pri.Res.curr.I0x")	0.00…1 000 000.0 A	0.01 A	The primary fundamental frequency RMS current measurement from the residual current channel I01 or I02.
Primary calculated I0 ("Pri.calc.I0")	0.00…1 000 000.0 A	0.01 A	The primary fundamental frequency RMS current measurement from the calculated current channel I0.
Primary residual current I0x TRMS ("Res.curr.I01 TRMS Pri")	0.00…1 000 000.0 A	0.01 A	The TRMS current (inc. harmonics up to 31st) measurement from the primary residual current channel I01 or I02.

Table. 5.2.1. - 15. Secondary residual current measurements.

Name	Range	Step	Description
Secondary residual current I0x ("Sec.Res.curr.I0x")	0.00…300.0 A	0.01 A	The secondary fundamental frequency RMS current measurement from the residual current channel I01 or I02.
Secondary calculated I0 ("Sec.calc.I0")	0.00…300.0 A	0.01 A	The secondary fundamental frequency RMS current measurement from the calculated current channel I0.
Secondary residual current I0x TRMS ("Res.curr.I0x TRMS Sec")	0.00…300.0 A	0.01 A	The secondary TRMS current (inc. harmonics up to 31st) measurement from the secondary residual current channel I01 or I02.

Table. 5.2.1. - 16. Residual current phase angle measurements.

Name	Range	Step	Description
Residual current angle I0x ("Res.curr.angle I0x")	0.00…360.00 deg	0.01 deg	The residual current angle measurement from the I01 or I02 current input.
Calculated I0 phase angle ("calc.I0 Pha.angle")	0.00…360.00 deg	0.01 deg	The calculated residual current angle measurement.

Table. 5.2.1. - 17. Per-unit sequence current measurements.

Name	Range	Step	Description
Positive sequence current ("Pos.seq.curr.")	0.00…1250.0 × In	0.01 × In	The measurement (in p.u.) from the calculated positive sequence current.
Negative sequence current ("Neg.seq.curr.")	0.00…1250.0 × In	0.01 × In	The measurement (in p.u.) from the calculated negative sequence current.
Zero sequence current ("Zero seq.curr.")	0.00…1250.0 × In	0.01 × In	The measurement (in p.u.) from the calculated zero sequence current.

Table. 5.2.1. - 18. Primary sequence current measurements.

Name	Range	Step	Description
Primary positive sequence current ("Pri.Pos.seq.curr.")	0.00…1 000 000.0 A	0.01 A	The primary measurement from the calculated positive sequence current.
Primary negative sequence current ("Pri.Neg.seq.curr.")	0.00…1 000 000.0 A	0.01 A	The primary measurement from the calculated negative sequence current.

Primary zero sequence current ("Pri.Zero seq.curr.")	0.00…1 000 000.0 A	0.01 A	The primary measurement from the calculated zero sequence current.

Table. 5.2.1. - 19. Secondary sequence current measurements.

Name	Range	Step	Description
Secondary positive sequence current ("Sec.Pos.seq.curr.")	0.00…300.0 A	0.01 A	The secondary measurement from the calculated positive sequence current.
Secondary negative sequence current ("Sec.Neg.seq.curr.")	0.00…300.0 A	0.01 A	The secondary measurement from the calculated negative sequence current.
Secondary zero sequence current ("Sec.Zero seq.curr.")	0.00…300.0 A	0.01 A	The secondary measurement from the calculated zero sequence current.

Table. 5.2.1. - 20. Sequence phase angle measurements.

Name	Range	Step	Description
Positive sequence current angle ("Pos.seq.curr.angle")	0.00…360.0 deg	0.01 deg	The calculated positive sequence current angle.
Negative sequence current angle ("Neg.seq.curr.angle")	0.00…360.0 deg	0.01 deg	The calculated negative sequence current angle.
Zero sequence current angle ("Zero seq.curr.angle")	0.00…360.0 deg	0.01 deg	The calculated zero sequence current angle.

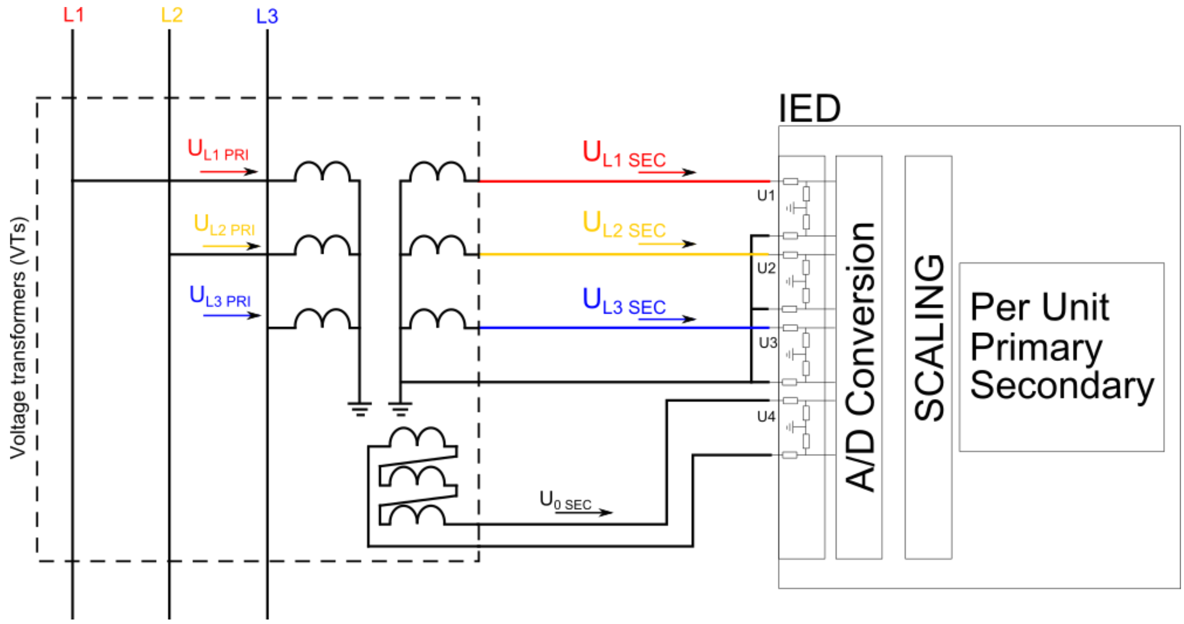
Table. 5.2.1. - 21. Harmonic current measurements.

Name	Range	Step	Default	Description
Harmonics calculation values ("Harm Abs.pr Perc.")	0: Percent 1: Absolute	-	0: Percent	Defines whether the harmonics are calculated as percentage or absolute values.
Harmonics display	0: Per unit 1: Primary A 2: Secondary A	-	0: Per unit	Defines how the harmonics are displayed: in p.u. values, as primary current values, or as secondary current values.
Maximum harmonics value ("IxxMaxH")	0.00…1 000 000.00 A	0.01 A		Displays the maximum harmonics value of the selected current input ILx or I0x.
Fundamental frequency ("Ixx Fund")	0.00…1 000 000.00 A	0.01 A		Displays the current value of the fundamental frequency from the selected current input ILx or I0x.
Ixx harmonics (2nd…31st harmonic)	0.00…1 000 000.00 A	0.01 A		Displays the selected harmonic from the current input ILx or I0x.

5.2.2. Voltage measurement and scaling

The voltage measurement module (VT module, or VTM) is used for measuring the voltages from voltage transformers. The measured values are processed into the measurement database and they are used by measurement and protection functions (the protection function availability depends of the relay type). It is essential to understand the concept of voltage measurements to be able to get correct measurements.

Figure. 5.2.2. - 9. Voltage measurement terminology



PRI: The primary voltage, i.e. the voltage which flows in the primary circuit and through the primary side of the voltage transformer.

SEC: The secondary voltage, i.e. the voltage which the voltage transformer transforms according to the ratio. This voltage is measured by the protection relay.

For the measurements to be correct the user needs to ensure that the measurement signals are connected to the correct inputs, that the voltage direction correct, and that the scaling is set correctly.

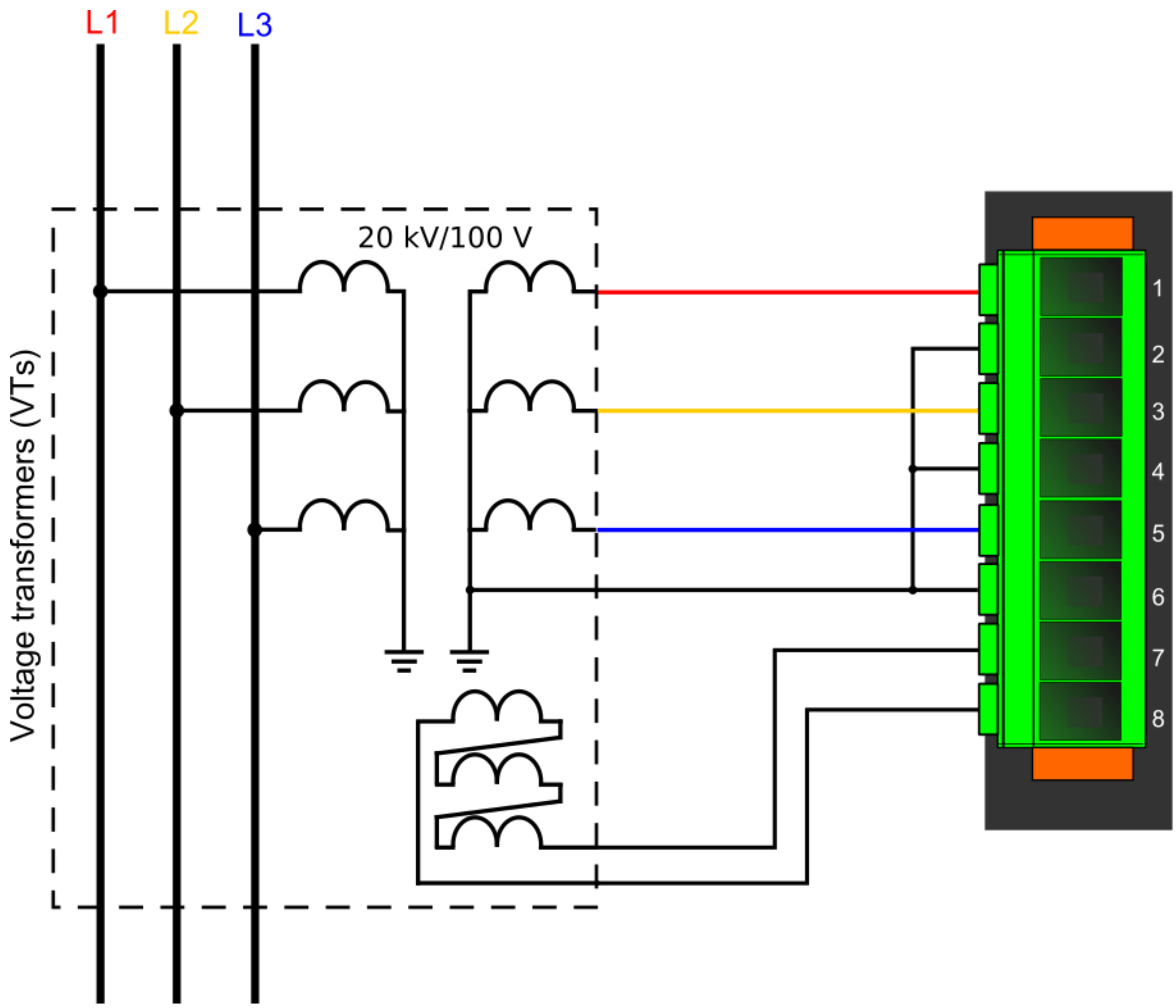
The relay calculates the scaling factors based on the set VT primary, and secondary voltage values. The relay measures secondary voltages, which are the voltage outputs from the VT installed into the application's primary circuit. The voltage can be measured directly from the system (up to 400 V) as well. The rated primary and secondary voltages of the VT need to be set for the relay to "know" the primary and per-unit values. In modern protection devices this scaling calculation is done internally after the voltage transformer's primary and secondary voltages are set.

Normally, the primary line-to-line voltage rating for VTs is 400 V...60 kV, while the secondary voltage ratings are 100 V...210 V. Non-standard ratings can also be directly connected as the scaling settings are flexible and have large ranges.

Example of VT scaling

The following figure presents how VTs are connected to the relay's measurement inputs. It also shows the VT ratings. In the figure below, three line-to-neutral voltages are connected along with the zero sequence voltage; therefore, the 3LN+U4 mode must be selected and the U4 channel must be set as U0. Other possible connections are presented later in this chapter.

Figure. 5.2.2. - 10. Connections.



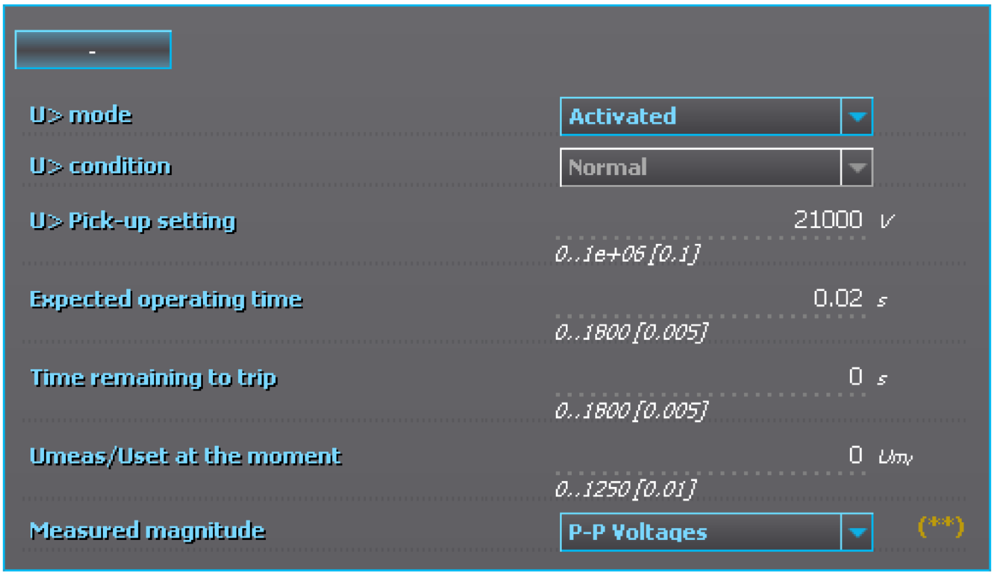
The following table presents the initial data of the connection.

Table. 5.2.2. - 22. Initial data.

Phase voltage VT	Zero sequence voltage VT
- VT primary: 20 000 V	- U4 VT primary: 20 000 V
- VT secondary: 100 V	- U4 VT secondary: 100 V
- the zero sequence voltage is connected similarly to line-to-neutral voltages (+U0).	
- in case wiring is incorrect, all polarities can be individually switched by 180 degrees in the relay.	

If the protection is voltage-based, the supervised voltage can be based either on line-to-line voltages or on line-to-earth voltages. This selection is defined in the "Measured magnitude" of each protection stage menu separately (*Protection* → *Voltage* → [protection stage menu] → *INFO*; see the image below). The number of available protection functions depends on the relay type.

Figure. 5.2.2. - 11. Selecting the measured magnitude.

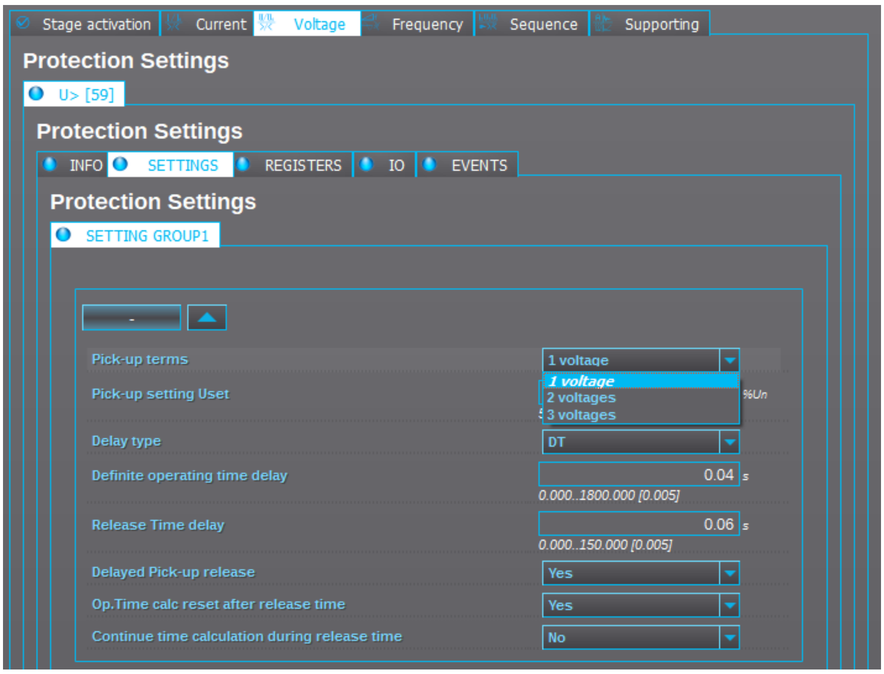


Voltage protection itself is based on the nominal voltage. A 20 000 V nominal voltage equals a 100 % setting in voltage-based protection functions. A 120 % trip setting in the overvoltage stage equals to 24 000 V on the primary level (in this case a 20 % increase equals 4000 V).

Once the setting have been sent to the device, AQtivate calculates the scaling factors and displays them for the user. The "VT scaling factor P/S" describes the ratio between the primary voltage and the secondary voltage. The per-unit scaling factors ("VT scaling factor p.u.") for both primary and secondary values are also displayed.

The triggering of a voltage protection stage can be based on one, two, or three voltages (the "Pick-up terms" setting at *Protection* → *Voltage* → [protection stage menu] → *Settings*). Fault loops are either line-to-line or line-to-neutral according to the "Measured magnitude" setting. As a default, the activation of any one voltage trips the voltage protection stage.

Figure. 5.2.2. - 12. Selecting the operating mode.

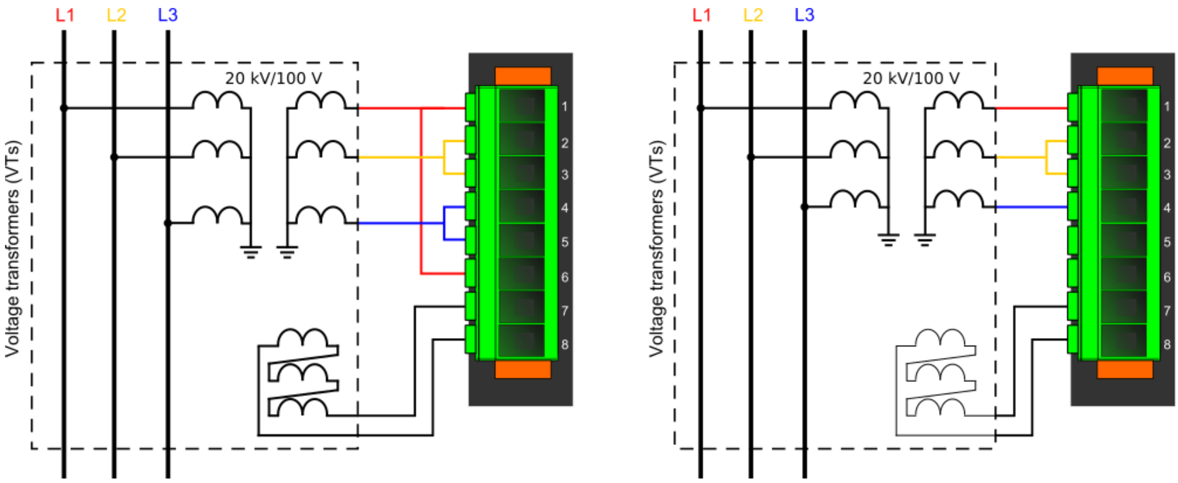


There are several different ways to use all four voltage channels. The voltage measurement modes are the following:

- 3LN+U0 (three line-to-neutral voltages and the measured zero sequence voltage U0)
- 3LN+U4 (three line-to-neutral voltages and the U4)
- 3LL+U4 (three line-to-line voltages and the U4)
- 2LL+U3+U4 (two line-to-line voltages, the U3, and the U4)

The 3LN+U0 is the most common voltage measurement mode. See below for example connections of voltage line-to-line measurement (3LL on the left, 2LL on the right).

Figure. 5.2.2. - 13. Example connections for voltage line-to-line measurement.

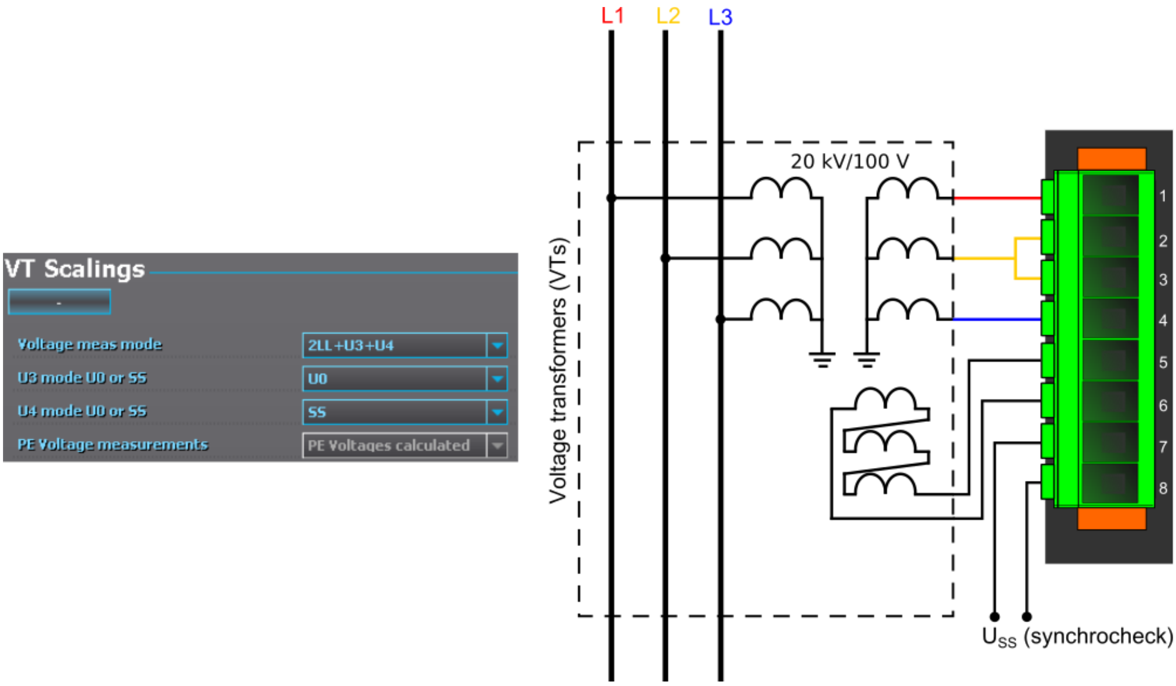


If only two line-to-line voltages are measured, the third one (U_{L31}) is calculated based on the U_{L12} and U_{L23} vectors. When measuring line-to-line voltages, the line-to-neutral voltages can also be calculated as long as the value of U0 is measured and known.

The voltage measurement channel U4 can also be used to measure either the zero sequence voltage (U0) or the side 2 voltage (Synchrocheck). If the 2LL+U3+U4 mode is selected, the third channel (U3) can be used for this purpose. Please note that U0 can only be measured by using a single channel.

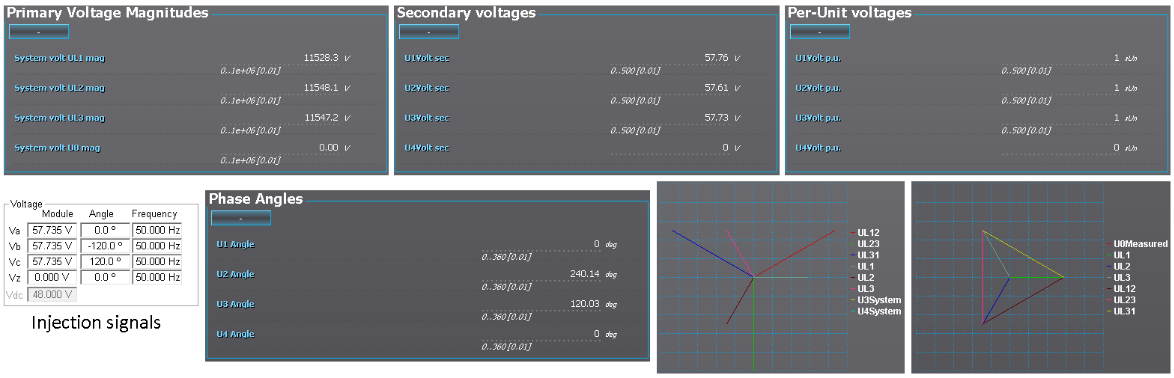
In the image below is an example of 2LL+U0+SS, that is, two line-to-line measurements with the zero sequence voltage and voltage from side 2 for Synchrocheck. Since U0 is available, line-to-neutral voltages can be calculated.

Figure. 5.2.2. - 14. 2LL+U0+SS settings and connections.



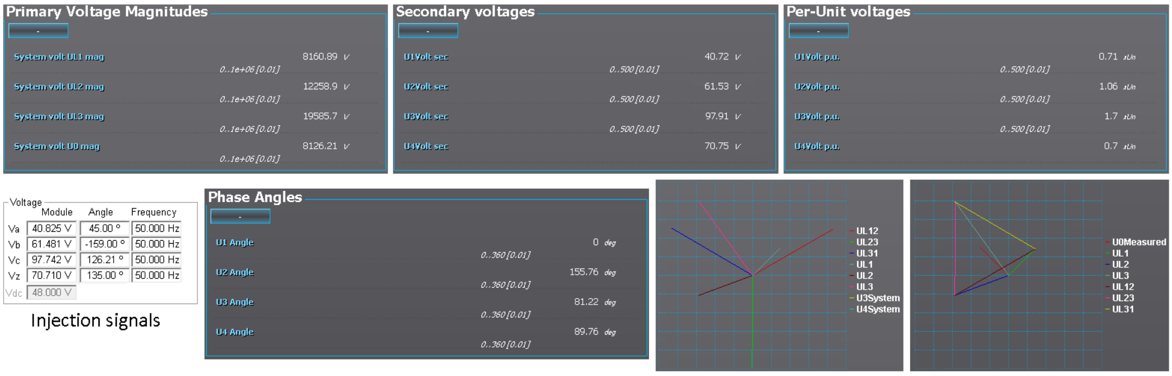
The image collection below presents the relay's behavior when nominal voltage is injected into the relay via secondary test equipment. The measurement mode is 3LN+U4 which means that the relay is measuring line-to-neutral voltages. The VT scaling has been set to 20 000 : 100 V. The U4 channel measures the zero sequence voltage which has the same ratio (20 000 : 100 V).

Figure. 5.2.2. - 15. Relay behavior when nominal voltage injected.



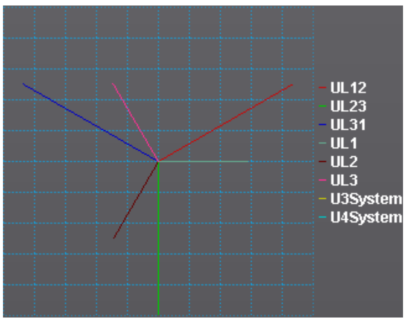
The image collection below presents the relay's behavior when voltage is injected into the relay via secondary test equipment during an earth fault. The measurement mode is 3LN+U4 which means that the relay is measuring line-to-neutral voltages. The VT scaling has been set to 20 000 : 100 V. The U4 channel measures the zero sequence voltage which has the same ratio (20 000 : 100 V).

Figure. 5.2.2. - 16. Relay behavior when voltage injected during an earth fault.



Troubleshooting

When the measured voltage values differ from the expected voltage values, the following table offers possible solutions for the problems.

Problem	Check / Resolution
The measured voltage amplitude in all phases does not match the injected voltage.	The scaling settings or the voltage measurement mode may be wrong, check that the settings match the expectations in AQtivate (*Measurement* → *Transformers* → *VT Module*).
The measured voltage amplitude does not match one of the measured phases./ The calculated U0 is measured even though it should not.	Check the wiring connections between the injection device or the VTs and the relay.
The measured voltage amplitudes are OK but the angles are strange./ The voltage unbalance protection trips immediately after activation./ The earth fault protection trips immediately after it is activated and voltage calculated.	The voltages are connected to the measurement module but the order or polarity of one or all phases is incorrect. In AQtivate, go to *Measurement* → *Phasors* and check the "System voltage vectors" diagram. When all connections are correct, the diagram (symmetric feeding) should look like this: 

Settings

Table. 5.2.2. - 23. Settings of the VT scaling.

Name	Range	Step	Default	Description
Voltage measurement mode ("Voltage meas mode")	0: 3LN+U4 1: 3LL+U4 2: 2LL+U3+U4	-	0: 3LN+U4	The relay's voltage wiring method. The voltages are scaled according the set voltage measurement mode.

U3 mode U0 or SS	0: Not Used 1: U0 2: SS	-	0: Not Used	The voltage channel U3 can be used to measure zero sequence voltage (U0) or the Synchrocheck voltage (SS). If neither is needed, the (default) option "Not Used" should be active. This setting is only valid if the "2LL+U3+U4" mode is selected.
U0 (U3) Measured from	0: Broken Delta 1: Neutral point 2: Open delta	-	0: Broken delta	Defines how the secondary voltage is scaled to the primary. Does not affect how protection operates, it only affects the displayed primary voltages. This parameter is visible when the "U3 mode U0 or SS" has been set to the "U0" mode.
U4 mode U0 or SS	0: Not Used 1: U0 2: SS	-	0: Not Used	The voltage channel U4 can be used to measure zero sequence voltage (U0) or the Synchrocheck voltage (SS). If neither is needed, the (default) option "Not Used" should be active.
U0 (U4) Measured from	0: Broken Delta 1: Neutral point 2: Open delta	-	0: Broken delta	Defines how the secondary voltage is scaled to the primary. Does not affect how protection operates, it only affects the displayed primary voltages. This parameter is visible when the "U4 mode U0 or SS" has been set to the "U0" mode.
Voltage memory	0: Disabled 1: Activated	-	0: Disabled	Activates voltage memory. Chapter "Voltage memory" describes the function in more detail.
P-E Voltage measurements	0: No P-E voltages available 1: P-E Voltages calculated 2: P-E Voltages measured	-	-	Indicates whether or not phase-to-earth voltages are available. Also indicates whether P-E voltages are measured from the voltage channels directly or if they are calculated from line-to-line and line-to-neutral voltages.
VT primary	1…1 000 000.0 V	0.1 V	20 000.0 V	The rated primary voltage of the voltage transformer.
VT secondary	0.2…400.0 V	0.1 V	100.0 V	The rated secondary voltage of the voltage transformer.
U3 Res/SS VT primary	1…1 000 000 V	0.1 V	20 000.0V	The primary nominal voltage of the connected U0 or SS VT. This setting is only valid if the "2LL+U3+U4" mode is selected.
U3 Res/SS VT secondary	0.2…400 V	0.1 V	100.0 V	The secondary nominal voltage of the connected U0 or SS VT. This setting is only valid if the "2LL+U3+U4" mode is selected.
U4 Res/SS VT primary	1…1 000 000 V	0.1 V	20 000.0 V	The primary nominal voltage of the connected U0 or SS VT.
U4 Res/SS VT secondary	0.2…400 V	0.1 V	100.0 V	The secondary nominal voltage of the connected U0 or SS VT.
U1 Polarity	0: - 1: Invert	-	0: -	The selection of the first voltage measurement channel's (U1) polarity (direction). The default setting is for the positive voltage to flow from connector 1 to connector 2, with the secondary voltage's starpoint pointing towards the line.
U2 Polarity	0: - 1: Invert	-	0: -	The selection of the second voltage measurement channel's (U2) polarity (direction). The default setting is for the positive voltage to flow from connector 1 to connector 2, with the secondary voltage's starpoint pointing towards the line.
U3 Polarity	0: - 1: Invert	-	0: -	The selection of the third voltage measurement channel's (U3) polarity (direction). The default setting is for the positive voltage to flow from connector 1 to connector 2, with the secondary voltage's starpoint pointing towards the line.
U4 Polarity	0: - 1: Invert	-	0: -	The selection of the fourth voltage measurement channel's (U4) polarity (direction). The default setting is for the positive voltage to flow from connector 1 to connector 2, with the secondary voltage's starpoint pointing towards the line.
VT scaling factor P/S	-	-	-	A relay feedback value; the calculated scaling factor that is the ratio between the primary voltage and the secondary voltage.
VT scaling factor p.u. Pri	-	-	-	A relay feedback value; the scaling factor for the primary voltage's per-unit value.

VT scaling factor p.u. Sec	-	-	-	A relay feedback value; the scaling factor for the secondary voltage's per-unit value.
U3 VT scaling factor P/S U0/SS	-	-	-	A relay feedback value; the scaling factor that is the ratio between the U3 channel's primary and secondary voltages. This setting is only valid if the "2LL+U3+U4" mode is selected.
U3 scaling factor p.u. Pri	-	-	-	A relay feedback value for channel U3; the scaling factor for the primary voltage's per-unit value. This setting is only valid if the "2LL+U3+U4" mode is selected.
U3 scaling factor p.u. Sec	-	-	-	A relay feedback value for channel U3; the scaling factor for the secondary voltage's per-unit value. This setting is only valid if the "2LL+U3+U4" mode is selected.
U4 VT scaling factor P/S U0/SS	-	-	-	A relay feedback value; the scaling factor that is the ration between the U4 channel's primary and secondary voltages. This setting is only valid is the "2LL+U3+U4" mode is selected.
U4 scaling factor p.u. Pri	-	-	-	A relay feedback value for channel U4; the scaling factor for the primary voltage's per-unit value. This setting is only valid if the "2LL+U3+U4" mode is selected.
U4 scaling factor p.u. Sec	-	-	-	A relay feedback value for channel U4; the scaling factor for the secondary voltage's per-unit value. This setting is only valid if the "2LL+U3+U4" mode is selected.

Measurements

The following measurements are available in the measured voltage channels.

Table. 5.2.2. - 24. Per-unit voltage measurements.

Name	Range	Step	Description
Voltage Ux ("UxVolt p.u.")	0.00…500.0 × U_n	0.01 V	The fundamental frequency RMS voltage measurement (in p.u.) from each of the voltage channels.
Voltage Ux TRMS ("UxVolt TRMS p.u.")	0.00…500.0 × U_n	0.01 V	The TRMS voltage (inc. harmonics up to 31st) measurement (in p.u.) from each of the voltage channels.

Table. 5.2.2. - 25. Secondary voltage measurements.

Name	Range	Step	Description
Secondary voltage Ux ("Ux Volt sec")	0.00…500.0 × U_n	0.01 V	The secondary fundamental frequency RMS voltage measurement from each of the voltage channels.
Secondary voltage Ux TRMS ("UxVolt TRMS sec")	0.00…500.0 × U_n	0.01 V	The secondary TRMS voltage (inc. harmonics up to 31st) measurement from each of the voltage channels.

Table. 5.2.2. - 26. Voltage phase angle measurements.

Name	Range	Step	Description
Ux Angle	0.00…360.00 deg	0.01 deg	The phase angle measurement from each of the four voltage inputs.

Table. 5.2.2. - 27. Per-unit sequence voltage measurements.

Name	Range	Step	Description
Positive sequence voltage ("Pos.seq.Volt.p.u.")	0.00…500.0 × U_n	0.01 × U_n	The measurement (in p.u.) from the calculated positive sequence voltage.

Negative sequence voltage ("Neg.seq.Volt.p.u.")	0.00…500.0 × U_n	0.01 × U_n	The measurement (in p.u.) from the calculated negative sequence voltage.
Zero sequence voltage ("Zero.seq.Volt.p.u.")	0.00…500.0 × U_n	0.01 × U_n	The measurement (in p.u.) from the calculated zero sequence voltage.

Table. 5.2.2. - 28. Primary sequence voltage measurements.

Name	Range	Step	Description
Primary positive sequence voltage ("Pos.seq.Volt.pri")	0.00…1 000 000.00 × U_n	0.01 V	The primary measurement from the calculated positive sequence voltage.
Primary negative sequence voltage ("Neg.seq.Volt.pri")	0.00…1 000 000.00 × U_n	0.01 V	The primary measurement from the calculated negative sequence voltage.
Primary zero sequence voltage ("Zero.seq.Volt.pri")	0.00…1 000 000.00 × U_n	0.01 V	The primary measurement from the calculated zero sequence voltage.

Table. 5.2.2. - 29. Secondary sequence voltage measurements.

Name	Range	Step	Description
Secondary positive sequence voltage ("Pos.seq.Volt.sec")	0.00…4800.0 V	0.01 V	The secondary measurement from the calculated positive sequence voltage.
Secondary negative sequence voltage ("Neg.seq.Volt.sec")	0.00…4800.0 V	0.01 V	The secondary measurement from the calculated negative sequence voltage.
Secondary zero sequence voltage ("Zero.seq.Volt.sec")	0.00…4800.0 V	0.01 V	The secondary measurement from the calculated zero sequence voltage.

Table. 5.2.2. - 30. Sequence voltage angle measurements.

Name	Range	Step	Description
Positive sequence voltage angle ("Pos.seq.Volt.Angle")	0.00…360.0 deg	0.01 deg	The calculated positive sequence voltage angle.
Negative sequence voltage angle ("Neg.seq.Volt.Angle")	0.00…360.0 deg	0.01 deg	The calculated negative sequence voltage angle.
Zero sequence voltage angle ("Zero.seq.Volt.Angle")	0.00…360.0 deg	0.01 deg	The calculated zero sequence voltage angle.

Table. 5.2.2. - 31. System primary voltage measurements.

Name	Range	Step	Description
System voltage magnitude UL12 ("System volt UL12 mag")	0.00…1 000 000.00 V	0.01 V	The primary fundamental frequency RMS line-to-line UL12 voltage (measured or calculated). You can also select the row where the unit for this is kV.
System voltage magnitude UL23 ("System volt UL23 mag")	0.00…1 000 000.00 V	0.01 V	The primary fundamental frequency RMS line-to-line UL23 voltage (measured or calculated). You can also select the row where the unit for this is kV.

System voltage magnitude UL31 ("System volt UL31 mag")	0.00…1 000 000.00 V	0.01 V	The primary fundamental frequency RMS line-to-line UL31 voltage (measured or calculated). You can also select the row where the unit for this is kV.
System voltage magnitude UL1 ("System volt UL1 mag")	0.00…1 000 000.00 V	0.01 V	The primary fundamental frequency RMS line-to-neutral UL1 voltage (measured or calculated). You can also select the row where the unit for this is kV.
System voltage magnitude UL2 ("System volt UL2 mag")	0.00…1 000 000.00 V	0.01 V	The primary fundamental frequency RMS line-to-neutral UL2 voltage (measured or calculated). You can also select the row where the unit for this is kV.
System voltage magnitude UL3 ("System volt UL3 mag")	0.00…1 000 000.00 V	0.01 V	The primary fundamental frequency RMS line-to-neutral UL3 voltage (measured or calculated). You can also select the row where the unit for this is kV.
System voltage magnitude U0 ("System volt U0 mag")	0.00…1 000 000.00 V	0.01 V	The primary fundamental frequency RMS zero sequence U0 voltage (measured or calculated). You can also select the row where the unit for this is kV. There is also a row where the unit is %.
System voltage magnitude U3 ("System volt U3 mag")	0.00…1 000 000.00 V	0.01 V	The primary measured fundamental frequency RMS Synchrocheck voltage (SS). This magnitude is displayed only when the "2LL+U3+U4" mode is selected and both U3 and U4 are in use. You can also select the row where the unit for this is kV.
System voltage magnitude U4 ("System volt U4 mag")	0.00…1 000 000.00 V	0.01 V	The primary measured fundamental frequency RMS Synchrocheck voltage (SS). This magnitude is displayed only when the "2LL+U3+U4" mode is selected and both U3 and U4 are in use. You can also select the row where the unit for this is kV.

Table. 5.2.2. - 32. Primary system voltage angles.

Name	Range	Step	Description
System voltage angle UL12 ("System volt UL12 ang")	0.00…360.0 deg	0.01 deg	The primary line-to-line angle UL12 (measured or calculated).
System voltage angle UL23 ("System volt UL23 ang")	0.00…360.0 deg	0.01 deg	The primary line-to-line angle UL23 (measured or calculated).
System voltage angle UL31 ("System volt UL31 ang")	0.00…360.0 deg	0.01 deg	The primary line-to-line angle UL23 (measured or calculated).

System voltage angle UL1 ("System volt UL1 ang")	0.00…360.0 deg	0.01 deg	The primary line-to-neutral angle UL1 (measured or calculated).
System voltage angle UL2 ("System volt UL2 ang")	0.00…360.0 deg	0.01 deg	The primary line-to-neutral angle UL2 (measured or calculated).
System voltage angle UL3 ("System volt UL3 ang")	0.00…360.0 deg	0.01 deg	The primary line-to-neutral angle UL3 (measured or calculated).
System voltage angle U0 ("System volt U0 ang")	0.00…360.0 deg	0.01 deg	The primary zero sequence angle U0 (measured or calculated).
System voltage angle U3 ("System volt U3 ang")	0.00…360.0 deg	0.01 deg	The primary measured Synchrocheck angle SS. This magnitude is only valid when the "2LL+U3+U4" mode is selected and both U3 and U4 are in use.
System voltage angle U4 ("System volt U4 ang")	0.00…360.0 deg	0.01 deg	The primary measured Synchrocheck angle SS. This magnitude is displayed only when the "2LL+U3+U4" mode is selected and both U3 and U4 are in use.

Table. 5.2.2. - 33. Harmonic voltage measurements.

Name	Range	Step	Default	Description
Harmonics calculation values ("Harm Abs.or Perc.")	0: Percent 1: Absolute	-	0: Percent	Defines whether the harmonics are calculated as percentages or absolute values.
Harmonics display	0: Per unit 1: Primary V 2: Secondary V	-	0: Per unit	Defines how the harmonics are displayed: in p.u. values, as primary voltage values, or as secondary voltage values.
Maximum harmonics value ("UxMaxH")	0.00…100 000.00 V	0.01 V	-	Displays the maximum harmonics value of the selected voltage input Ux.
Fundamental frequency ("Ux Fund")	0.00…100 000.00 V	0.01 V	-	Displays the voltage value of the fundamental frequency from the selected voltage input Ux.
Ux harmonics (2^{nd}...31^{st} harmonic)	0.00...100 000.00 V	0.01 V	-	Displays the selected harmonic from the voltage input Ux.

5.2.3. Power and energy calculation

The relays that are equipped with both a voltage and a current card can calculate power, and can therefore have power-based protection and monitoring functions (the number of available functions depends of the relay type). In addition to power calculations, energy magnitudes are also calculated.

Power is divided into three magnitudes: apparent power (S), active power (P) and reactive power (Q). Energy measurement calculates magnitudes for active and reactive energy. Energy can flow to the forward direction (exported) or to the reverse direction (imported).

If a unit has more than one CT measurement module, the user can choose which module's current measurement is used by the power calculation.

Line-to-neutral voltages available

Power is calculated from line-to-neutral voltages and phase currents. If line-to-line voltages are connected, the relay can calculate line-to-neutral voltages based on the measured zero sequence voltage. The following equations apply for power calculations with the line-to-neutral mode and the line-to-line voltage mode (with U0 connected and measured):

Figure. 5.2.3. - 17. Three-phase power (S) calculation.

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

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

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

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

Figure. 5.2.3. - 18. Three-phase active power (P) calculation.

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

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

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

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

In these equations, phi (φ) is the angle difference between voltage and current.

Figure. 5.2.3. - 19. 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 can be to the forward or the reverse direction. The direction of active power can be indicated with the power factor (Cos (φ), or Cosine phi), which is calculated according the following formula:

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

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

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

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

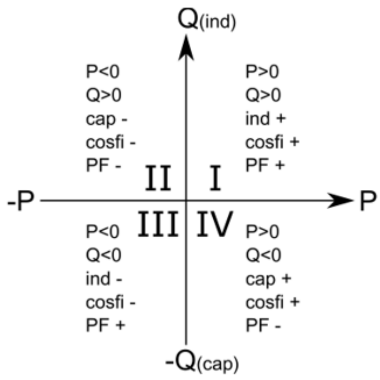
The direction of reactive power is divided into four quadrants. Reactive power may be inductive or capacitive on both forward and reverse directions. Reactive power quadrant can be indicated with Tan (φ) (tangent phi), which is calculated according the following formula:

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

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

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

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



Power factor calculation is done similarly to the power factor calculation but the polarity is defined by the reactive power direction. Therefore, the 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

If the line-to-line voltages are measured but the zero sequence voltage is not measured or is not otherwise known, the three-phase power calculation is based on Aron's theorem:

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

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

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

Both cos(φ) and tan(φ) are calculated in the same way as in the line-to-neutral mode.

Troubleshooting

Check the "Troubleshooting" section in chapters “Current measurement and scaling” and “Voltage measurement and scaling” for more information. Most power and energy measurement problems are usually related to the same issues (i.e. wiring errors, wrong measurement modes, faulty frequency settings, etc.).

Settings

Table. 5.2.3. - 34. Power and energy measurement settings

Name	Range	Step	Default	Description

Three-phase active energy measurement ("EP meas 3ph")	0: Disabled 1: Enabled	-	0: Disabled	Enables/disables the active energy measurement.
Three-phase reactive energy measurement ("EQ meas 3ph")	0: Disabled 1: Enabled	-	0: Disabled	Enables/disables the reactive energy measurement.
Three-phase energy prefix ("E 3ph M or k")	0: Mega 1: Kilo	-	0: Mega	Defines whether energy is measured with the prefix 'kilo' (10^3) or 'mega' (10^6).
PQ Quadrant	0: Undefined 1: Q1 Fwd Ind 2: Q2 Rev Cap 3: Q3 Rev Ind 4: Q4 Fwd Cap	-	0: Undefined	Indicates what the power PQ quadrant is at that 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	Indicates what the power VA quadrant is at that moment.
Reset energy calculators ("Reset 3ph Energies")	0: - 1: Reset	-	0: -	Resets the memory of the three-phase energy calculators. Goes automatically back to the "-" state after the reset is finished.
EP per phase measurement ("EP meas per phase")	0: Disabled 1: Enabled	-	0: Disabled	Enables/disables the active energy per phase measurement.
EQ per phase measurement ("EQ meas per phase")	0: Disabled 1: Enabled	-	0: Disabled	Enables/disables the reactive energy per phase measurement.
Per phase energy prefix ("E phs M or k")	0: Mega 1: Kilo	-	0: Mega	Defines whether energy (per phase) is measured with the prefix 'kilo' (10^3) or 'mega' (10^6).
Reset energy calculators (per phase) ("Reset E per phase")	0: - 1: Reset	-	0: -	Resets the memory of the indivisual phase energy calculator. Goes automatically back to the "-" state after the reset is finished.

Table. 5.2.3. - 35. Energy Dose Counter 1 settings

Name	Range	Step	Default	Description
Energy dose counter mode	0: Disabled 1: Activated	-	0: Disabled	Enables/disables energy dose counters generally.
DC 1…4 enable	0: Disabled 1: Enabled	-	0: Disabled	Enables/disables the 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.React.EQ.CAP 3: 3PH.Fwd.React.EQ.IND 4: 3PH.Rev.React.EQ.CAP 5: 3PH.Rev.React.EQ.IND	-	0: 3PH.Fwd.Act.EP	Selects whether the energy is active or reactive, whether the direction of the energy is forward of reverse, and whether reactive energy is inductive or capacitive.
DC 1…4 Input signal	-1 × 10^6…1 × 10^6	0.01	-	The total amount of energy consumed.
DC 1…4 Pulse magnitude	0…1800 kW/var	0.005 kW/var	1 kW/Var	The set pulse size. An energy pulse is given every time the set magnitude is exceeded.
DC 1…4 Pulse length	0…1800 s	0.005 s	1 s	The total length of a control pulse.
DC1…4 Pulses sent	0…4 294 967 295	1	-	Indicates the total number of pulses sent.

Table. 5.2.3. - 36. DC 1…4 Pulse out settings

Name	Range	Step	Default	Description
DC 1…4 Pulse out	OUT1…OUTx	-	None selected	The selection of the controlled physical outputs.

Power measurements

The following power calculations are available when the voltage and the current cards are available.

Table. 5.2.3. - 37. Three-phase power calculations.

Name	Range	Step	Description
3PH Apparent power (S)	-1x10^6… 1x10^6 kVA	0.01 kVA	The total three-phase apparent power. In AQtivate, the row below displays this in MVA.
3PH Active power (P)	-1x10^6…1x10^6 kW	0.01 kW	The total three-phase active power. In AQtivate, the row below displays this in MW.
3PH Reactive power (Q)	-1x10^6…1x10^6 kVar	0.01 kVar	The total three-phase reactive power. In AQtivate, the row below displays this in MVar.
3PH Tan(phi)	-1x10^6…1x10^6	0.01	The direction of three-phase active power
3PH Cos(phi)	-1x10^6…1x10^6	0.01	The direction of three-phase reactive power
3PH PF	-1x10^6…1x10^6	0.0001	The three-phase power factor

Table. 5.2.3. - 38. Single phase power calculations (L1...L3).

Name	Range	Step	Description
Lx Apparent power (S)	-1x10^6…1x10^6 kVA	0.01 kVA	The apparent power of Phase Lx
Lx Active power (P)	-1x10^6…1x10^6 kW	0.01 kW	The active power of Phase Lx
Lx Reactive power (Q)	-1x10^6…1x10^6 kVar	0.01 kVar	The reactive power of Phase Lx
Lx Tan(phi)	-1x10^6…1x10^6	0.01	The direction of Phase Lx's active power
Lx Cos(phi)	-1x10^6…1x10^6	0.01	The direction of Phase Lx's reactive power
Lx PF	-1x10^6…1x10^6	0.0001	The power factor of Phase Lx

Energy measurements

The following energy calculations are available when the voltage and the current cards are available. Please note that the unit prefix is determined by the user's selection between 'kilo' and 'mega' in "Three-phase energy prefix ("E 3ph M or k")" under the general "Power and energy measurement settings".

Table. 5.2.3. - 39. Three-phase energy calculations.

Name	Range	Step	Description
Exp.Active Energy (kWh or MWh)	-999 999 995 904.00…999 999 995 904.00	0.01	The total amount of exported active energy.
Imp.Active Energy (kWh or MWh)	-999 999 995 904.00…999 999 995 904.00	0.01	The total amount of imported active energy.
Exp/Imp.Act.E balance (kWh or MWh)	-999 999 995 904.00…999 999 995 904.00	0.01	The sum of imported and exported active energy.
Exp.React.Cap.E. (kVarh or MVarh)	-999 999 995 904.00…999 999 995 904.00	0.01	The total amount of exported reactive capacitive energy.
Imp.React.Cap.E. (kVarh or MVarh)	-999 999 995 904.00…999 999 995 904.00	0.01	The total amount of imported reactive capacitive energy.
Exp/Imp React.Cap.E.bal. (kVarh or MVarh)	-999 999 995 904.00…999 999 995 904.00	0.01	The sum of imported and exported reactive capacitive energy.
Exp.React.Ind.E. (kVarh or MVarh)	-999 999 995 904.00…999 999 995 904.00	0.01	The total amount of exported reactive inductive energy.
Imp.React.Ind.E. (kVarh or MVarh)	-999 999 995 904.00…999 999 995 904.00	0.01	The total amount of imported reactive inductive energy.
Exp/Imp React.Ind.E.bal. (kVarh or MVarh)	-999 999 995 904.00…999 999 995 904.00	0.01	The sum of imported and exported reactive inductive energy.

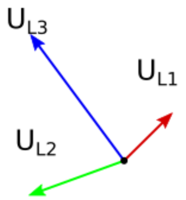
Table. 5.2.3. - 40. Single phase energy calculations (L1...L3).

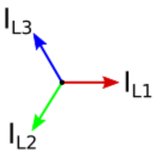
Name	Range	Step	Description
Lx Exp.Active Energy (kWh or MWh)	$-1x10^9$… $1x10^9$	0.01	The exported active energy of the phase.
Lx Imp.Active Energy (kWh or MWh)	$-1x10^9$… $1x10^9$	0.01	The imported active energy of the phase.
Lx Exp/Imp.Act.E balance (kWh or MWh)	$-1x10^9$… $1x10^9$	0.01	The sum of the phase's imported and exported active energy.
Lx Exp.React.Cap.E. (kVarh or MVarh)	$-1x10^9$… $1x10^9$	0.01	The exported reactive capacitive energy of the phase.
Lx Imp.React.Cap.E. (kVarh or MVarh)	$-1x10^9$… $1x10^9$	0.01	The imported reactive capacitive energy of the phase.
Lx Exp/Imp React.Cap.E.bal. (kVarh or MVarh)	$-1x10^9$… $1x10^9$	0.01	The sum of the phase's imported and exported reactive capacitive energy.
Lx Exp.React.Ind.E. (kVarh or MVarh)	$-1x10^9$… $1x10^9$	0.01	The exported reactive inductive energy of the phase.
Lx Imp.React.Ind.E. (kVarh or MVarh)	$-1x10^9$… $1x10^9$	0.01	The imported reactive inductive energy of the phase.
Lx Exp/Imp React.Ind.E.bal. (kVarh or MVarh)	$-1x10^9$… $1x10^9$	0.01	The sum of the phase's imported and exported reactive inductive energy.

Calculation examples

Here is an example of power calculation. Both wiring methods (line-to-line and line-to-neutral) are checked with the same signal injection. The voltage scaling is set to 20 000 : 100 V and the current scaling is set to 1000 : 5 A.

Voltages (line-to-neutral):	Currents:
U_{L1} = 40.825 V, 45.00°	I_{L1} = 2.5 A, 0.00°
U_{L2} = 61.481 V, -159.90°	I_{L2} = 2.5 A, -120.00°
U_{L3} = 97.742 V, 126.21°	I_{L3} = 2.5 A, 120.00°





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

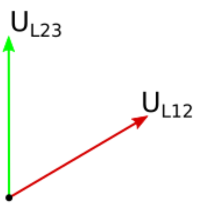
$$P_{L1} = U_{L1} \times I_{L1} \cos\varphi = 40.825\text{ V} \times 2.5\text{ A} \cos(45° - 0°) = 72.2\text{ W (secondary) } 2.89\text{ MW (primary)}$$

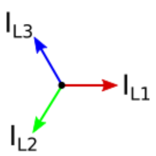
$$Q_{L1} = U_{L1} \times I_{L1} \sin\varphi = 40.825\text{ V } \times 2.5\text{ A} \sin(45° - 0°) = 72.2\text{ var (secondary) } 2.89\text{ MVar (primary)}$$

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

Name	Value	Name	Value	Name	Value	Name	Value
L1 (S)	4.08 MVA	L2 (S)	6.15 MVA	L3 (S)	9.77 MVA	3PH (S)	20.00 MVA
L1 (P)	2.89 MW	L2 (P)	4.72 MW	L3 (P)	9.71 MW	3PH (P)	17.32 MW
L1 (Q)	2.89 Mvar	L2 (Q)	-3.94 Mvar	L3 (Q)	1.06 Mvar	3PH (Q)	0.01 Mvar
L1 Tan	1.00	L2 Tan	-0.83	L3 Tan	0.11	3PH Tan	0.00
L1 Cos	0.71	L2 Cos	0.77	L3 Cos	0.99	3PH Cos	0.87

Voltages (line-to-line):	Currents:
U_{L12} = 100.00 V, 30.00°	I_{L1} = 2.5 A, 0.00°
U_{L23} = 100.00 V, -90.00°	I_{L2} = 2.5 A, -120.00°
	I_{L3}= 2.5 A, 120.00°





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

$$S = 100\ \text{V} \times 2.5\ \text{A} + 100\ \text{V} \times 2.5\ \text{A} = 500\ \text{VA (sec)}\ 20.00\ \text{MVA (pri)}$$

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

$$P = 100\ \text{V} \times 2.5\ \text{A} \cos -(30° - 0°) + 100\ \text{V} \times 2.5\ \text{A} \cos(270° - 240°) = 433\ \text{W}\ (sec)\ 17.32\ \text{MW}\ (pri)$$

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

$$Q = 100\ \text{V} \times 2.5\ \text{A} \sin -(30° - 0°) + 100\ \text{V} \times 2.5\ \text{A} \sin(270° - 240°) = 0\ \text{var (sec)}\ 0\ \text{Mvar}\ (pri)$$

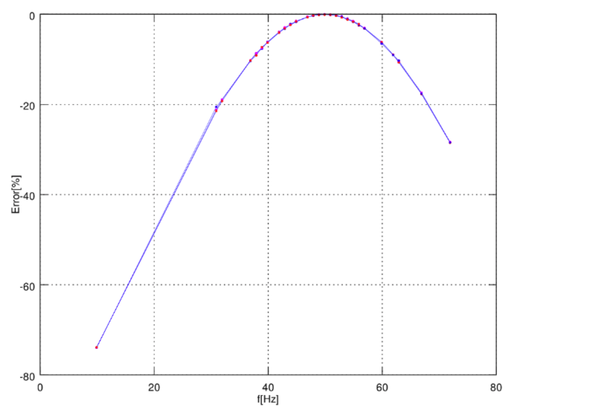
$$3PH\ Tan(phi) = {}^{Q}/_{P} = {}^{0.01}/_{17.32} = 0.00 \qquad 3PH\ Cos(phi) = {}^{P}/_{S} = {}^{17.32}/_{20.00} = 0.87$$

Name	Values
3PH (S)	20.00 MVA
3PH (P)	17.32 MW
3PH (Q)	0.00 Mvar
3PH Tan	0.00
3PH Cos	0.87

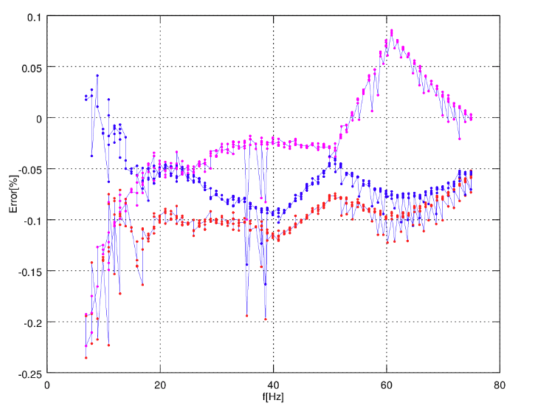
5.2.4. Frequency tracking and scaling

Measurement sampling can be set to the frequency tracking mode or to the fixed user-defined frequency sampling mode. The benefit of frequency tracking is that the measurements are within a pre-defined accuracy range even when the fundamental frequency of the power system changes.

Table. 5.2.4. - 41. Frequency tracking effect (FF changes from 6 Hz to 75 Hz).



The measurement error with a fixed 50 Hz sampling frequency when the frequency changes. The constant current is 5 A, the frequency sweep is from 6 Hz to 75 Hz.



The measurement error with frequency tracking when the frequency changes. The constant current is 5 A, the frequency sweep is from 6 Hz to 75 Hz.

As the figures above show, the sampling frequency has a major effect on the relay's measurement accuracy. If the sampling is not tracked to the system frequency, for example a 10 Hz difference between the measured and the set system frequency can give a measurement error of over 5 %.The figures also show that when the frequency is tracked and the sampling is adjusted according to the detected system frequency, the measurement accuracy has an approximate error of -0.1...- 0.2 % in the whole frequency range.

AQ-2xx series devices have a measurement accuracy that is independent of the system frequency. This has been achieved by adjusting the sample rate of the measurement channels according to the measured system frequency; this way the FFT calculation always has a whole power cycle in the buffer. The measurement accuracy is further improved by Arcteq's patented calibration algorithms that calibrate the analog channels against eight (8) system frequency points for both magnitude and angle. This frequency-dependent correction compensates the frequency dependencies in the used, non-linear measurement hardware and improves the measurement accuracy significantly. Combined, these two methods give an accurate measurement result that is independent of the system frequency.

Troubleshooting

When the measured current, voltage or frequency values differ from the expected values, the following table offers possible solutions for the problems.

Problem	Check / Resolution
The measured current or voltage amplitude is lower than it should be./ The values are "jumping" and are not stable.	The set system frequency may be wrong. Please check that the frequency settings match the local system frequency, or change the measurement mode to "Tracking" (*Measurement* → *Frequency* → "Smpl mode") so the relay adjusts the frequency itself.
The frequency readings are wrong.	In Tracking mode the relay may interpret the frequency incorrectly if no current is injected into the CT (or voltage into the VT). Please check the frequency measurement settings (*Measurement* → *Frequency*).

Settings

Table. 5.2.4. - 42. Settings of the frequency tracking.

Name	Range	Step	Default	Description
Sampling mode ("Smpl mode")	0: Fixed 1: Tracking	-	0: Fixed	Defines which measurement sampling mode is in use: the fixed user-defined frequency, or the tracked system frequency.
System nominal frequency ("Sys.nom.f")	7.000…75.000 Hz	0.001 Hz	50 Hz	The user-defined system nominal frequency that is used when the "Sampling mode" setting has been set to "Fixed".
Tracked system frequency ("Track.sys.f")	0.000…75.000 Hz	0.001 Hz	-	Displays the rough measured system frequency.
Sampling frequency in use ("Sampl.f used")	0.000…75.000 Hz	0.001 Hz	-	Displays the tracking frequency that is in use at that moment.
Frequency reference 1 ("f Ref1")	0: None 1: CT1IL1 2: CT2IL1 3: VT1U1 4: VT2U1	-	1: CT1IL1	The first reference source for frequency tracking.
Frequency reference 2 ("f Ref2")	0: None 1: CT1IL2 2: CT2IL2 3: VT1U2 4: VT2U2	-	1: CT1IL2	The second reference source for frequency tracking.
Frequency reference 3 ("f Ref3")	0: None 1: CT1IL3 2: CT2IL3 3: VT1U3 4: VT2U3	-	1: CT1IL3	The third reference source for frequency tracking.

Frequency tracker quality ("f.tr qual")	0: No trackable channels 1: Reference 1 trackable 2: Reference 2 trackable 3: References 1 & 2 trackable 4: Reference 3 trackable 5: Reference 1 & 3 trackable 6: References 2 & 3 trackable 7: All references trackable	-	-	Defines the frequency tracker quality. If the measured current (or voltage) amplitude is below the threshold, the channel tracking quality is 0 and cannot be used for frequency tracking. If all channels' magnitudes are below the threshold, there are no trackable channels.
Frequency measurement in use ("f.meas in use")	0: No track ch 1: Ref1 2: Ref2 3: Ref3	-	-	Indicates which reference is used at the moment for frequency tracking.
Start behavior	0: Start tracking immediately 1: First nominal or tracked	-	0: Start tracking immediately	Defines the how the tracking starts. Tracking can start immediately, or there can be a set delay time between the receiving of the first trackable channel and the start of the tracking.
Start sampling with ("Start smpl with")	0: Use track frequency 1: Use nom frequency	-	0: Use track frequency	Defines the start of the sampling. Sampling can begin with a previously tracked frequency, or with a user-set nominal frequency.
Use nominal frequency until ("Use nom freq until")	0…1800.000s	0.005s	0.100s	Defines how long the nominal frequency is used after the tracking has started. This setting is only valid when the "Sampling mode" setting is set to "Tracking" and when the "Start behavior" is set to "First nominal or tracked".
Channel A tracked frequency ("Tracked f CHA")	0.000…75.000 Hz	0.001 Hz	50 Hz	Displays the rough value of the tracked frequency in Channel A.
Channel B tracked frequency ("Tracked f CHB")	0.000…75.000 Hz	0.001 Hz	50 Hz	Displays the rough value of the tracked frequency in Channel B.
Channel C tracked frequency ("Tracked f CHC")	0.000…75.000 Hz	0.001 Hz	50 Hz	Displays the rough value of the tracked frequency in Channel C.

5.3. General menu

The *General* menu consists of basic settings and indications of the device. Additionally, the all activated functions and their status are displayed in the *Protection*, *Control* and *Monitor* profiles.

Table. 5.3. - 43. Parameters and indications in the *General* menu.

Name	Description	Range	Step	Default
Device name	The file name uses these fields when loading the aqs configuration file from the AQ-200 unit.	-	-	Unitname
Device location		-	-	Unitlocation

Timesync. source	If an external clock time synchronization source is available, the type is defined with this parameter. In the internal mode there is no external Timesync source. IRIG-B requires a serial fiber communication option card.	0: Internal 1: External NTP 2: External Serial 3: IRIG-B	-	0: Internal
Enable stage forcing	When this parameter is enabled it is possible for the user to force the protection, control and monitoring functions to different statuses like START and TRIP. This is done in the function's *Info* page with the *Status force to* parameter.	0: Disabled 1: Enabled	-	0: Disabled
System phase rotating order	Allows the user to switch the expected order in which the phase measurements are wired to the unit.	0: A-B-C 1: A-C-B	-	0: A-B-C
Language	Changes the parameter description languages in the HMI.	0: User defined 1: English 2: Suomi 3: Svenska 4: Español 5: Français	-	1: English
Clear events	Clears the event history recorded in the AQ-200 device.	0: - 1: Clear	-	0: -
Display brightness	Changes the display brightness. Brightness level 0 turns the display off.	0…8	1	4
Display sleep timeout	If no buttons are pressed after a set time, the display will change the brightness to whatever is set on the *Display sleep brigthness* parameter. If set to 0, this feature is not in use.	0…3600 s	1 s	0 s
Display sleep brightness	Defines the brightness of the display when *Display sleep timeout* has elapsed. Brightness level 0 turns the display off.	0…8	1	0
Return to default view	If the user navigates to a menu and gives no input after a period of time defined with this parameter, the unit will return to the default view automatically. If time is set to 0 s, this feature is not in use.	0…3600 s	10 s	0 s
LED test	When activated, all LEDs are lit up. LEDs with multiple possible colors blink each color.	0: - 1: Activated	-	0: -
Reset latches	Resets the latched signals in the logic and the matrix. When a reset command is given the parameter will return back to "-" automatically.	0: - 1: Reset	-	0: -
Measurement recorder	Enables the *Measurement recorder* tool. The Measurement recorder is configured in *Tools → Misc → Measurement recorder.*	0: Disabled 1: Enabled	-	0: Disabled
Mimic reconfigure	Reload the mimic to the unit.	0: - 1: Reconfigure	-	0: -

Table. 5.3. - 44. The *General* menu indications

Name	Description
Serial number	The unique serial number identification of the unit.
SW version	The firmware software version of the unit.
HW conf.	The order code identification of the unit.
UTC time	The UTC time value which the device's clock uses.

5.4. Protection functions

5.4.1. Non-directional overcurrent (I>; 50/51)

The non-directional overcurrent function is used for instant overcurrent and short circuit protection. The number of stages in the function depends on the relay model. The operating decisions are based on phase current magnitude, constantly measured by the function. The available phase current magnitudes are equal to fundamental frequency RMS values, to TRMS values (including harmonics up to 32^{nd}), or to peak-to-peak values. The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

The outputs of the function are the START, TRIP and BLOCKED signals. The non-directional overcurrent function uses a total of eight (8) 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 between definite time (DT) mode and inverse definite minimum time (IDMT) mode. The IDMT operation supports both IEC and ANSI standard time delays as well as custom parameters. The function includes CT saturation checking which allows the function to start and operate accurately during CT saturation.

The operational logic consists of the following:

- input magnitude selection
- input magnitude processing
- saturation check
- threshold comparator
- block signal check
- time delay characteristics
- output processing.

The basic design of the protection function is the three-pole operation.

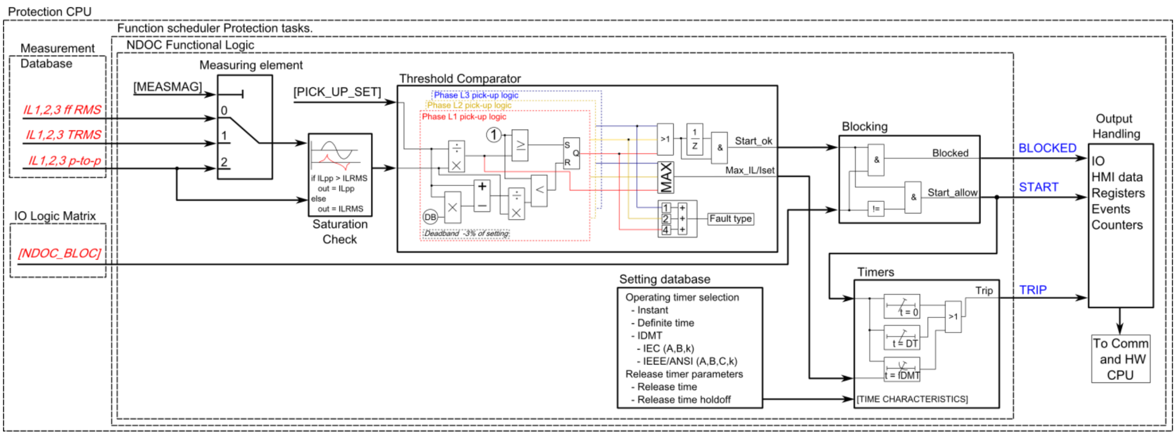
The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed current magnitudes.

The function outputs the START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signal. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the non-directional overcurrent function.

Figure. 5.4.1. - 20. Simplified function block diagram of the I> function.



Measured input

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

Table. 5.4.1. - 45. Measurement inputs of the I> 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

The selection of the AI channel in use is made with a setting parameter. In all possible input channel variations the pre-fault condition is presented with a 20 ms averaged history value from -20 ms from 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 to change them by editing the setting group.

Table. 5.4.1. - 46. 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: Side 1 2: Side 2	-	1: Side 1

Pick-up

The I_{set} setting parameter controls the pick-up of the I> function. This defines the maximum allowed measured current before action from the function. The function constantly calculates the ratio between the I_{set} and the measured magnitude (I_m) for each of the three phases. The reset ratio of 97 % is built into the function and is always relative to the I_{set} value. The setting value is common for all measured phases, and when the I_m exceeds the I_{set} value (in single, dual or all phases) it triggers the pick-up operation of the function.

Table. 5.4.1. - 47. Pick-up settings.

Name	Description	Range	Step	Default
I_{set}	Pick-up setting	0.10…50.00 × I_n	0.01 × I_n	1.20 × I_n

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

Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. Additionally, the non-directional overcurrent function includes an internal inrush harmonic blocking option which is applied according to the parameters set by the user. 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. 5.4.1. - 48. Internal inrush harmonic blocking settings.

Name	Description	Range	Step	Default
Inrush harmonic blocking (internal-only trip)	2^{nd} harmonic blocking enable/disable	0: No 1: Yes	-	0: No
2^{nd} harmonic block limit (Iharm/Ifund)	2^{nd} harmonic blocking limit	0.10…50.00 $\%I_{fund}$	0.01 $\%I_{fund}$	0.01 $\%I_{fund}$

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a-time stamped blocking event with information of the startup current values and its fault type to be issued.

The blocking signal can also be tested in the commissioning phase by a software switch signal when the relay's testing mode "Enable stage forcing" is activated (*General → Device*).

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

Operating time characteristics for trip and reset

This function supports definite time delay (DT) and inverse definite minimum time delay (IDMT). For detailed information on these delay types please refer to the chapter "General properties of a protection function" and its section "Operating time characteristics for trip and reset".

Events and registers

The non-directional overcurrent function (abbreviated "NOC" in event block names) generates events and registers from the status changes in START, TRIP and BLOCKED. The user can select the status ON or OFF for messages in the main event buffer. The function offers four (4) independent stages; the events are segregated for each stage operation.

The triggering event of the function (START, TRIP or BLOCKED) is recorded with a time stamp and with process data values.

Table. 5.4.1. - 49. Event codes.

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
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

The function registers its operation into the last twelve (12) time-stamped registers; this information is available for all provided instances separately. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.

Table. 5.4.1. - 50. Register content.

Date and time	Event code	Fault type	Trigger current	Fault current	Pre-fault 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	0 ms...1800 s	Setting group 1...8 active

5.4.2. Non-directional earth fault (I0>; 50N/51N)

The non-directional earth fault function is used for instant and time-delayed earth fault protection. The number of stages in the function depend on the device model. The operating characteristics are based on the selected neutral current magnitudes which the function measures constantly. The available analog measurement channels are I01 and I02 (residual current measurement) and I0Calc (residual current calculated from phase current). The user can select these channels to use fundamental frequency RMS values, TRMS values (including harmonics up to 32nd), or peak-to-peak values. The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

The outputs of the function are the START, TRIP and BLOCKED signals. The non-directional earth fault function uses a total of eight (8) separate setting groups which can be selected from one common source.

The function can operate on instant or time-delayed mode. In the time-delayed mode the operation can be selected for definite time (DT) or for inverse definite minimum time (IDMT); the IDMT operation supports both IEC and ANSI standard time delays as well as custom parameters. The function includes the checking of CT saturation which allows the function to start and operate accurately even during CT saturation.

The operational logic consists of the following:

- input magnitude selection
- input magnitude processing
- saturation check
- threshold comparator
- block signal check
- time delay characteristics
- output processing.

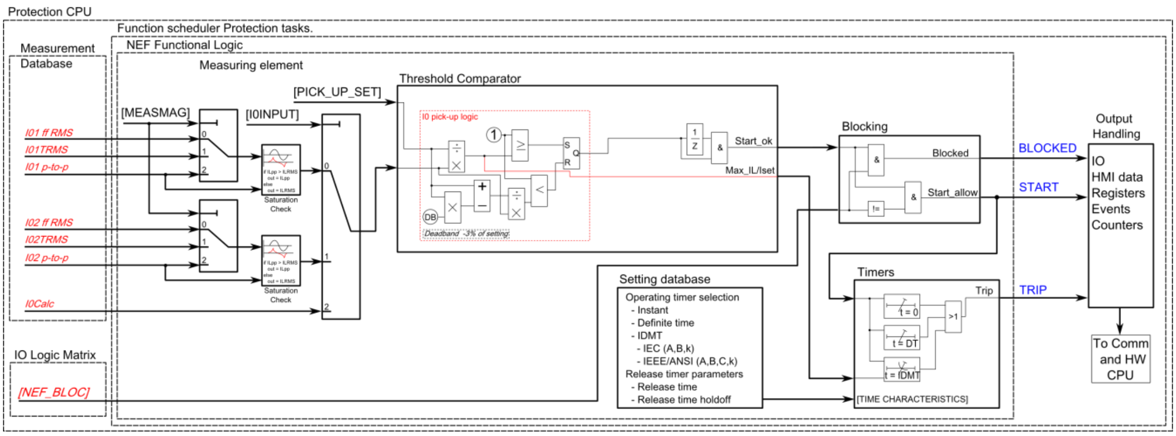
The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed current magnitudes.

The function outputs the START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signals. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the non-directional earth fault function.

Figure. 5.4.2. - 21. Simplified function block diagram of the I0> fucntion.



Measured input

The function block uses analog current measurement values and always uses peak-to-peak measurements from samples. The user can select the monitored magnitude to be equal to fundamental frequency RMS values, to TRMS values from the whole harmonic specter of 32 components, or to peak-to-peak values. A -20 ms averaged value of the selected magnitude is used for pre-fault data registering.

Table. 5.4.2. - 51. Measurement inputs of the I0> 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

The selection of the AI channel currently in use is made with a setting parameter. In all possible input channel variations the pre-fault condition is presented with a 20 ms averaged history value from -20 ms from a 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 to change them by editing the setting group.

Table. 5.4.2. - 52. 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: Side 1 2: Side 2	-	1: Side 1
Input selection	Defines which measured residual current is used by the function.	1: I01 2: I02 3: I0Calc	-	1: I01

Pick-up

The $I0_{set}$ setting parameter controls the the pick-up of the I0> function. This defines the maximum allowed measured current before action from the function. The function constantly calculates the ratio between the $I0_{set}$ and the measured magnitude (I_m) for each of the three phases. The reset ratio of 97 % is built into the function and is always relative to the $I0_{set}$ value. The setting value is common for all measured phases. When the I_m exceeds the $I0_{set}$ value (in single, dual or all phases) it triggers the pick-up operation of the function.

Table. 5.4.2. - 53. Pick-up settings.

Name	Description	Range	Step	Default
$I0_{set}$	Pick-up setting	0.0001…40.00 × I_n	0.0001 × I_n	1.20 × I_n

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

Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. Additionally, non-directional earth fault protection includes an internal inrush harmonic blocking option which is applied according to the parameters set by the user. 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. 5.4.2. - 54. 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	-	0: No
2nd harmonic block limit (Iharm/Ifund)	2nd harmonic blocking limit	0.10…50.00 $\%I_{fund}$	0.01 $\%I_{fund}$	0.01 $\%I_{fund}$

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and processes the release time characteristics similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup current values and its fault type to be issued.

The blocking signal can also be tested in the commissioning phase by a software switch signal when the relay's testing mode "Enable stage forcing" is activated (*General* → *Device*).

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

Operating time characteristics for trip and reset

This function supports definite time delay (DT) and inverse definite minimum time delay (IDMT). For detailed information on these delay types please refer to the chapter "General properties of a protection function" and its section "Operating time characteristics for trip and reset".

Events and registers

The non-directional earth fault function (abbreviated "NEF" in event block names) generates events and registers from the status changes in START, TRIP and BLOCKED. The user can select the status ON or OFF for messages in the main event buffer. The function offers four (4) independent stages; the events are segregated for each stage operation.

The triggering event of the function (START, TRIP or BLOCKED) is recorded with a time stamp and with process data values.

Table. 5.4.2. - 55. Event codes.

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

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.

Table. 5.4.2. - 56. Register content.

Date and time	Event code	Fault type	Trigger current	Fault current	Pre-fault 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	0 ms...1800 s	Setting group 1...8 active

5.4.3. Directional overcurrent (Idir>; 67)

The directional overcurrent function is used for instant and time-delayed overcurrent and short-circuits. A device with both voltage and current protection modules can have four (4) available stages of the function (Idir>, Idir>>, Idir>>>, Idir>>>>). The operating decisions are based on phase current magnitudes which the function constantly measures. The selectable monitored phase current magnitudes are equal to fundamental frequency RMS values, to TRMS values (including harmonics up to 31^{st}), or to peak-to-peak values. The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

The outputs of the function are the START, TRIP and BLOCKED signals. The directional overcurrent function uses a total of eight (8) 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 between definite time (DT) mode and inverse definite minimum time (IDMT). The IDMT operation supports both IEC and ANSI standard time delays as well as custom parameters. The function includes CT saturation checking which allows the function to start and operate accurately during CT saturation.

The operational logic consists of the following:

- input magnitude selection
- input magnitude and angle processing
- saturation check
- threshold comparator
- block signal check
- time delay characteristics
- output processing.

The basic design of the protection function is the three-pole operation.

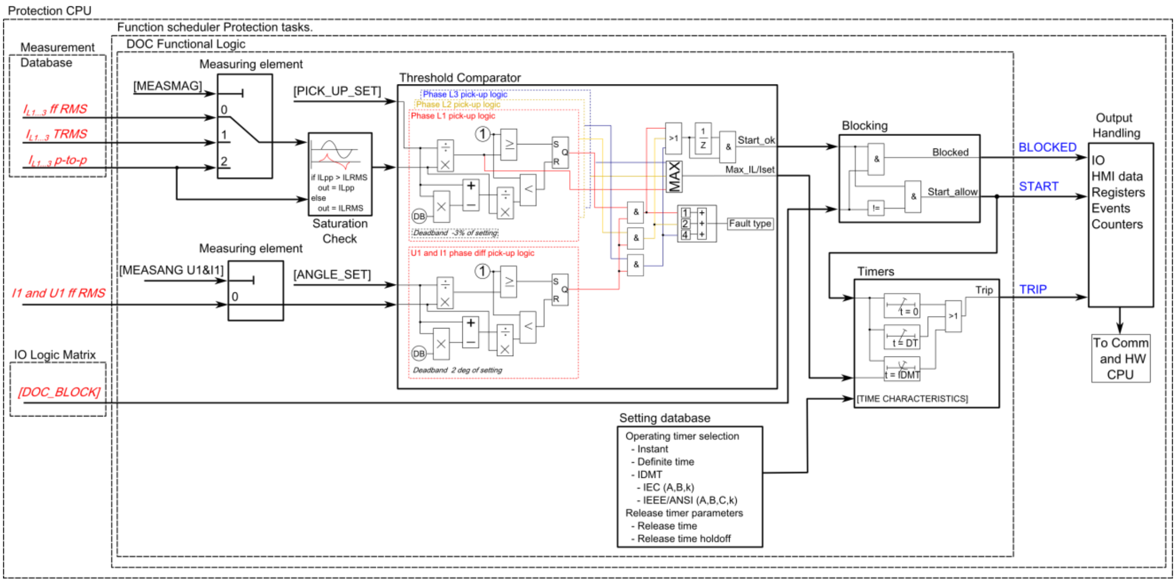
The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed current magnitudes.

The function outputs the START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signal. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the directional overcurrent function.

Figure. 5.4.3. - 22. Simplified function block diagram of the Idir> function.



Measured input

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

The fault current angle is based on the comparison between the positive sequence voltage U_1 and the positive sequence current I_1. If the positive sequence voltage is not available (three line-to-line voltages but no U_0), the voltage angle is based on a faulty phase line-to-line voltage. If the voltage drops below 1 V in the secondary side during a fault, the voltage memory is used for 0.5 seconds. After that the reference angle of voltage is forced to 0°.

Table. 5.4.3. - 57. Measurement inputs of the Idir> 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

The selection of the AI channel in use is made with a setting parameter. In all possible input channel variations the pre-fault condition is presented with a 20 ms averaged history value from -20 ms from 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 to change them by editing the setting group.

Table. 5.4.3. - 58. 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 the unit has more than one current measurement module.	1: Side 1 2: Side 2	-	1: Side 1

Real-time information displayed by the function

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through AQtivate software when it is connected to the relay and its Live Edit mode is active.

Table. 5.4.3. - 59. Information displayed by the function.

Name	Unit	Description
Operating angle now	Deg (°)	The positive sequence current angle in relation to the 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 the next pick-up
I_{meas}/I_{set} at the moment	I_m/I_{set}	The ratio between the positive sequence current and the pick-up value.

Pick-up

The I_{set} setting parameter controls the pick-up of the I> function. This defines the maximum allowed measured current before action from the function. The function constantly calculates the ratio between the I_{set} and the measured magnitude (I_m) for each of the three phases. The reset ratio of 97 % is built into the function and is always relative to the I_{set} value. The setting value is common for all measured phases, and when the I_m exceeds the I_{set} value (in single, dual or all phases) it triggers the pick-up operation of the function.

The trip characteristic can be set to directional or non-directional. In the non-directional mode only the pick-up value of the positive sequence current magnitude must be fulfilled in order for the function to trip. In the directional mode the fault must also be in the monitored direction to fulfill the terms to trip. By default, the tripping area is ±88° (176°). The reference angle is based on the calculated positive sequence voltage U_1 angle. If the U_1voltage is not available and only line-to-line voltages are measured, the reference angle is based on a healthy line-to-line voltage. During a short-circuit the reference angle is based on impedance calculation.

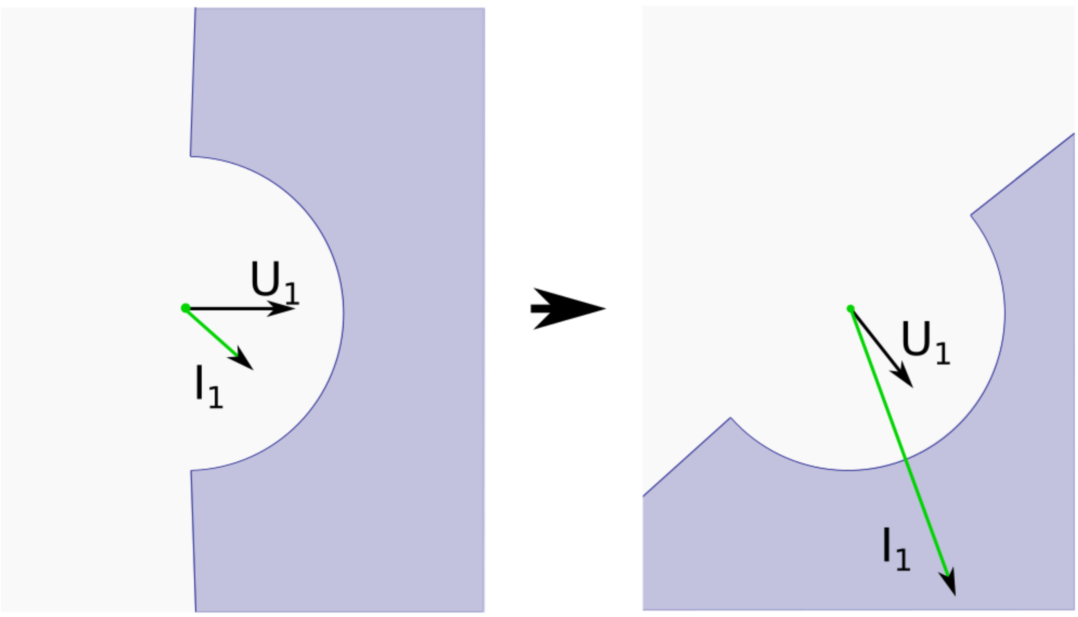
If the voltage drops below 1 V in the secondary side, the angle memory is used for 0.5 seconds. The angle memory forces the reference angle to be equal to the value measured or calculated before the fault. The angle memory captures the measured voltage angle 100 ms before the fault starts. After 0.5 seconds the angle memory is no longer used, and the reference angle is forced to 0°. The inbuilt reset ratio for the tripping area angle is 2°.

Table. 5.4.3. - 60. Pick-up settings.

Name	Description	Range	Step	Default
I_{set}	Pick-up setting	0.10…40.00 × I_n	0.01 × I_n	1.20 × I_n
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 the START signal generation of the function. The START signal is allowed if the blocking condition is not active.

Figure. 5.4.3. - 23. Angle tracking of the Idir> function (3LN/3LL + U_0 mode).



Please note in the picture above that the tripping area is linked to the angle of the positive sequence voltage U_1. The angle of the positive sequence current I_1 is compared to U_1 angle, and if the fault is in the correct direction, it is possible to perform a trip when the amplitude of I_{L1}, I_{L2} or I_{L3} increases above the pick-up limit.

If the 3LL mode is used without the U_0 measurement in a single-phase fault situation, the voltage reference comes from the healthy phase and the current reference from the faulty phase. In a short-circuit the angle comes from impedance calculation.

Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. Additionally, the non-directional overcurrent function includes an internal inrush harmonic blocking option which is applied according to the parameters set by the user. 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. 5.4.3. - 61. Internal inrush harmonic blocking settings.

Name	Description	Range	Step	Default
Inrush harmonic blocking (internal-only trip)	Enables and disables the 2nd harmonic blocking.	0: No 1: Yes	-	0: No
2nd harmonic block limit (Iharm/Ifund)	The 2nd harmonic blocking limit.	0.10…50.00 $\%I_{fund}$	0.01 $\%I_{fund}$	0.01 $\%I_{fund}$

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup current values and its fault type to be issued.

The blocking signal can also be tested in the commissioning phase by a software switch signal when the relay's testing mode "Enable stage forcing" is activated (*General → Device*).

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

Operating time characteristics for trip and reset

This function supports definite time delay (DT) and inverse definite minimum time delay (IDMT). For detailed information on these delay types please refer to the chapter "General properties of a protection function" and its section "Operating time characteristics for trip and reset".

Events and registers

The directional overcurrent function (abbreviated "DOC" in event block names) generates events and registers from the status changes in START, TRIP and BLOCKED. The user can select the status ON or OFF for messages in the main event buffer. The function offers four (4) independent stages; the events are segregated for each stage operation.

The triggering event of the function (START, TRIP or BLOCKED) is recorded with a time stamp and with process data values.

Table. 5.4.3. - 62. Event codes.

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
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

The function registers its operation into the last twelve (12) time-stamped registers; this information is available for all provided instances separately. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.

Table. 5.4.3. - 63. Register content.

Register name	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event code	4800-5003 Descr.
Fault type	L1-E...L1-L2-L3
Trigger current	Start average current
Fault current	Trip -20 ms averages
Pre-fault current	Start -200 ms averages
Trip time remaining	0 s...1800 s
Used SG	Setting group 1...8 active
Operating angle	0...250°

5.4.4. Directional earth fault (I0dir>; 67N)

The directional earth fault function is used for instant and time-delayed earth fault protection. A device with both voltage and current protection modules can have four (4) stages in the function (I0dir>, I0dir>>, I0dir>>>, I0dir>>>>). The operating decisions are based on selected neutral current or voltage magnitudes which the function constantly measures. The available residual current magnitudes are fundamental frequency RMS values, TRMS values (including harmonics up to 31st), or peak-to-peak values that come from inputs I01 and I0 (residual current measurement) or from I0Calc (residual current calculated from phase current measurements). The current angle is compared to the angle of measured or calculated zero sequence voltage. A certain amount of zero sequence voltage has to be present to activate the trip. The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

The outputs of the function are the START, TRIP and BLOCKED signals. The directional earth fault function uses a total of eight (8) separate setting groups which can be selected from one common source.

The function can operate on instant or time-delayed mode. In the time-delayed mode the operation can be selected for definite time (DT) or for inverse definite minimum time (IDMT); the IDMT operation supports both IEC and ANSI standard time delays as well as custom parameters.

The operational logic consists of the following:

- input magnitude selection
- input magnitude processing
- threshold comparator
- angle check
- block signal check
- time delay characteristics
- output processing.

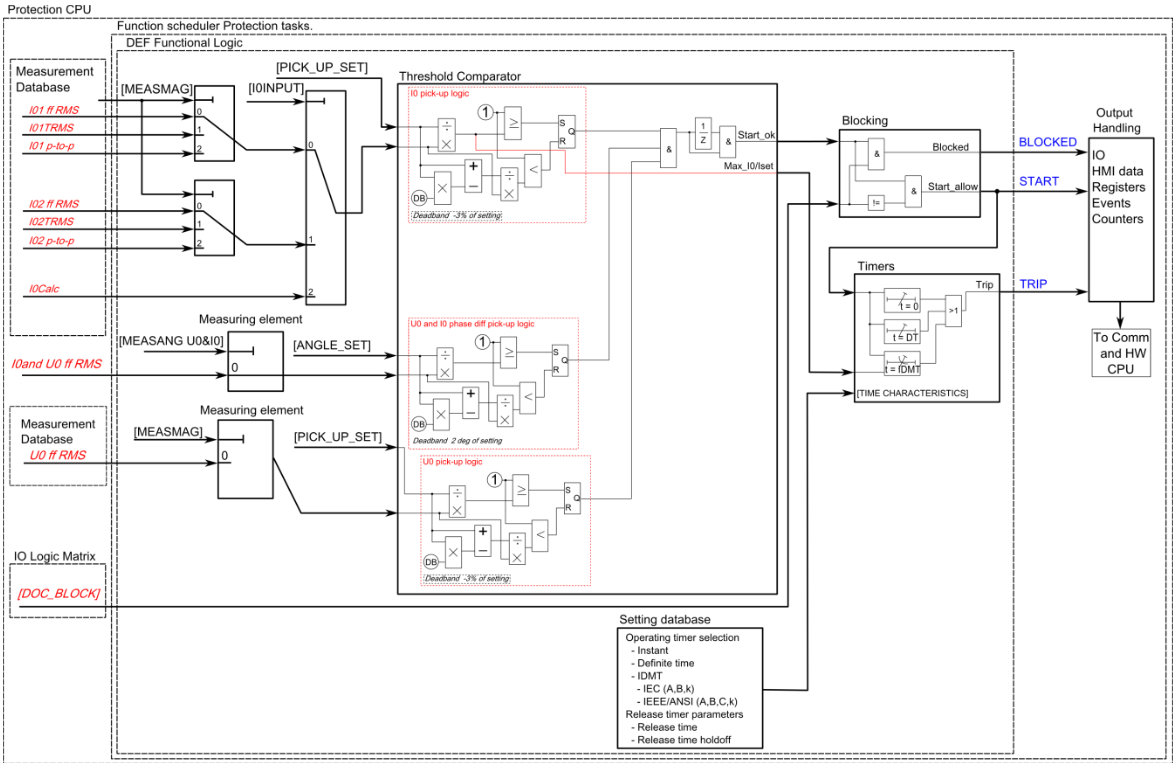
The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed current magnitudes.

The function outputs the START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the ten (10) output signals. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a cumulative counter for the START, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the directional earth fault function.

Figure. 5.4.4. - 24. Simplified function block diagram of the I0dir> function.



Measured input

The function block uses analog current measurement values and always uses peak-to-peak measurements from samples. The user can select the monitored magnitude to be equal to fundamental frequency RMS values, to TRMS values from the whole harmonic specter of 32 components, or to peak-to-peak values. A -20 ms averaged value of the selected magnitude is used for pre-fault data registering.

The fault current angle is based on comparing the neutral voltage U_0 angle. Both I_0 and U_0 must be above the squelch limit to be able to detect the angle. The squelch limit for the I_0 current is 0.01 x I_n and for the U_0 voltage 0.01 x U_n.

Table. 5.4.4. - 64. Measurement inputs of the I0dir> 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

The selection of the AI channel currently in use is made with a setting parameter. In all possible input channel variations the pre-fault condition is presented with a 20 ms averaged history value from -20 ms from a 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 to change them by editing the setting group.

Table. 5.4.4. - 65. General settings of the function.

Name	Description	Range	Step	Default
U0 directional phase	If the connected neutral voltage polarity is opposite to the 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 (*Measurements → Transformers → VT module*).	1: Select 2: U0 Calculated 3: U3 Input 4: U4 Input	-	1: 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: Side 1 2: Side 2	-	1: Side 1
Input selection	Defines which measured residual current is used by the function.	1: I01 2: I02 3: I0Calc	-	1: I01

Pick-up

The the pick-up of the I0dir> function is controlled by the $I0_{set}$ setting parameter and the $U0_{set}$ setting parameter. The former defines the maximum allowed measured current, while the latter defines the maximum allowed measured voltage and checks the angle difference before action from the function. The function constantly calculates the ratio between the $I0_{set}$ and the $U0_{set}$ and the measured magnitudes ($I_m$and U_m). The reset ratio of 97 % is built into the function and is always relative to the $I0_{set}$ (or $U0_{set}$) value. When the I_m exceeds the $I0_{set}$ value it triggers the pick-up operation of the function.

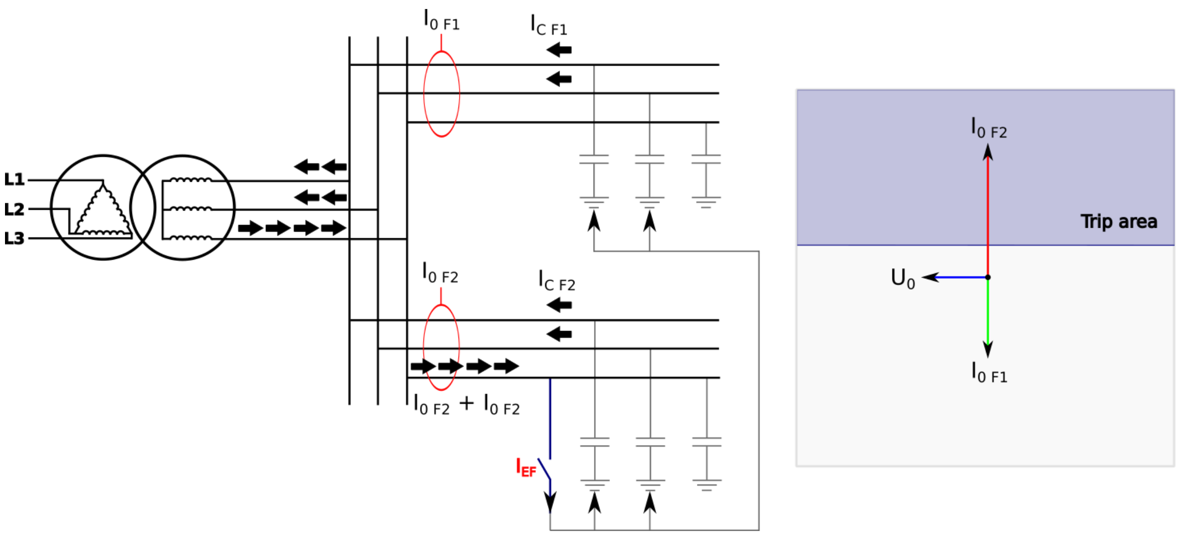
Table. 5.4.4. - 66. Pick-up settings.

Name	Description	Range	Step	Default
$I0_{set}$	Pick-up setting	0.01…40.00 × I_n	0.001 × I_n	1.20 × I_n
$U0_{set}$	Pick-up setting	1…75 %U_n	0.01 %U_n	20 %U_n
Earthing type	Network earthing method	1: Unearthed 2: Petersen coil earthed 3: Earthed network 4: $I0_{Cos}$ & $I0_{Sin}$ broad range mode	-	1: Unearthed
Multi-criteria detection	Activation of detecting healthy or unhealthy feeder by analyzing symmetrical components of currents and voltages. Visible when earthing type is set to $I0_{Cos}$ & $I0_{Sin}$ broad range mode.	1: Not used 2: Used	-	1: Not used
Unearthed/Compensated border angle	Dividing the angle between unearthed and compensated tripping (see description later in this document). Visible when earthing type is set to $I0_{Cos}$ & $I0_{Sin}$ broad range mode.	-45.0…90°	0.1°	45°
Angle	Trip area size (earthed network)	±45.0…135.0°	0.1°	±88°
Angle offset	Protection area direction (earthed network)	0.0…360.0°	0.1°	0.0°
Angle blinder	I0 angle blinder (Petersen coil earthed)	-90.0…0.0°	0.1°	-90°

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

Unearthed network

Figure. 5.4.4. - 25. Angle tracking of I0dir> function (unearthed network model).



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

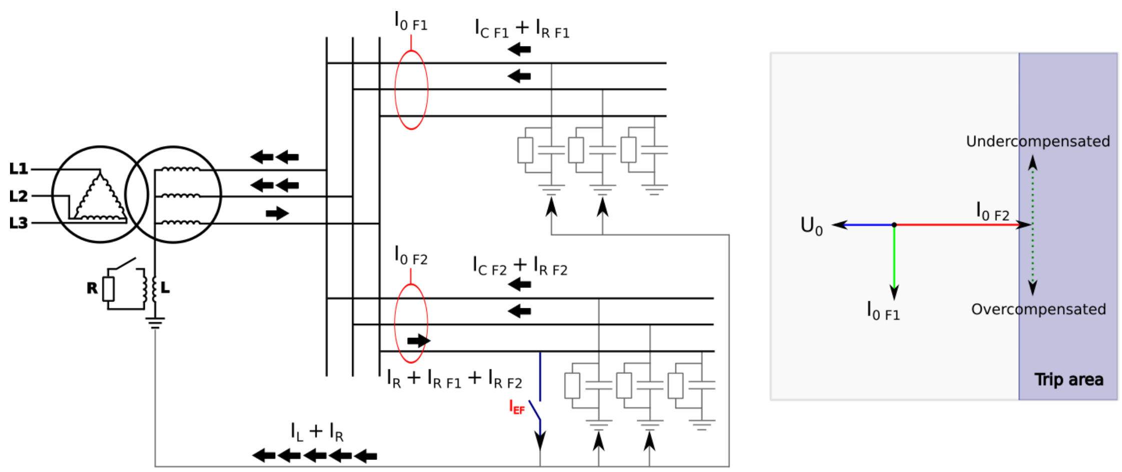
The amplitude of the fault current depends on the capacitance of the network. The outgoing feeders are the sources for capacitive currents. The bigger the network the greater the capacitive current during a fault. Each outgoing feeder produces capacitance according to the zero sequence capacitive reactance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

The resistance of the fault affects the size of the voltage drop during a fault. In direct earth fault the zero sequence voltage amplitude is equal to the system's line-to-earth voltage. In direct earth fault the voltage of a faulty phase drops close to zero and healthy phase voltages increase to the amplitude of line-to-line voltages.

Petersen coil earthed (Compensated) network

There are many benefits to a Petersen coil earthed network. The amount of automatic reclosing is highly decreased and the maintenance of the breakers is therefore diminished. Arc faults die on their own, and cables and equipment suffer less damage. In emergency situations a line-to-earth fault can be used for a specific time.

Figure. 5.4.4. - 26. Angle tracking of I0dir> function (Petersen coil earthed network model).

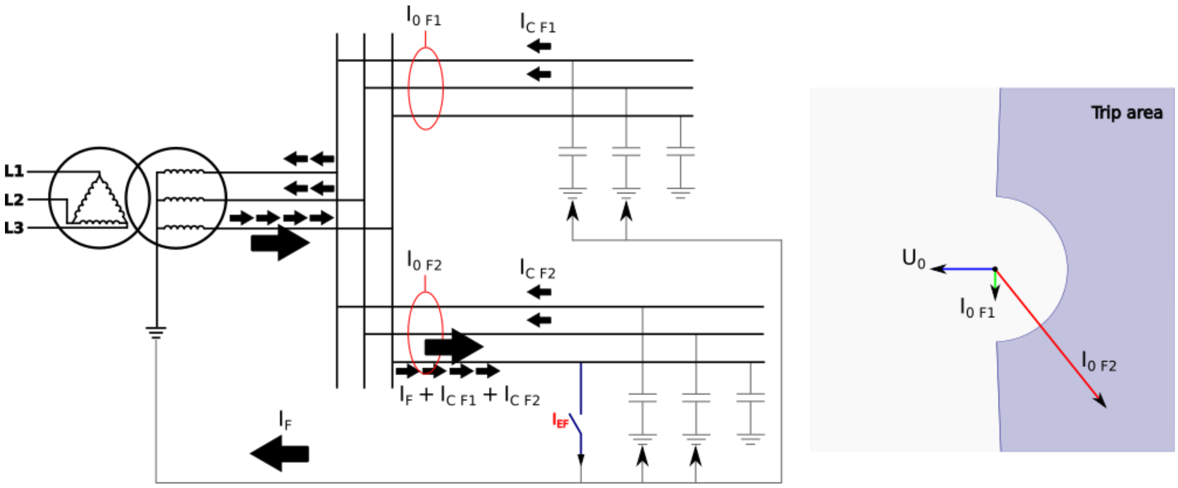


When the Petersen coil earthed (compensated) network mode is chosen, the device expects the fault current to be in the opposite direction to the zero sequence voltage. Healthy phases of both healthy and faulty feeders produce a capacitive current similar to the unearthed network. The inductance of the Petersen coil compensates the capacitive current and therefore the residual current in a fault location is close to zero. The size of the inductance is chosen according to the prospective earth fault current of the network. The desired compensation grade is achieved when the K factor is close to 1.0 and the network is fully compensated. The network is overcompensated when the K factor is greater than 1.0, and undercompensated when the K factor is smaller than 1.0.

The inductance connected to the star point of an incoming transformer or -as in most cases- to a earthing transformer compensates the capacitance of the network; however, this prevents the capacitive fault current to be measured. The fault detection is handled by connecting the resistance on parallel with the inductance. This resistance includes the amplitude of the fault current. In undercompensated or overcompensated situations the resistive component does not change during the fault; therefore, selective tripping is ensured even when the network is slightly undercompensated or overcompensated.

Directly earthed or small impedance network

Figure. 5.4.4. - 27. Angle tracking of I0dir> function (directly earthed or small impedance network).



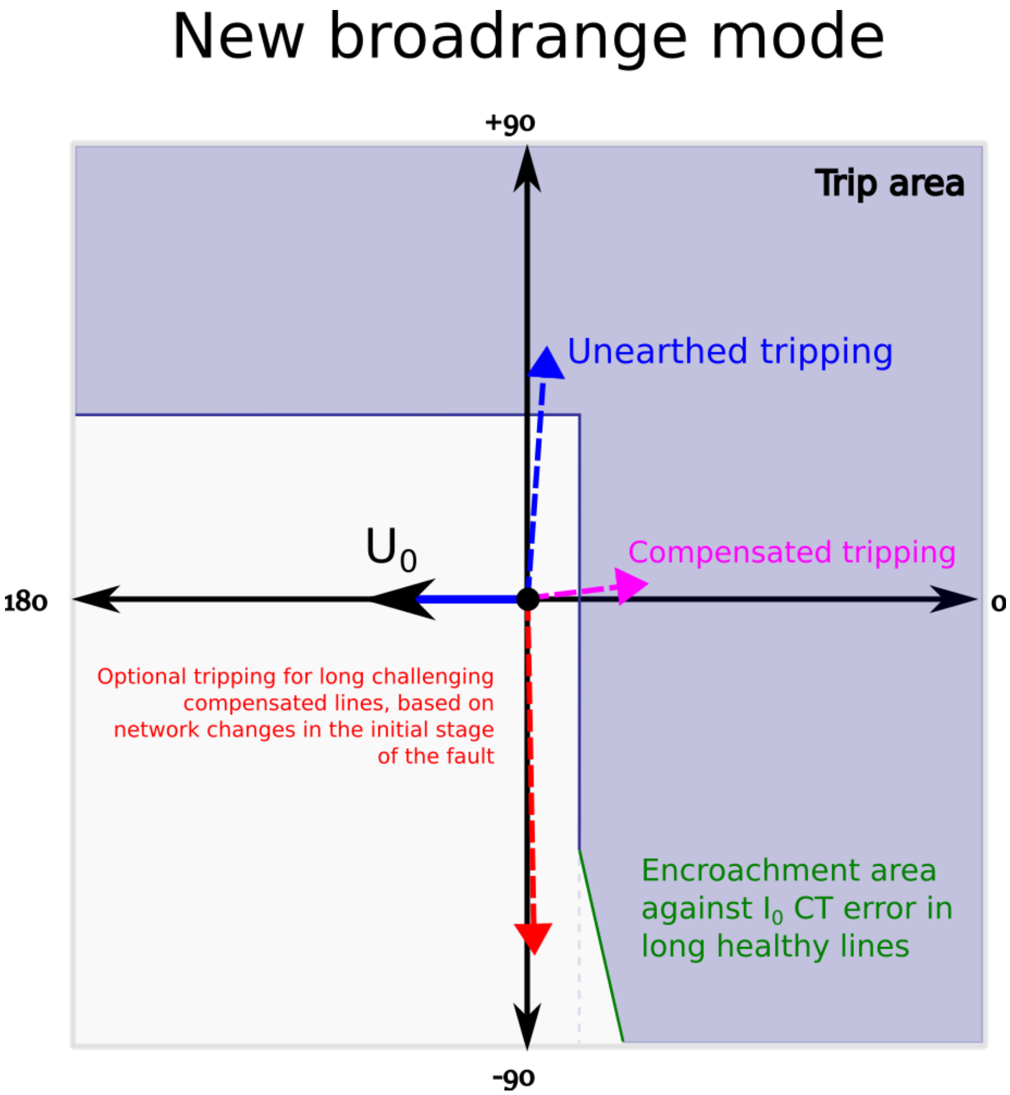
In a directly earthed network the amplitude of a single-phase fault current is similar to the amplitude of a short-circuit current. Directly earthed or small impedance network schemes are normal in transmission, distribution and industry.

The 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 detecting earth faults in compensated long-distance cables and overhead lines, it is in some cases difficult to distinguish between a healthy and a faulty feeder. Merely measuring the angle and the magnitude of residual voltage and currents is not always enough, as changes in symmetrical components of phase currents and voltages are also needed. Additionally, when protecting feeders from earth faults, two modes are used depending on the network status (unearthed or compensated). When changing between these two statuses the setting group must be changed, and especially with distributed compensation the change may be difficult or impossible to arrange. Finally, 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, Arcteq has developed an improved alternative to these traditional directional earth fault protections.

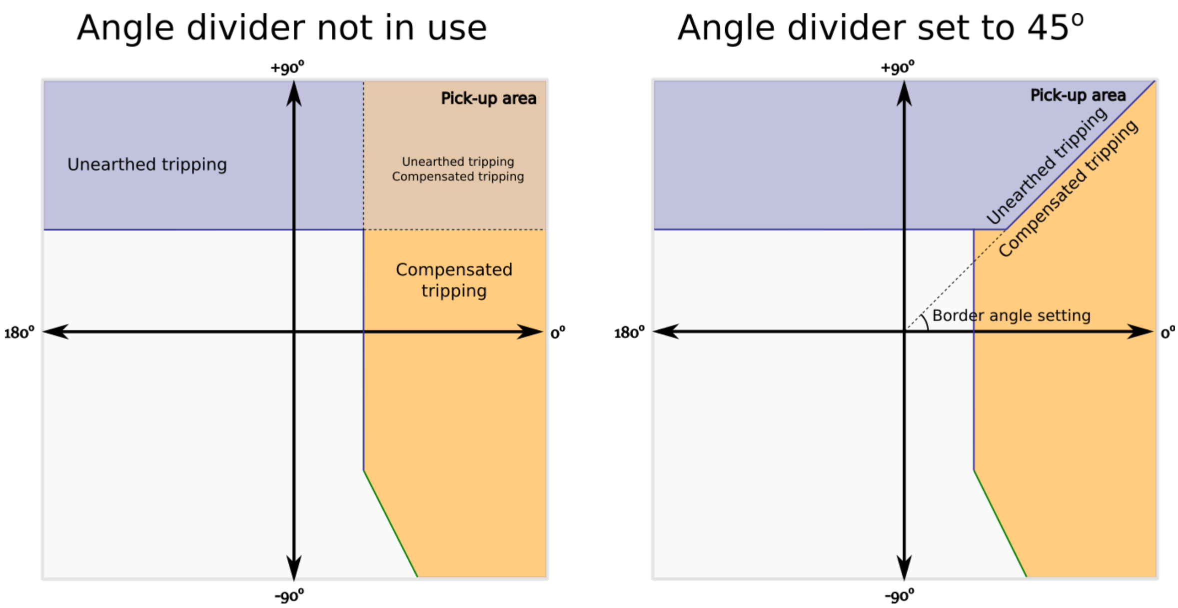
Figure. 5.4.4. - 28. Angle tracking of the I0dir> function (broad range mode).



The new broad range mode is capable of detecting an earth fault directionally in both unearthed and compensated networks not only by combining the two stages together but by using a new multi-criteria detection. This optional additional tripping condition for compensated networks uses Arcteq's patented, high-resolution intermittent earth fault algorithm with added symmetrical component calculation of phase currents and voltages. If this mode is activated, the alarming criteria is comprised 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 the traditional method. The multi-criteria algorithm can be tested with COMTRADE files supplied by Arcteq. The function requires a connection of three-phase currents, residual current and residual voltage to operate correctly.

To avoid unnecessary alarms the user can add an encroachment area against I0 CT errors in compensated long healthy lines.

Figure. 5.4.4. - 29. Effect of angle divider when in use and when disabled.



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

Real-time information displayed by the function

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through AQtivate software when it is connected to the relay and its Live Edit mode is active.

Table. 5.4.4. - 67. Information displayed by the function.

Name	Unit	Description
U0> Pick-up setting	V	The 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 the current.
I0 Magnitude	$\times I0_n$	The per-unit-value of the monitored residual current.
I0 Wattmetric I0xCos(fi)	$\times I0_n$	The wattmetric per-unit-value of the monitored residual current.
I0 Varmetric I0xSin(fi)	$\times I0_n$	The varmetric per-unit-value of the monitored residual current.
I0 direction now	Undefined Forward Reverse	The detected direction of the residual current.
I0 meas/I0 set now	$\times I0_n$	The ratio between the monitored residual current and the pick-up value.
U0 meas now	$\%U0_n$	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

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. Additionally, the directional earth fault protection function includes an internal inrush harmonic blocking option which is applied according to the parameters set by the user. 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. 5.4.4. - 68. Internal inrush harmonic blocking settings.

Name	Description	Range	Step	Default
Inrush harmonic blocking (internal-only trip)	Enables and disables the 2nd harmonic blocking.	0: No 1: Yes	-	0: No
2nd harmonic block limit (Iharm/Ifund)	The 2nd harmonic blocking limit.	0.10…50.00 $\%I_{fund}$	0.01 $\%I_{fund}$	0.01 $\%I_{fund}$

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup current values and its fault type to be issued.

The blocking signal can also be tested in the commissioning phase by a software switch signal when the relay's testing mode "Enable stage forcing" is activated (*General → Device*).

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

Operating time characteristics for trip and reset

This function supports definite time delay (DT) and inverse definite minimum time delay (IDMT). For detailed information on these delay types please refer to the chapter "General properties of a protection function" and its section "Operating time characteristics for trip and reset".

Events and registers

The directional overcurrent function (abbreviated "DEF" in event block names) generates events and registers from the status changes in START, TRIP and BLOCKED. The user can select the status ON or OFF for messages in the main event buffer. The function offers four (4) independent stages; the events are segregated for each stage operation.

The triggering event of the function (START, TRIP or BLOCKED) is recorded with a time stamp and with process data values.

Table. 5.4.4. - 69. Event codes.

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
5194	81	DEF1	10	I0Cosfi Trip ON
5195	81	DEF1	11	I0Cosfi Trip OFF
5196	81	DEF1	12	I0Sinfi Trip ON
5197	81	DEF1	13	I0Sinfi Trip 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
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 OF
5256	82	DEF2	8	I0Sinfi Start ON
5257	82	DEF2	9	I0Sinfi Start OFF
5258	82	DEF2	10	I0Cosfi Trip ON
5259	82	DEF2	11	I0Cosfi Trip OFF
5260	82	DEF2	12	I0Sinfi Trip ON
5261	82	DEF2	13	I0Sinfi Trip 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
5322	83	DEF3	10	I0Cosfi Trip ON
5323	83	DEF3	11	I0Cosfi Trip OFF
5324	83	DEF3	12	I0Sinfi Trip ON
5325	83	DEF3	13	I0Sinfi Trip 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
5386	84	DEF4	10	I0Cosfi Trip ON
5387	84	DEF4	11	I0Cosfi Trip OFF
5388	84	DEF4	12	I0Sinfi Trip ON
5389	84	DEF4	13	I0Sinfi Trip OFF

The function registers its operation into the last twelve (12) time-stamped registers; this information is available for all provided instances separately. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.

Table. 5.4.4. - 70. Register content.

Column name	Content description
Event Code	dd.mm.yyyy hh:mm:ss.mss
Date & Time	5184-5389 Descr.
I_0 pre-triggering current	Start average current
I_0 fault current	Trip -20 ms averages
Fault capacity I_0	Trip -20 ms averages
Fault resist I_0	Trip -20 ms averages
Fault U_0 (%)	Trip -20 ms averages
Fault U_0 (V)	Trip -20 ms averages
I_0 fault angle	0...360°
Trip time remaining	0 ms...1800 s
Used SG	Setting group 1...8 active
Network GND	Unearthed, Petersen coil earthed, Earthed network
I_0 pre-fault current	Start -200 ms averages

5.4.5. Current unbalance (I2>; 46)

The current unbalance function is used for instant and time-delayed unbalanced network protection and for detecting broken conductors. The number of stages in the function depends on the relay model. The operating decisions are based on negative and positive sequence current magnitudes which the function constantly measures. In the broken conductor mode (I2/I1) the minimum allowed loading current is also monitored in the phase current magnitudes.

There are two possible operating modes available: the I2 mode monitors the negative sequence current, while the I2/I1 mode monitors the ratio between the negative sequence current and the positive sequence current. The relay calculates the symmetrical component magnitudes in use from the phase current inputs I_{L1}, I_{L2} and I_{L3}. The zero sequence current is also recorded into the registers as well as the angles of the positive, negative and zero sequence currents in order to better verify any fault cases. The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

The outputs of the function are the START, TRIP and BLOCKED signals. The current unbalance function uses a total of eight (8) 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 between definite time (DT) or inverse definite minimum time (IDMT). The IDMT operation supports both IEC and ANSI standard time delays as well as custom parameters.

The operational logic consists of the following:

- input magnitude selelction
- input magnitude processing
- threshold comparator
- block signal check
- time delay characteristics
- output processing.

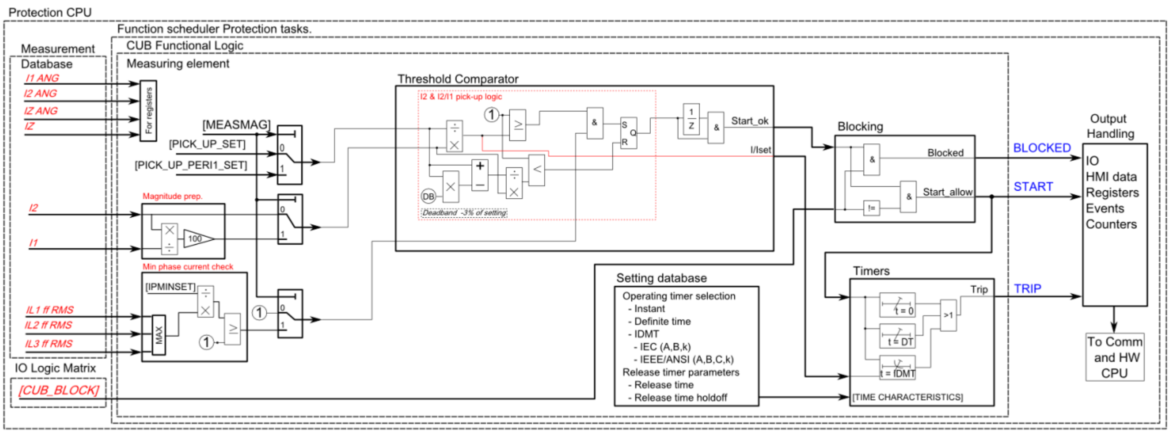
The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed current magnitudes.

The function outputs START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signals. In instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the current unbalance function.

Figure. 5.4.5. - 30. Simplified function block diagram of the I2> function.



Measured input

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

Table. 5.4.5. - 71. Measurement inputs of the I2> 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

The selection of the AI channel currently in use is made with a setting parameter. In all possible input channel variations the pre-fault condition is presented with a 20 ms averaged history value from -20 ms from the 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 to change them by editing the setting group.

Name	Description	Range	Step	Default
Meas. side	Defines which current measurement module is used by the function. Visible if the unit has more than one current measurement module.	1: Side 1 2: Side 2	-	1: Side 1
Measured magnitude	Defines whether the ratio between the positive and the negative sequence currents are supervised or whether only the negative sequence is used in detecting unbalance.	1: I2pu 2: I2/I1	-	1: I2pu

Pick-up

The setting parameters $I2_{set}$ *and* $I2/I1_{set}$ control the the pick-up of the I2> function. They define the maximum allowed measured negative sequence current or the negative/positive sequence current ratio before action from the function. The function constantly calculates the ratio between the I_{set} and the measured magnitude (I_m). The reset ratio of 97 % is built into the function and is always relative to the I_{xset} value. The reset ratio is the same for both modes.

Table. 5.4.5. - 72. Pick-up settings.

Name	Description	Range	Step	Default
I2set	Pick-up setting for I2 mode	0.01…40.00 × I_n	0.01 × I_n	0.2 × I_n

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 the START signal generation of the function. The START signal is allowed if the blocking condition is not active.

Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's 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 the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and processes the release time characteristics similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup current values and its fault type to be issued.

The blocking signal can also be tested in the commissioning phase by a software switch signal when the relay's testing mode "Enable stage forcing" is activated (*General → Device*).

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

Operating time characteristics for trip and reset

The operating timers' behavior during a 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 the start signal.
- Definite time operation (DT): gives the TRIP signal after a user-defined time delay regardless of the measured current as long as the current is above or below the i_{set} value and thus the pick-up element is active (independent time characteristics).
- Inverse definite minimum time (IDMT): gives the TRIP signal after a time which is in relation to the set pick-up value I_{set} and the measured current I_m (dependent time characteristics).

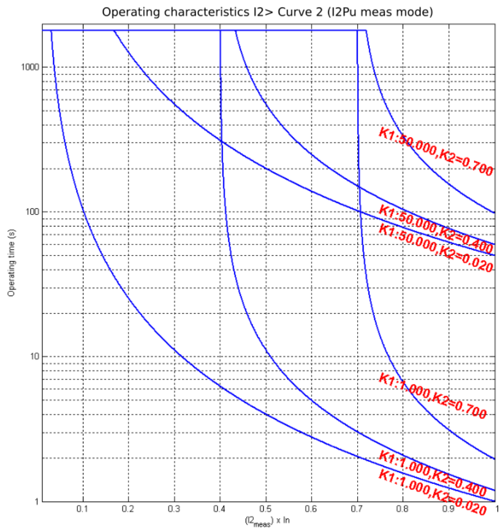
Both IEC and IEEE/ANSI standard characteristics as well as user settable parameters are available for the IDMT operation.

Unique to the current unbalance protection is the availability of the "Curve2" delay which follows the formula below:

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

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

Figure. 5.4.5. - 31. Operation characteristics curve for I2> Curve2.



The following table presents the setting parameters for the function's time characteristics.

Table. 5.4.5. - 73. Setting parameters for operating time characteristics.

Name	Range	Step	Default	Description
Delay type	DT IDMT	-	DT	Selection of the delay type time counter. The selection possibilities are dependent (IDMT, Inverse Definite Minimum Time) and independent (DT, Definite Time) characteristics.
Definite operating time delay	0.000...1800.000 s	0.005 s	0.040 s	Definite time operating delay. This setting is active and visible when DT is the selected delay type. When set to 0.000 s the stage operates as an instant (PIOC, 50) stage without added delay. When the parameter is set to 0.005...1800 s the stage operates as an independent delayed (PTOC, 51).
Delay curve series	IEC IEEE Non-standard	-	IEC	This setting is active and visible when IDMT the selected delay type. The delay curve series for an IDMT operation follows either IEC or IEEE/ANSI standard-defined characteristics. Non-standard characteristics include delay curves outside of the two standards.
Delay characteristics IEC	NI EI VI LTI Param	-	NI	This setting is active and visible when IDMT the selected delay type. 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 then allows setting the characteristics following the same formula as the IEC curves mentioned here.
Delay characteristics IEEE	LTI LTVI LTEI MI VI EI STI STEI Param	-	LTI	This setting is active and visible when IDMT is the selected delay type. 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 then allows setting the 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…25.00 s	0.01 s	0.05 s	This setting is active and visible when IDMT is the selected delay type. Time dial/multiplier setting for IDMT characteristics.
A	0.0000…250.0000	0.0001	0.0860	This setting is active and visible when IDMT is the selected delay type. Constant A for IEC/IEEE characteristics.
B	0.0000…5.0000	0.0001	0.1850	This setting is active and visible when IDMT is the selected delay type. Constant B for IEC/IEEE characteristics.
C	0.0000…250.0000	0.0001	0.0200	This setting is active and visible when IDMT is the selected delay type. Constant C for IEEE characteristics.
K	0.0000…250.0000	0.0001	0.0200	This setting is active and visible when Curve1 is the selected delay curve. Constant K for Curve1 characteristics.

Table. 5.4.5. - 74. Setting parameters for reset time characteristics.

Name	Range	Step	Default	Description
Release time delay	0.000…150.000 s	0.005 s	0.06 s	Resetting time. The time that is allowed between pick-ups when the pick-up has not lead into a trip operation. During this time the START signal is held on for the timers if the delayed pick-up release is active.
Delayed pick-up release	No Yes	-	Yes	Resetting characteristics selection is either time-delayed or instant after the pick-up element is released. If activated, the START signal is reset after a 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 a set release time unless a pick-up element is 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 continues until a set release time has elapsed even if the pick-up element is reset.

The user can reset characteristics through the application. The default setting is a 60 ms delay; the time calculation is held during the release time.

In the release delay option the operating time counter calculates the operating time during the release. When using this option the function does not trip if the input signal is not re-activated while the release time count is on-going.

Events and registers

The current unbalance function (abbreviated "CUB" in event block names) generates events and registers from the status changes in START, TRIP, and BLOCKED. The user can select the status ON or OFF for messages in the main event buffer. The function offers four (4) independent stages; the events are segregated for each stage operation.

The triggering event of the function (START, TRIP or BLOCKED) is recorded with a time stamp and with process data values.

Table. 5.4.5. - 75. Event codes.

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
2244	35	CUB4	4	Block ON
2245	35	CUB4	5	Block OFF

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.

Table. 5.4.5. - 76. Register content.

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

5.4.6. Harmonic overcurrent (Ih>; 50H/51H/68H)

The harmonic overcurrent function is used for non-directional instant overcurrent and short-circuit protection. The number of stages in the function depends on the relay model. The function constantly measures the selected harmonic component of the selected measurement channels, the value being either absolute or relative to the fundamental frequency value. The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

The outputs of the function are the START, TRIP and BLOCKED signals. The non-directional harmonic overcurrent function uses a total of eight (8) separate setting groups which can be selected from one common source.

The function can operate on instant or time-delayed mode. Either START or TRIP signal can be used when the instant mode is selected to block other protection stages. In time-delayed mode the operation can be selected between definite time (DT) mode and inverse definite minimum time (IDMT) mode. The START signal can be used to block other stages; if the situation lasts longer, the TRIP signal can be used on other actions as time-delayed.The IDMT operation supports both IEC and ANSI standard time delays as well as custom parameters.

The operational logic consists of the following:

- input magnitude selection
- input magnitude processing
- saturation check
- threshold comparator
- block signal check
- time delay characteristics
- output processing.

The basic design of the protection function is the three-pole operation.

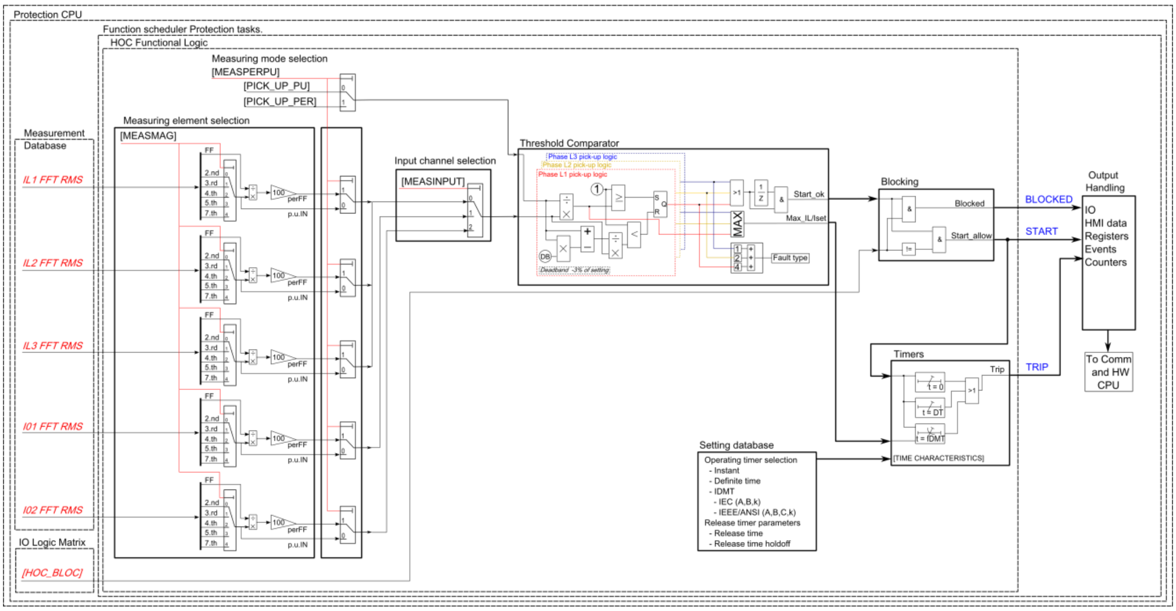
The inputs of the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed current magnitudes.

The function outputs the START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signal. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the non-directional harmonic overcurrent function.

Figure. 5.4.6. - 32. Simplified function block diagram of the Ih> function.



Measured input

The function block uses analog current measurement values from phase currents or from residual currents. Each measurement input of the function block uses fundamental frequency values and harmonic components of the selected current input. The user can select the monitored magnitude to be equal to either the per unit RMS values of the harmonic component or the harmonic component percentage content, compared to the fundamental frequency RMS values. A -20ms averaged value of the selected magnitude is used for pre-fault data registering.

Table. 5.4.6. - 77. Measurement inputs of the Ih> function.

Signal	Description	Time base
IL1FFT	The 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.	5 ms
IL2FFT	The 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.	5 ms
IL3FFT	The 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.	5 ms

I01FFT	The magnitudes (RMS) of residual $I0_1$ 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.	5 ms
I02FFT	The magnitudes (RMS) of residual $I0_2$ 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.	5 ms

The selection of the AI channel, the monitored harmonic, and the monitoring type (per unit or percentage of fundamental frequency) is made with setting parameters. In all possible input channel variations the pre-fault condition is presented with a 20 ms averaged history value from -20 ms from START or TRIP event.

General settings

The function can be set to monitor the ratio between the measured harmonic and either the measured fundamental component or the per unit value of the harmonic current. The user must select the correct measurement input.

Table. 5.4.6. - 78. Operating mode selection settings.

Name	Range	Step	Default	Description
Ih> meas side	Defines which current measurement module is used by the function. Visible if the unit has more than one current measurement module.	1: Side 1 2: Side 2	-	1: Side 1
Harmonic selection	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	-	2^{nd} harmonic	Selection of the monitored harmonic component.

Per unit or relative	× I_n Ih/IL	-	× I_n	Selection of the monitored harmonic mode. Either directly per unit x I_n 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 current or residual current).

Each function stage provides these same settings. Multiple stages of the function can be set to operate independently of each other.

Pick-up

The setting parameter Ih_{set} per unit or *Ih/IL* (depending on the selected operating mode) controls the pick-up of the Ih> function. This defines the maximum allowed measured current before action from the function. The function constantly calculates the ratio between the Ih_{set} per unitor *Ih/IL* and the measured magnitude (I_m) for each of the three phases. The reset ratio of 97 % is built into the function and is always relative to the Ih_{set} per unit or *Ih/IL*value. The setting value is common for all measured phases, and when the I_m exceeds the I_{set} value (in single, dual or all phases) it triggers the pick-up operation of the function.

Table. 5.4.6. - 79. Pick-up settings.

Name	Range	Step	Default	Description
Ih_{set} pu	0.05…2.00 × I_n	0.01 × I_n	0.20 × I_n	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 the START signal generation of the function. The START signal is allowed if the blocking condition is not active.

Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's 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 the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup current values and its fault type to be issued.

The blocking signal can also be tested in the commissioning phase by a software switch signal when the relay's testing mode "Enable stage forcing" is activated (*General → Device*).

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

Operating time characteristics for trip and reset

This function supports definite time delay (DT) and inverse definite minimum time delay (IDMT). For detailed information on these delay types please refer to the chapter "General properties of a protection function" and its section "Operating time characteristics for trip and reset".

Events and registers

The harmonic overcurrent function (abbreviated "HOC" in event block names) generates events and registers from the status changes in START, TRIP and BLOCKED. The user can select the status ON or OFF for messages in the main event buffer. The function offers four (4) independent stages; the events are segregated for each stage operation.

The triggering event of the function (START, TRIP or BLOCKED) is recorded with a time stamp and with process data values.

Table. 5.4.6. - 80. Event codes.

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

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.

Table. 5.4.6. - 81. Register content.

Date and time	Event code	Fault type	Trigger current	Fault current	Pre-fault 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	0 ms...1800 s	Setting group 1...8 active

5.4.7. Circuit breaker failure protection (CBFP; 50BF)

The circuit breaker failure protection function is used for monitoring the circuit breaker operation after it has been tripped. The function can also be used to retrip a failing breaker; if the retrip fails, an incomer breaker can be tripped by using the function's output. The retrip functionality can be disabled if the breaker does not have two open coils.

The function can be triggered by the following:

- overcurrent (phase and residual)
- digital output monitor
- digital signal
- any combination of the above-mentioned triggers.

In the current-dependent mode the function constantly measures phase current magnitudes and the selected residual current. In the signal-dependent mode any of the device's binary signals can be used to trigger the function. In the digital output-dependent mode the function monitors the status of the selected output relay control signal. The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

The outputs of the function are CBFP START, RETRIP, CBFP ACT and BLOCKED signals. The circuit breaker failure protection function uses a total of eight (8) separate setting groups which can be selected from one common source. Additionally, the function's operating mode can be changed via setting group selection.

The operational logic consists of the following:

- input magnitude processing
- input magnitude selection
- threshold comparator
- block signal check
- time delay characteristics
- output processing.

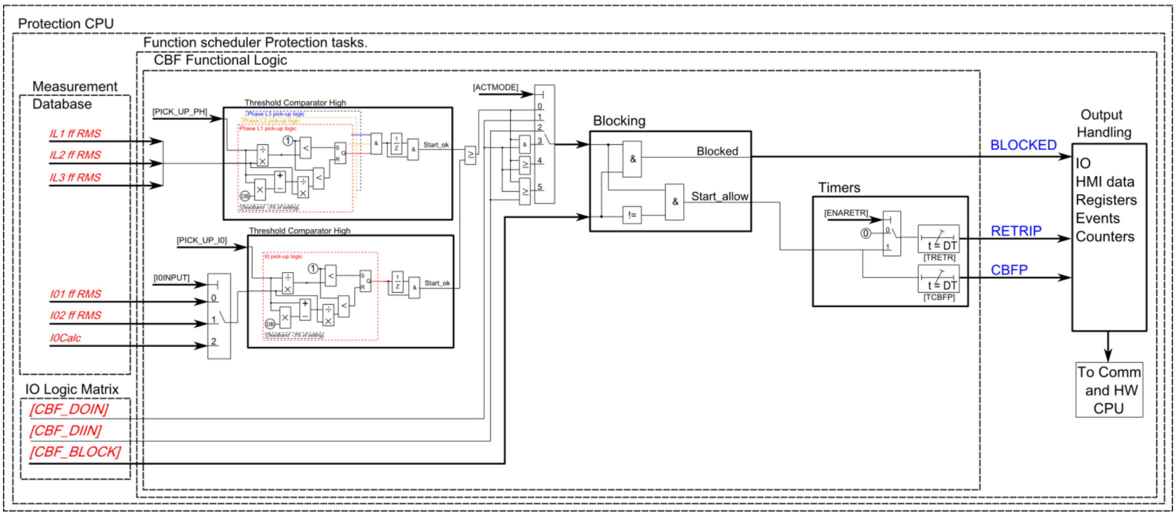
The inputs of the function are the following:

- operating mode selections
- setting parameters
- digital input signals
- measured and pre-processed current magnitudes.

The function' output signals can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the two (2) output signals. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counters for RETRIP, CBFP, CBFP START and BLOCKED events.

The following figure presents a simplified function block diagram of the circuit breaker failure protection function.

Figure. 5.4.7. - 33. Simplified function block diagram of the CBFP function.



Measured input

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

Table. 5.4.7. - 82. Measurement inputs of 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	Monitors digital output relay status	5 ms
DIIN	Monitors digital input status	5 ms

The selection of the AI channel in use is made with a setting parameter. In all possible input channel variations the pre-fault condition is presented with a 20 ms averaged history value from -20 ms from 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 to change them by editing the setting group.

Table. 5.4.7. - 83. General settings of the function.

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

Pick-up

The setting parameters I_{set} and $I0_{set}$ control the pick-up and the activation of the current-dependent CBFP function. They define the minimum allowed measured current before action from the function. The function constantly calculates the ratio between the I_{set} or the $I0_{set}$ and the measured magnitude (I_m) for each of the three phases and the selected residual current input. The reset ratio of 97 % is built into the function and is always relative to the I_{set} value. The setting value is common for all measured phases. When the I_m exceeds the I_{set} value (in single, dual or all phases) it triggers the pick-up operation of the function.

Table. 5.4.7. - 84. Operating mode and input signals selection.

Name	Range	Step	Default	Description
I0Input	0: Not in use 1: I01 2: I02 3: I0Calc	-	0: Not in use	Selection of the residual current monitoring from the two separate residual measurements (I01 and I02) or from the phase current's 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. The mode can be dependent on current measurement, digital channel status or any combination of the three.

Table. 5.4.7. - 85. Pick-up settings.

Name	Range	Step	Default	Description
I_{set}	0.01…40.00 × I_n	0.01 × I_n	0.20 × I_n	The pick-up threshold for the phase current measurement. This setting limit defines the upper limit for the phase current pick-up element.
$I0_{set}$	0.005...40.000 × I_n	0.001 × I_n	1.200 × I_n	The pick-up threshold for the 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 the START signal generation of the function. The START signal is allowed if the blocking condition is not active. There is no delay between the activation of the monitored signal and the activation of the pick-up when using binary signals.

Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's 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 the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and processes the release time characteristics similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup current values and its fault type to be issued.

The blocking signal can also be tested in the commissioning phase by a software switch signal when the relay's testing mode "Enable stage forcing" is activated (*General → Device*).

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

Operating time characteristics

The operating timers’ behavior during a function can be set depending on the application. The same pick-up signal starts both timers. When retrip is used the time grading should be set as follows: the sum of specific times (i.e. the retrip time, the expected operating time, and the pick-up conditions' release time) is shorter the set CBFP time. This way, when retripping another breaker coil clears the fault, any unnecessary function triggers are avoided.

The following table presents the setting parameters for the function's operating time characteristics.

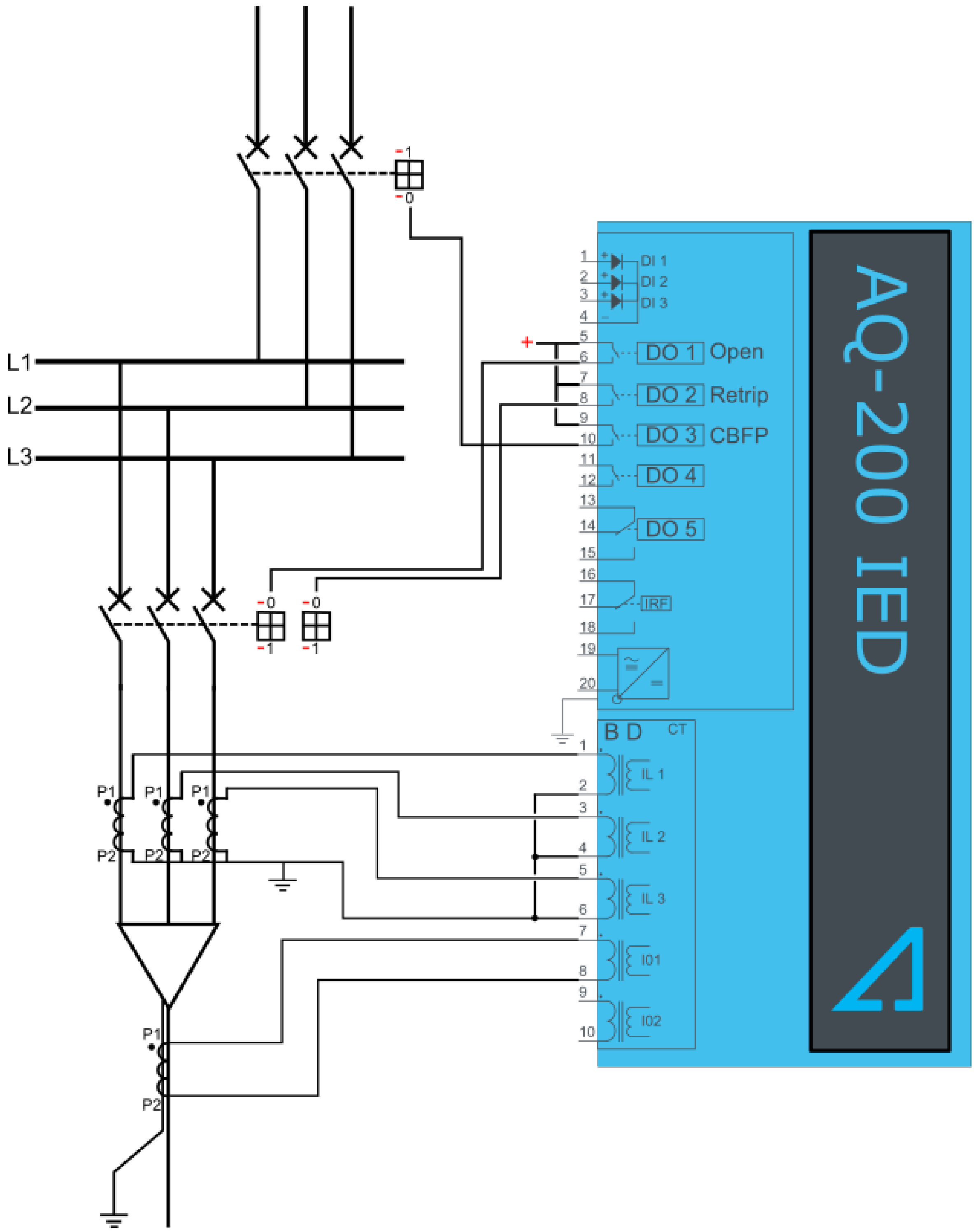
Table. 5.4.7. - 86. Setting parameters for operating time characteristics.

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

The following figures present some typical cases of the CBFP function.

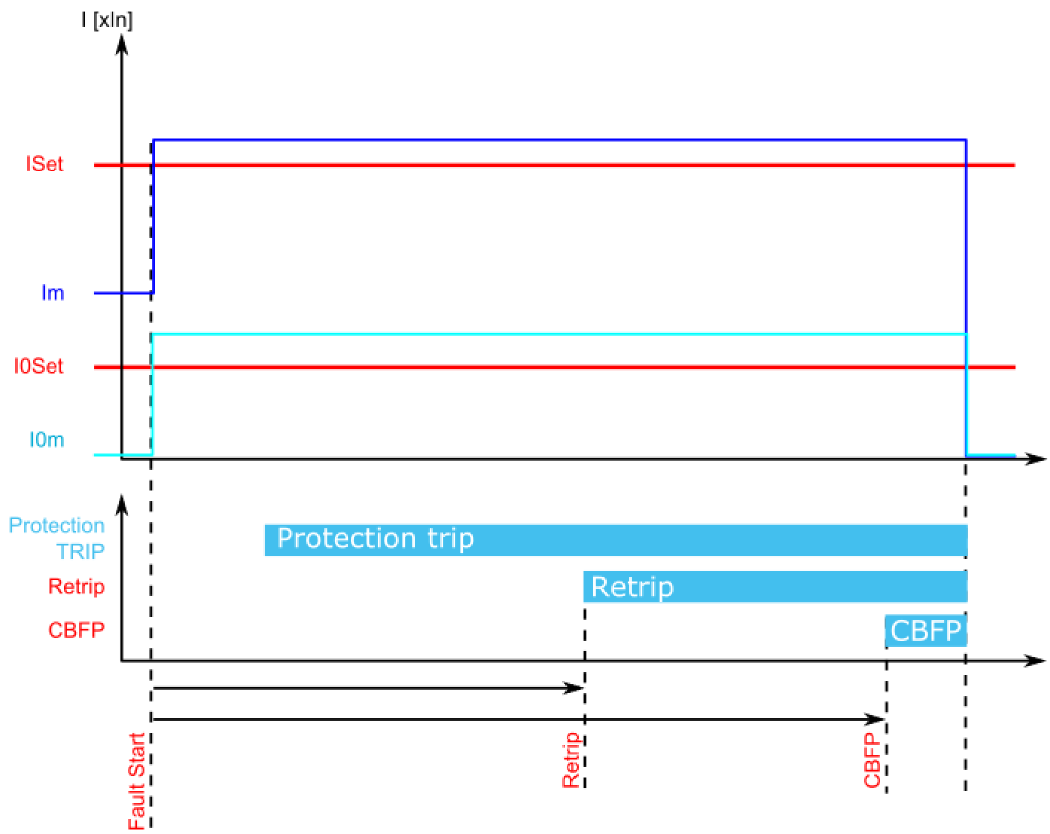
Trip, Retrip and CBFP are configured to the device.

Figure. 5.4.7. - 34. Trip, Retrip and CBFP are configured to the device.



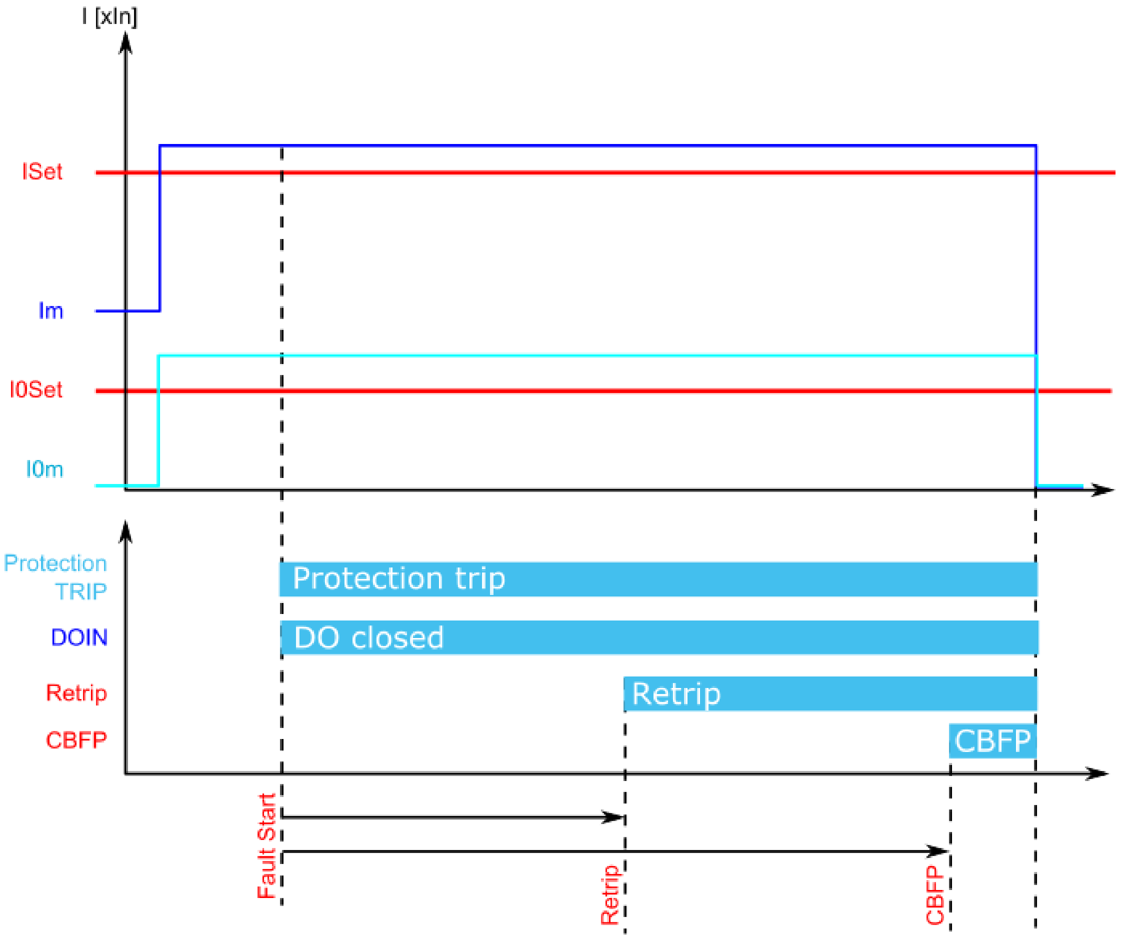
The retrip functionality can be used in application whose circuit breaker has a retrip or a redundant trip coil available. The trip signal is wired normally to the breaker's trip coil from the device's trip output. The retrip is wired from its own device output contact in parallel with the circuit breaker's second tripping coil. The CBFP signal is wired normally from its device output contact to the incomer breaker. Below are a few operational cases regarding the various applications.

Figure. 5.4.7. - 35. Retrip and CBFP when current is the only selected criterion.



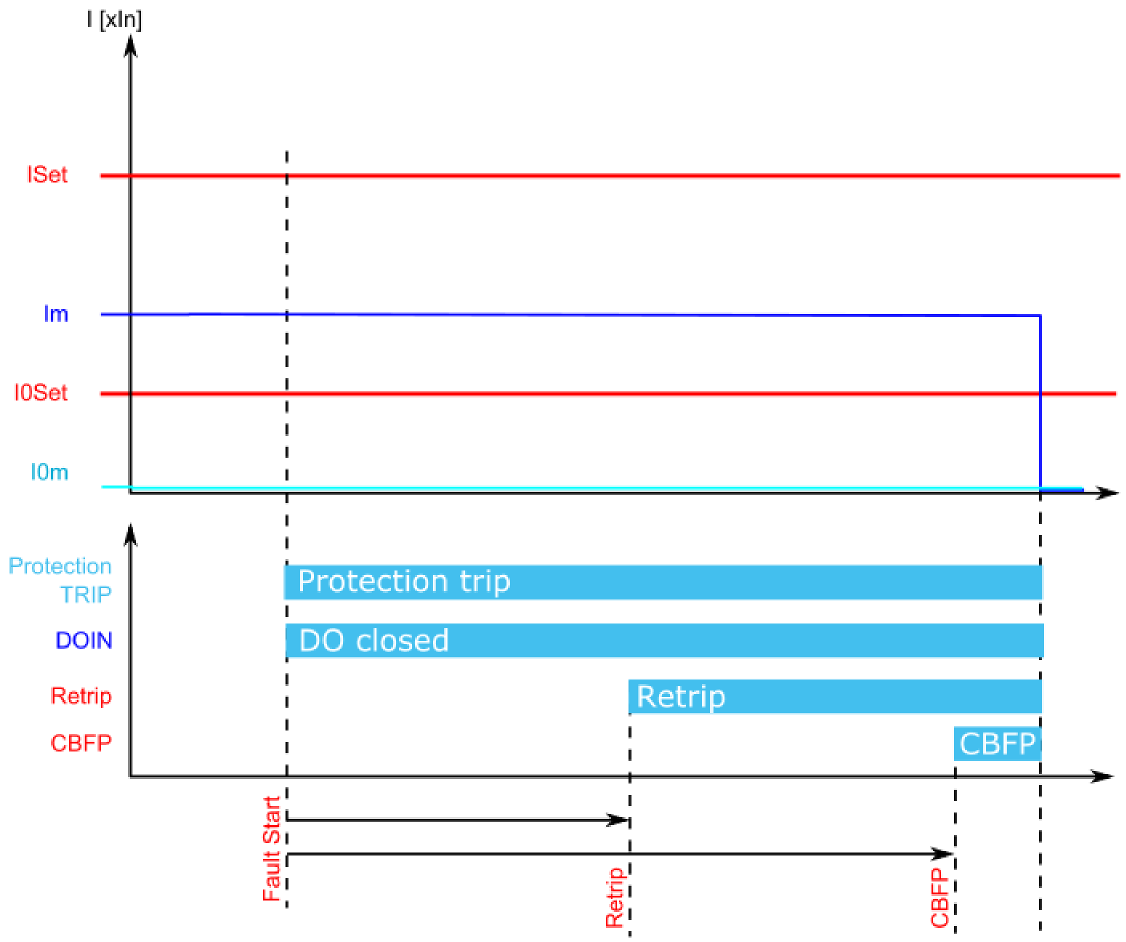
When the current threshold setting of I_{set} and/or $I0_{set}$ is exceeded, the current-based protection is activated and the counters for Retrip and CBFP start to calculate the set operating time. The tripping of the primary protection stage is not monitored in this configuration; therefore, if the current is not reduced below the setting limit, Retrip is sent to the incomer breaker. If the current is not reeduced within a set time limit, CBFP is also sent to the incomer breaker. If the primary protection function clears the fault, both counters (Retrip and CBFP) are reset as soon as the measured current is below the threshold settings.

Figure. 5.4.7. - 36. Retrip and CBFP when "current and digital output" are the selected criteria.



When the current threshold setting of I_{set} and/or $I0_{set}$ is exceeded, the current-based protection is activated. At the same time, the counters for Retrip and CBFP are halted until the monitored output contact is controlled (that is, the primary protection operates). When the tripping signal reaches the primary protection stage, the Retrip and CBFP counters start to calculate the set operating time. The tripping of the primary protection stage is constantly monitored in this configuration. If the current is not reduced below the setting limit and the primary stage tripping signal is not reset, Retrip is sent to the incomer breaker. If the current is not reduced within a set time limit, CBFP is also sent to the incomer breaker. If the primary protection function clears the fault, both counters (Retrip and CBFP) are reset as soon as the measured current is below the threshold settings or the tripping signal is reset. This configuration allows the CBFP to be controlled solely on current-based functions and other function trips can be excluded from the CBFP functionality.

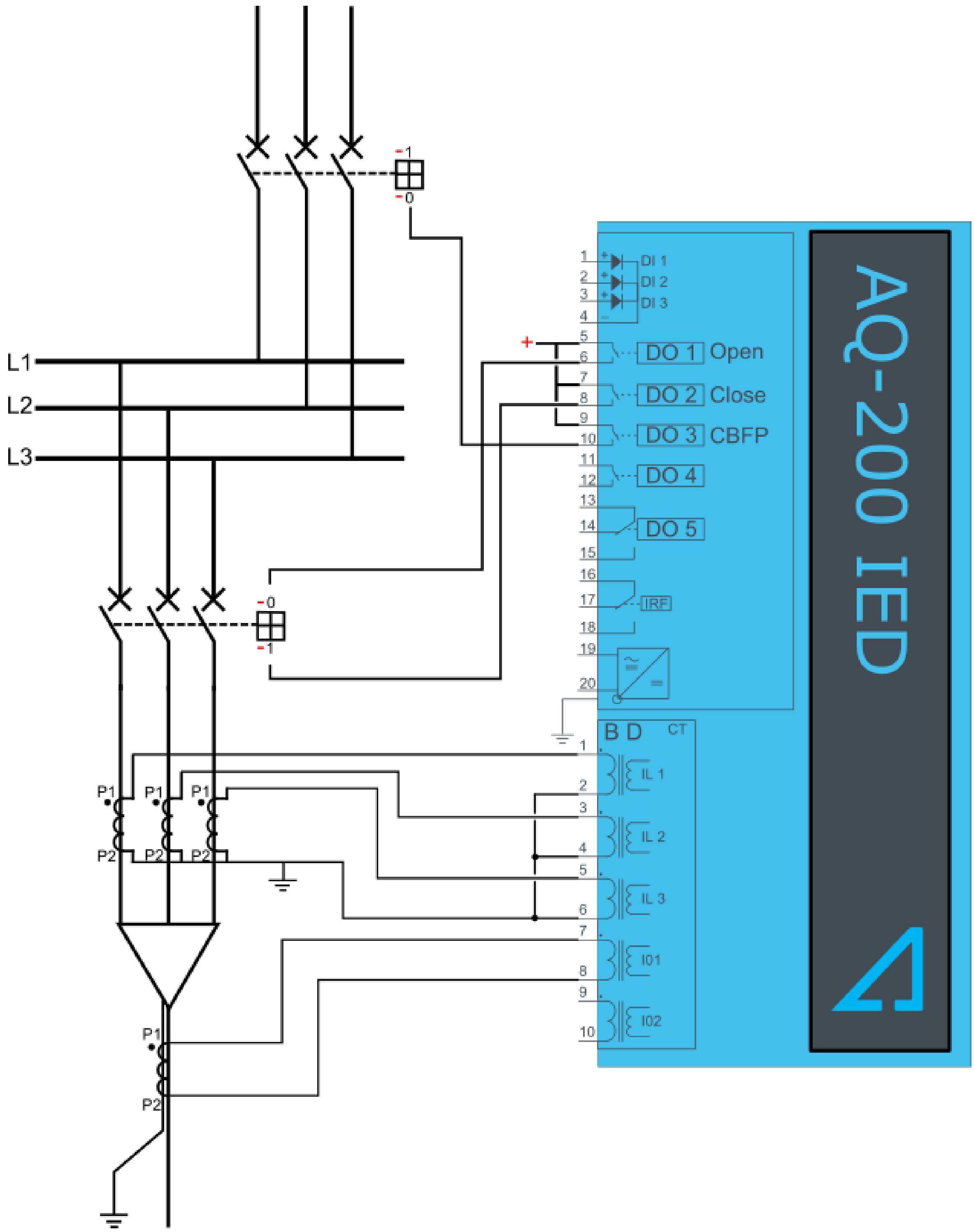
Figure. 5.4.7. - 37. Retrip and CBFP when "current or digital output" is the selected criterion.



When the current threshold setting of I_{set} and/or $I0_{set}$ is exceeded, the current-based protection is activated and the counters for RETRIP and CBFP START to calculate the set operating time. When the TRIP signal reaches the primary protection stage, the RETRIP and CBFP counters start to calculate the set operating time. The tripping of the primary protection stage is constantly monitored in this configuration regardless of what the status of the current is. The pick-up of the CBFP is active unless the current is reduced below the setting limit and the primary stage tripping signal is reset. If either of these conditions is met (i.e. the current is below the limit or the signal is reset) within the set time limit, a RETRIP signal is sent to the incomer breaker. If either of the conditions is active, CBFP is also sent to the incomer breaker. If the primary protection function clears the fault, both counters (RETRIP and CBFP) are reset as soon as the measured current is below the threshold settings and the tripping signal is reset. This configuration allows the CBFP to be controlled solely on current-based functions with added security from current monitoring. Other function trips can also be included to the CBFP functionality.

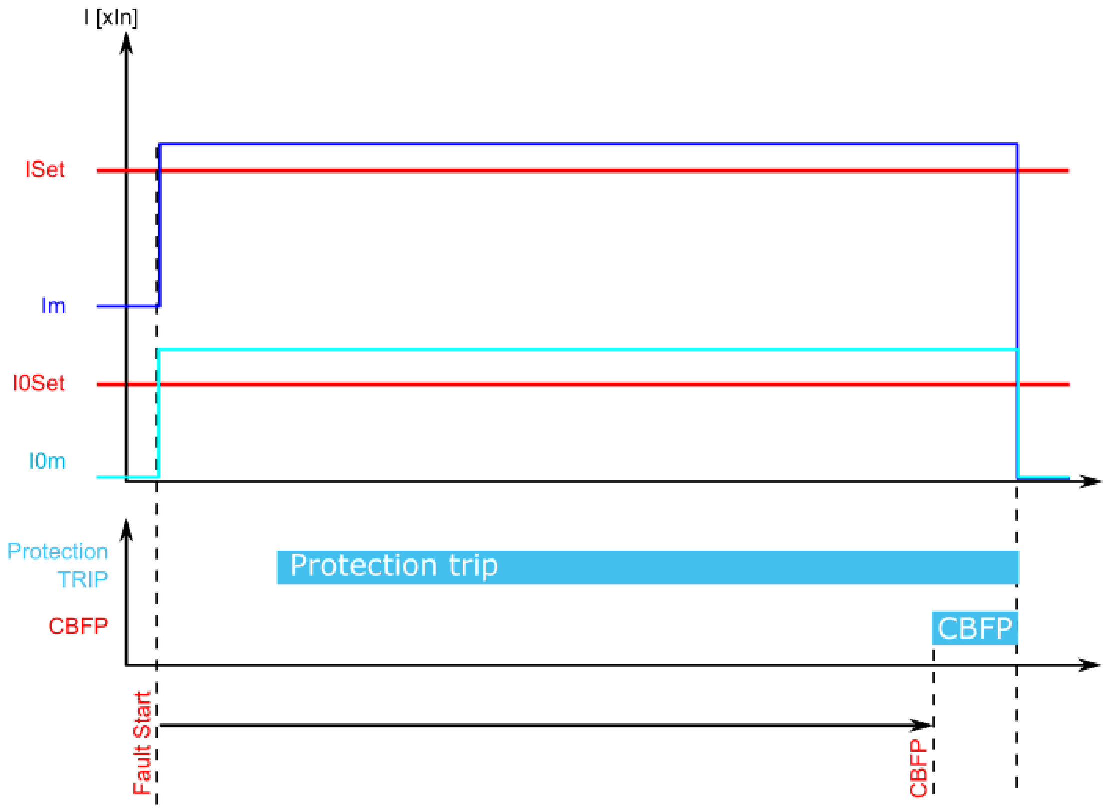
Trip and CBFP are configured to the device.

Figure. 5.4.7. - 38. Trip and CBFP are configured to the device.



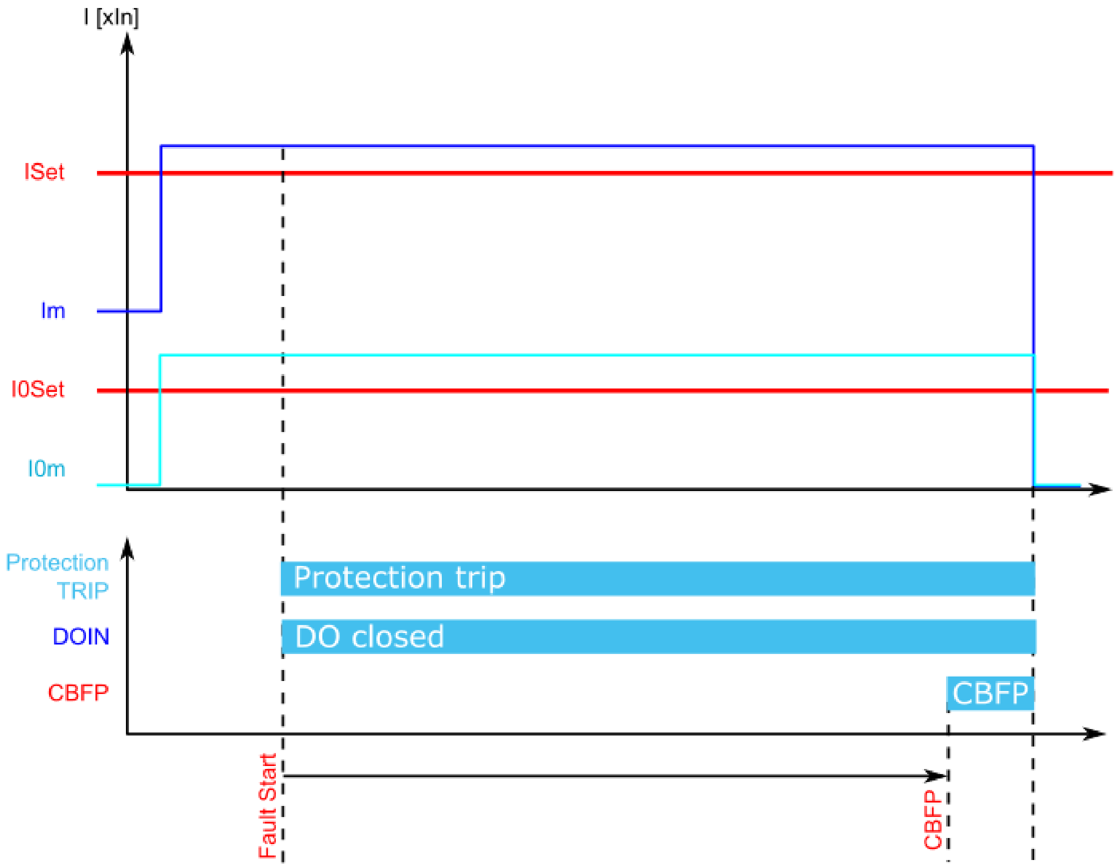
Probably the most common application is when the device's trip output controls the circuit breaker trip coil and a single, dedicated CBFP contact controls the CBFP. Below are a few operational cases regarding the various applications and settings of the CBFP function.

Figure. 5.4.7. - 39. CBFP when current is the only selected criterion.



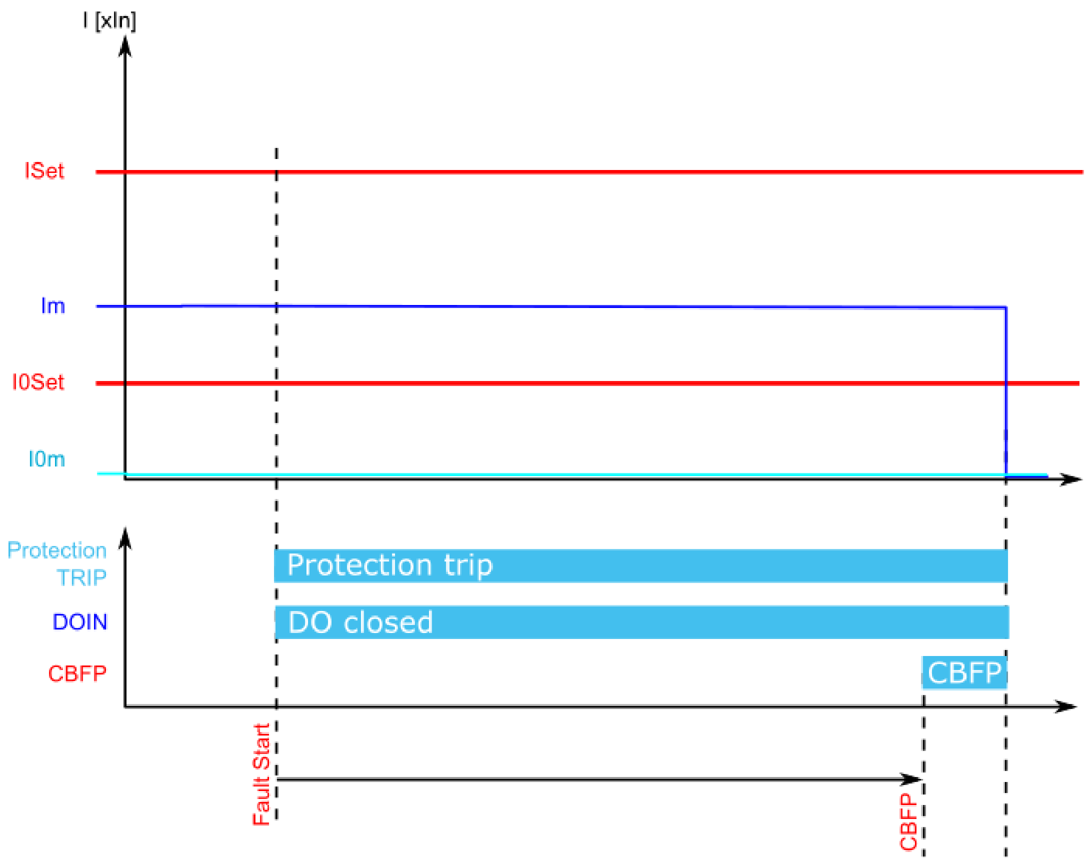
When the current threshold setting of I_{set} and/or $I0_{set}$ is exceeded, the current-based protection is activated and the counter for CBFP starts to calculate the set operating time. The tripping of the primary protection stage is not monitored in this configuration; therefore, if the current is not reduced below the setting limit, CBFP is sent to the incomer breaker. If the primary protection function clears the fault, the counter for CBFP resets as soon as the measured current is below the threshold settings.

Figure. 5.4.7. - 40. CBFP when "current and digital output" are the selected criteria.



When the current threshold setting of I_{set} and/or $I0_{set}$ is exceeded, the current-based protection is activated. At the same time, the counters for RETRIP and CBFP are halted until the monitored output contact is controlled (that is, the primary protection operates). When the tripping signal reaches the primary protection stage, the CBFP counter starts to calculate the set operating time. The tripping of the primary protection stage is constantly monitored in this configuration. If the current is not reduced below the setting limit and the primary stage tripping signal is not reset, CBFP is sent to the incomer breaker. If the primary protection function clears the fault, the counter for CBFP are reset as soon as the measured current is below the threshold settings or the tripping signal is reset. This configuration allows the CBFP to be controlled solely on current-based functions and other function trips can be excluded from the CBFP functionality.

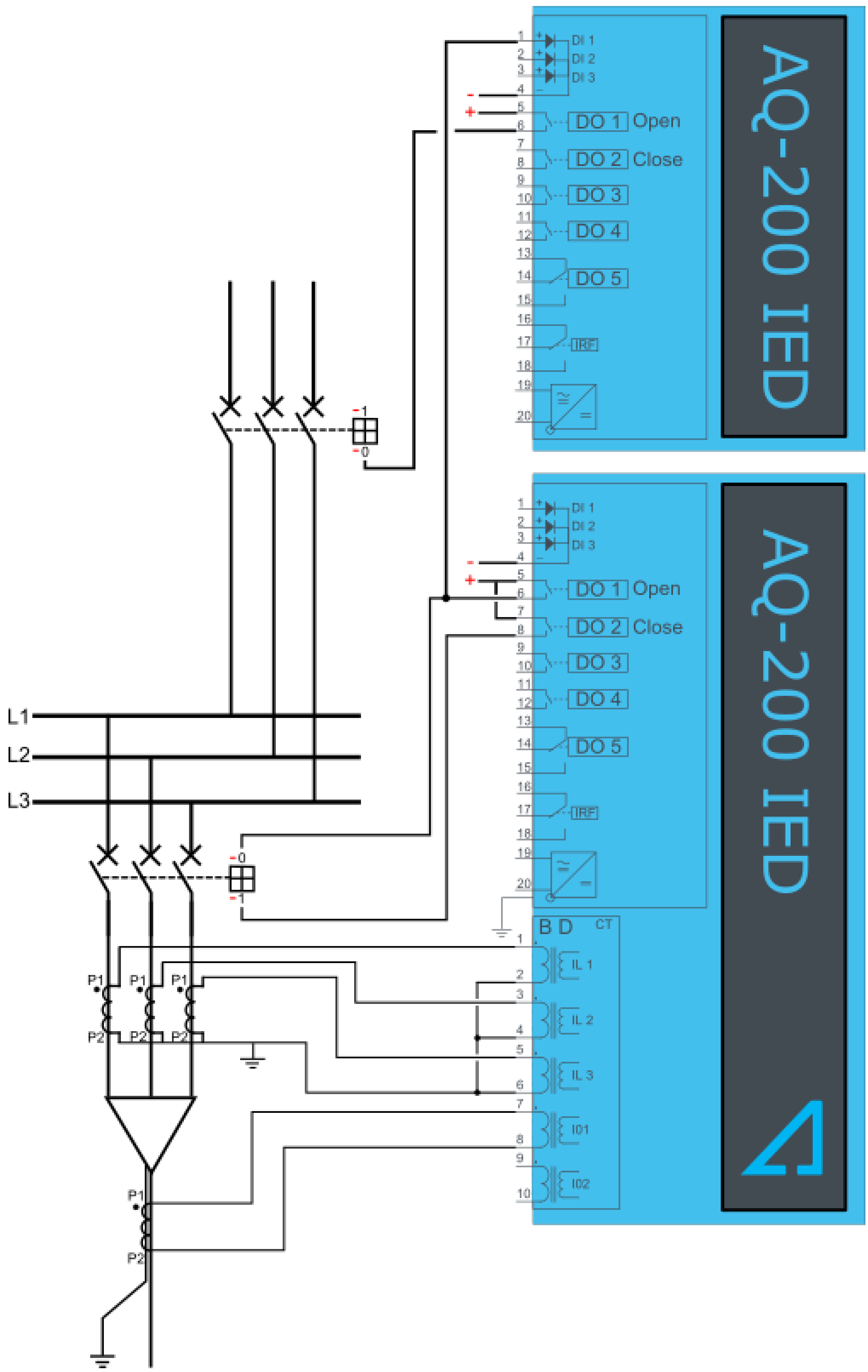
Figure. 5.4.7. - 41. CBFP when "current or digital output" is the selected criterion.



The counter for CBFP starts to calculate the set operating time either when the current exceeds its setting limit or when the primary protection stage trips. The tripping of the primary protection stage is constantly monitored in this configuration regardless of what the status of the current is. The pick-up of the CBFP is active unless the current is reduced below the setting limit and the primary stage tripping signal is reset. If either of these conditions (i.e. the current is below the limit or the signal is reset) is met within the set time limit, a RETRIP signal is sent to the incomer breaker. If either of the conditions is active, CBFP is also sent to the incomer breaker. If the primary protection function clears the fault, the CBFP counter is reset as soon as the measured current is below the threshold settings and the tripping signal is reset. This configuration allows the CBFP to be controlled solely on current-based functions with added security from current monitoring. Other function trips can also be included to the CBFP functionality.

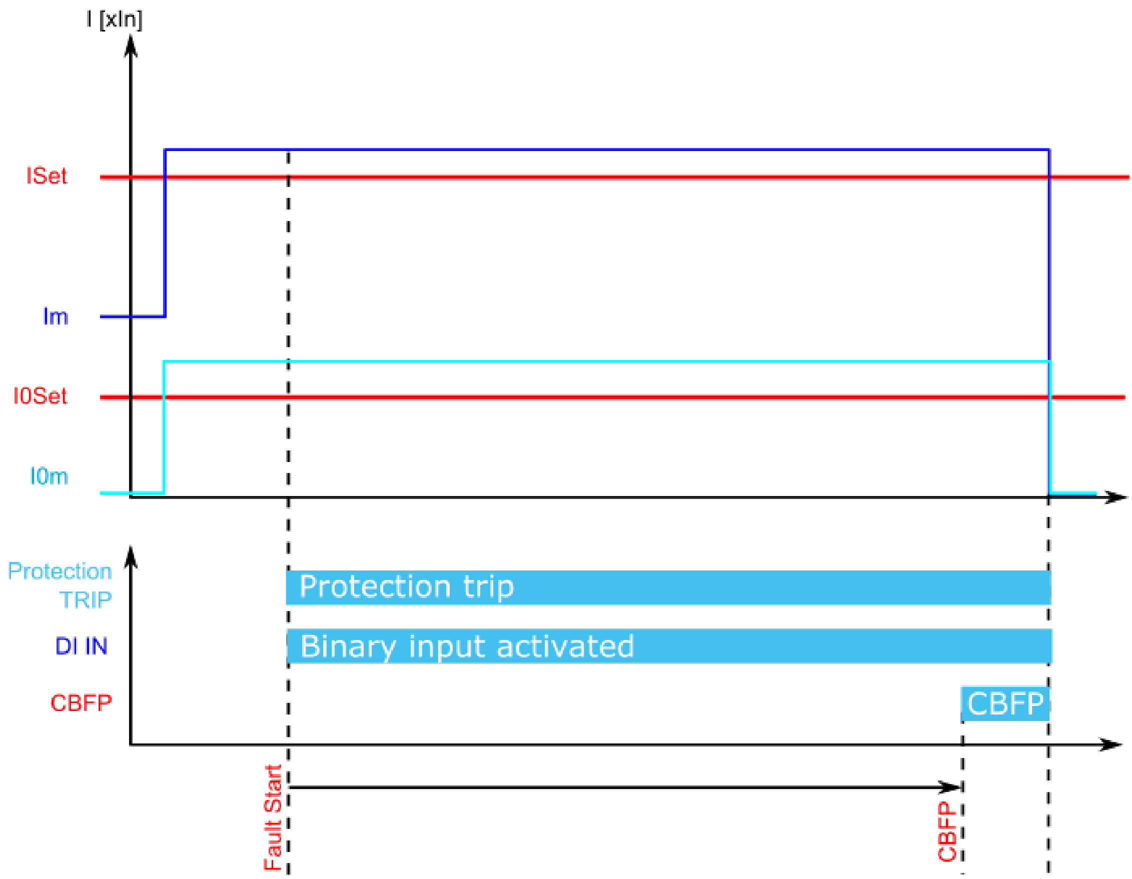
Device is configured as a dedicated CBFP unit.

Figure. 5.4.7. - 42. Device is configured as a dedicated CBFP unit.



Some applications require a dedicated circuit breaker protection unit. When the CBFP function is configured to operate with a digital input signal it can be used in these applications. When the device is used for this purpose the tripping signal is wired to the device digital input and the device's own trip signal is used for the CBFP purpose only. In this application incomer the RETRIP and CBFP signals are also available with different sets of requirements. The RETRIP signal can be used for tripping the section's feeder breaker and the CBFP signal for tripping the incomer. The following example does not use retripping and the CBFP signal is used as the incomer trip from the outgoing breaker trip signal. The trip signal can also be transported between different devices by using GOOSE messages.

Figure. 5.4.7. - 43. Dedicated CBFP operation from digital input signal.



In this mode the CBFP operates only from a digital input signal. Current and output relay monitoring can be used. The counter for the CBFP starts when the digital input is activated. If the counter is active until the CBFP counter is used, the device issues a CBFP command to the incomer breaker. In this application the device tripping signals from all outgoing feeders can be connected to one dedicated CBFP device which operates either on current-based protection or on all possible faults' CBFP protection.

Events and registers.

The circuit breaker failure protection function (abbreviated "CBF" in event block names) generates events and registers from the status changes in RETRIP, in CBFP-activated and CBFP-blocked signals, as well as in internal pick-up comparators. The user can select the status ON or OFF for messages in the main event buffer.

The triggering event of the function (RETRIP, CBFP-ACTIVATED or BLOCKED) is recorded with a time stamp and with process data values.

Table. 5.4.7. - 87. Event codes.

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
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

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data for ACTIVATED, BLOCKED, etc. The table below presents the structure of the function's register content.

Table. 5.4.7. - 88. Register content.

Date and time	Event code	Trigger current	Time to RETRact	Time to CBFPact	F type	S type	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	Setting group 1...8 active

5.4.8. Restricted earth fault/cable end differential (I0d>; 87N)

The restricted earth fault function is used for residual differential current measurement for transformers. This function can also be used as the cable end differential function. The operating principle is low-impedance differential protection with bias characteristics the user can set. A differential current is calculated with the sum of the phase currents and the selected residual current input. In cable end differential mode the function provides natural measurement unbalance compensation for higher operating sensitivity in monitoring cable end faults.

The restricted earth fault function constantly monitors phase currents and selected residual current instant values as well as calculated bias current and differential current magnitudes.

The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

The outputs of the function are TRIP and BLOCKED signals. The function uses a total of eight (8) separate setting groups which can be selected from one common source. The operating mode of the function can be changed via setting group selection.

The operational logic consists of the following:

- input magnitude selection
- input magnitude processing
- differential characteristic comparator
- block signal check
- output processing.

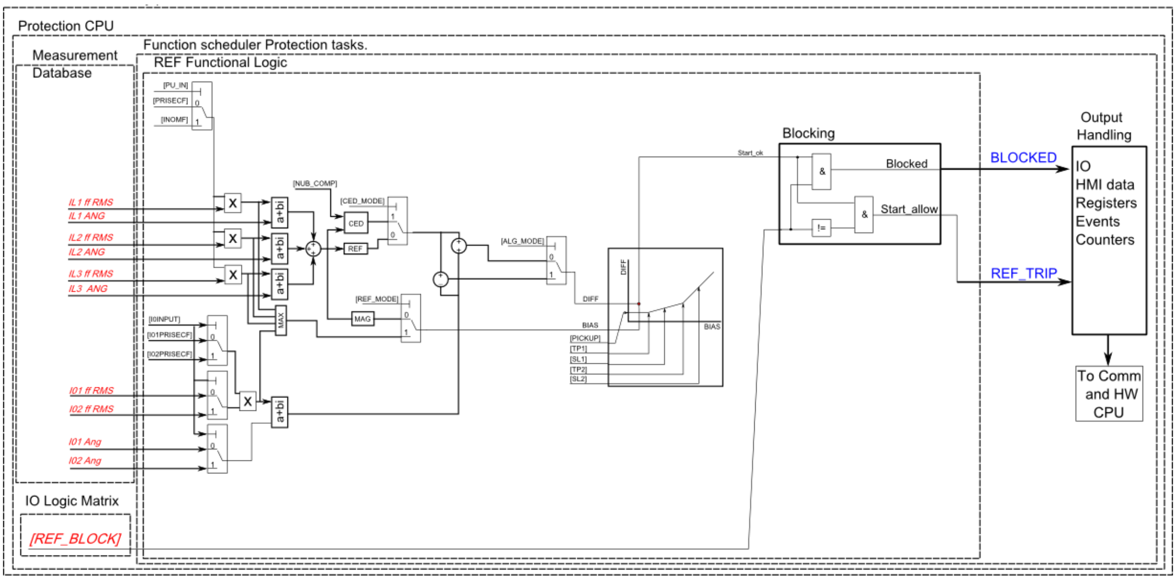
The inputs for the function are the following:

- setting parameters
- measured and pre-processed current magnitudes.

The function's output signals can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the two (2) output signals. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the REF, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the restricted earth fault function.

Figure. 5.4.8. - 44. Simplified function block diagram of the I0d> function.



Measured input

The function block uses analog current measurement values. It uses the fundamental frequency magnitude of the current measurement inputs, and the calculated residual current with residual current measurement. The user can select inputs I01 or I02 for residual current measurement.

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

Table. 5.4.8. - 89. Measurement inputs of the I0d> 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

The selection of the AI channel currently in use 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 to change them by editing the setting group.

Table. 5.4.8. - 90. General settings.

Name	Range	Step	Default	Description
I0d> in side	1: Side 1 2: Side 2	-	1: Side 1	Defines which current measurement module is used by the function.
Restricted earth fault (REF) or Cable End Differential	0: REF 1: CED	-	0: REF	Selection of the operating characteristics. If REF is selected, the function operates with normal accuracies. If CED is selected, the natural unbalance created by the phase current CT:s can be compensated for more sensitive operation. The default setting is REF.
Comp. natural unbal.	0:- 1: Comp	-	-	When activated while the line is energized, the currently present calculated residual current is compensated to 0. This compensation only has an effect in the CED mode.

Operating characteristics

The current-dependent pick-up and activation of the function are controlled by setting parameters, which define the current calculating method used as well as the operating characteristics.

Table. 5.4.8. - 91. Pick-up settings.

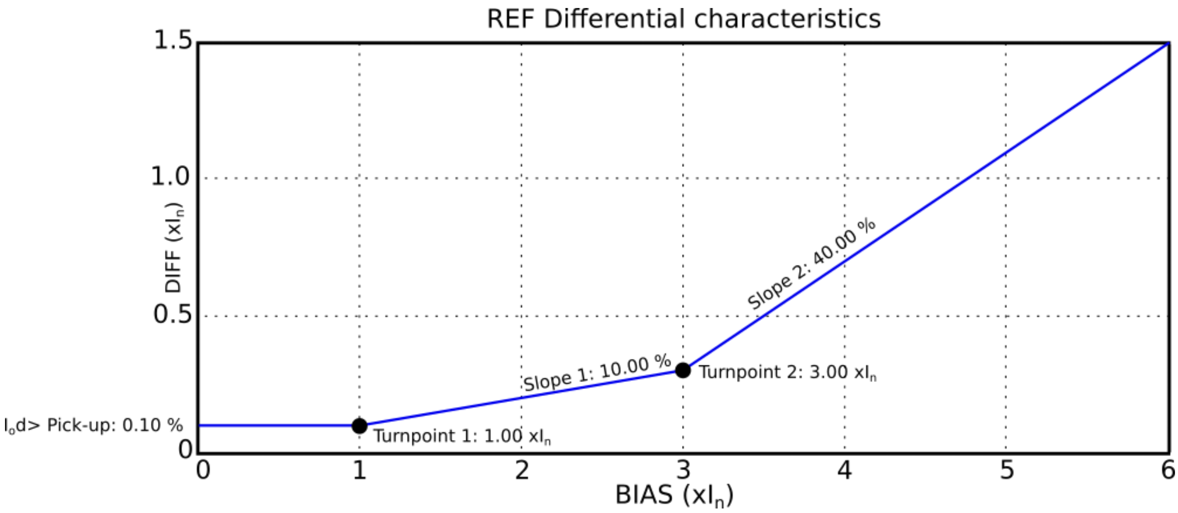
Name	Range	Step	Default	Description
I0 Input	0: I01 1: I02	-	0: I01	Selection of the used residual current measurement input.
I0 Direction	0: Add 1: Subtract	-	0: Add	Differential current calculation mode. This matches the directions of the calculated and measured residual currents to the application. The default setting (0: Add) means that I0Calc + I01 or I0Calc + I02 in a through fault yields no differential current.
Bias current calc	0: Residual current (3I0 + I0Calc)/2 1: Maximum (Phase and I0 max)	-	0: Residual current	Selection of the bias current calculation. Differential characteristics biasing can use either the calculated residual current or the maximum of all measured currents. The residual current mode is more sensitive while the maximum current is coarser.
I0d> pick-up	0.01…50.00 % (of I_n)	0.01 %	10 %	Setting for basic sensitivity of the differential characteristics.
Turnpoint 1	0.01…50.00 × I_n	0.01 × I_n	1.00 × I_n	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 2	0.01…50.00 × I_n	0.01 × I_n	3.00 × I_n	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 settings can be selected via setting groups. The pick-up activation of the function is not directly equal to the TRIP signal generation of the function. The TRIP signal is allowed if the blocking condition is not active.

The following figure presents the differential characteristics with default settings.

Figure. 5.4.8. - 45. Differential characteristics for the I0d> function with default settings.



The equations for the differential characteristics are the following:

Figure. 5.4.8. - 46. Differential current (the calculation is based on user-selected inputs and direction).

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

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

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

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

Figure. 5.4.8. - 47. Bias current (the calculation is based on the user-selected mode).

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

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

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

Figure. 5.4.8. - 48. Characteristics settings.

$$Diff_{bias<TP1} = I0_{d>pick-up}$$

$$Diff_{biasTP1...TP2} = SL1 \times (Ix - TP1) + I0_{d>pick-up}$$

$$Diff_{bias>TP2} = SL2 \times (Ix - TP2) + SL1 \times (TP2 - TP1) + I0_{d>pick-up}$$

Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's 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 the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the TRIP function has been activated before the blocking signal, it resets and processes the release time characteristics similarly to when the pick-up signal is reset.

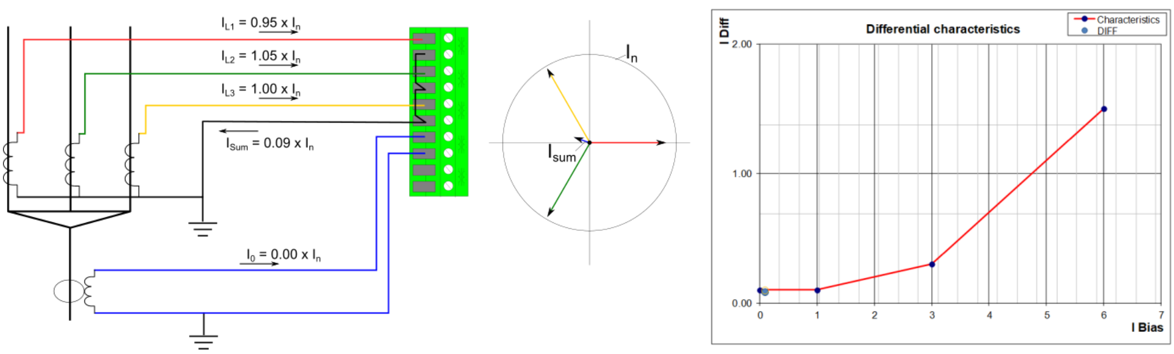
The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup current values and its fault type to be issued.

The blocking signal can also be tested in the commissioning phase by a software switch signal when the relay's testing mode "Enable stage forcing" is activated (*General* → *Device*).

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

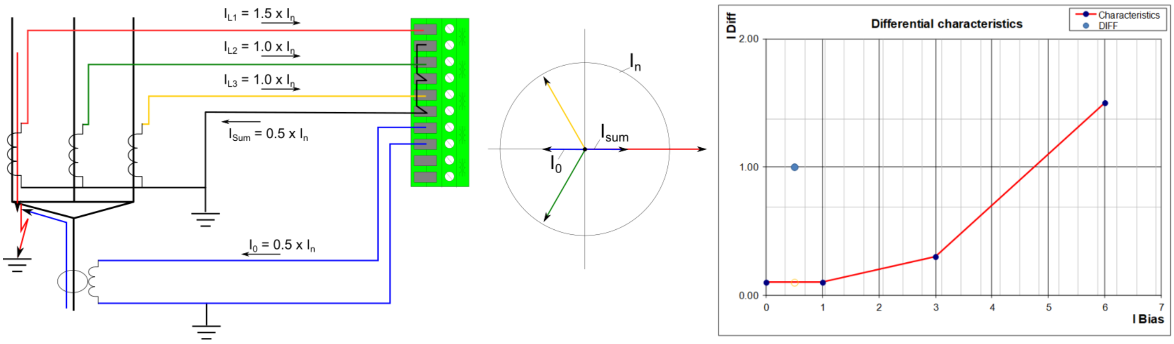
the following figures present some typical applications for this function.

Figure. 5.4.8. - 49. Cable end differential with natural unbalance in the phase current measurement.



When calculating residual current from the phase currents, the natural unbalance can be around 10 % while the used CTs are still within the promised 5P class (which is probably the most common CT accuracy class). When the current natural unbalance is compensated in this situation, the differential settings may be set to be more sensitive and the natural unbalance does not, therefore, affect the calculation.

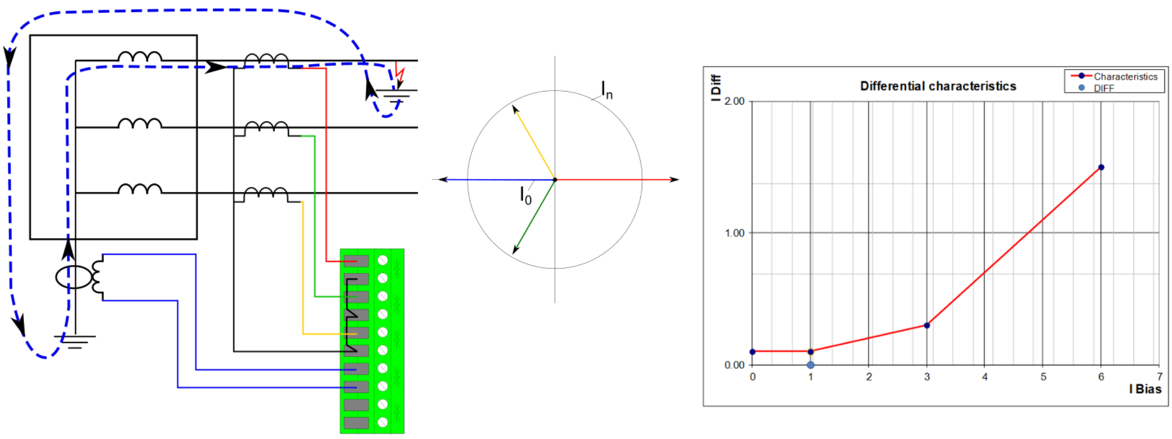
Figure. 5.4.8. - 50. Cable end differential when a fault occurs.



If a starting fault occurs in the cable end, the CED mode catches the difference between the ingoing and the outgoing residual currents. The resulting signal can be used for alarming or tripping purposes for the feeder with the failing cable end. The user can freely change both the settings and the sensitivity of the algorithm.

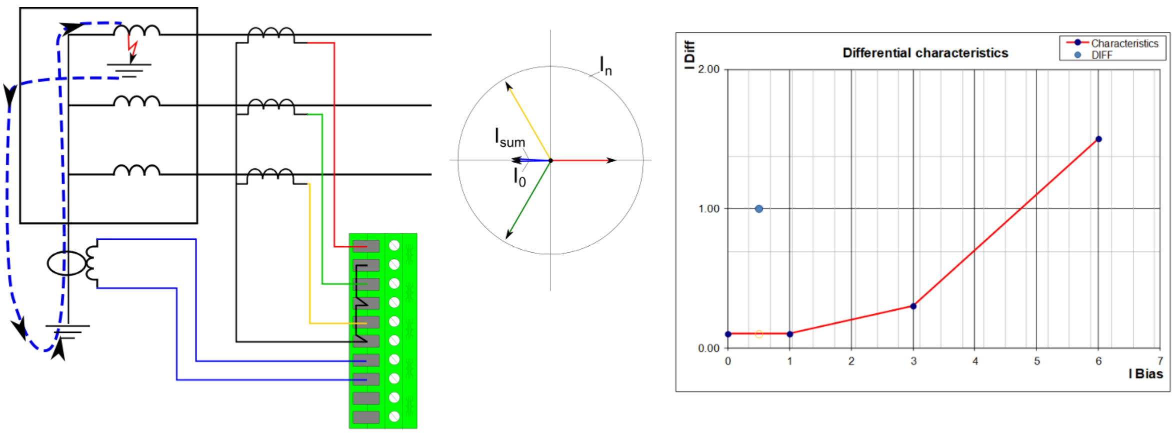
Restricted earth fault protection is usually used in the Y winding of a power transformer. This function is needed to prevent the main differential protection from being tripped by faults occurring outside the protection area; in some cases, the function has to be disabled or its sensitivity limited to catch earth faults inside the protection area. For this purpose, the restricted earth fault function is stable since it only monitors the side it is wired to, and compares the calculated and measured residual currents. During an outside earth fault the circulating residual current in the faulty phase winding does not cause a trip because the comparison of the measured starpoint current and the calculated residual current differential is close to zero.

Figure. 5.4.8. - 51. Restricted earth fault outside a Y winding transformer.



If the fault is located inside of the transformer and thus inside of the protection area, the function catches the fault with high sensitivity. Since the measured residual current now flows in the opposite direction than in the outside fault situation, the measured differential current is high.

Figure. 5.4.8. - 52. Restricted earth fault inside a Y winding transformer.



Events and registers

The restricted earth fault function (abbreviated "REF" in event block names) generates events and registers from the status changes in TRIP-activated and BLOCKED signals. The user can select the status ON or OFF for messages in the main event buffer.

The triggering event of the function (TRIP-activated or BLOCKED) is recorded with a time stamp and with process data values.

Table. 5.4.8. - 92. Event codes.

Event number	Event channel	Event block name	Event code	Description
4224	66	REF1	0	I0d> (87N) Trip ON
4225	66	REF1	1	I0d> (87N) Trip OFF
4226	66	REF1	2	I0d> (87N) Block ON
4227	66	REF1	3	I0d> (87N) Block OFF

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data for ACTIVATED, BLOCKED, etc. The table below presents the structure of the function's register content.

Table. 5.4.8. - 93. Register content.

Date and time	Event code	Average trigger currents	Maximum 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	Setting group 1...8 active

5.4.9. Overvoltage (U>; 59)

The overvoltage function is used for instant and time-delayed overvoltage protection. Each device with a voltage protection module has four (4) available stages of the function (U>, U>>, U>>>, U>>>>). The function constantly measures phase voltage magnitudes or line-to-line magnitudes. Overvoltage protection is based on line-to-line fundamental frequency or to line-to-line neutral fundamental frequency (as the user selects). If the protection is based on line-to-line voltage, overvoltage protection is not affected by earth faults in isolated or compensated networks. The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

The outputs of the function are the START, TRIP and BLOCKED signals. The overvoltage function uses a total of eight (8) 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 between definite time (DT) mode and inverse definite minimum time (IDMT).

The operational logic consists of the following:

- input magnitude selection
- input magnitude processing
- threshold comparator
- block signal check
- time delay characteristics
- output processing.

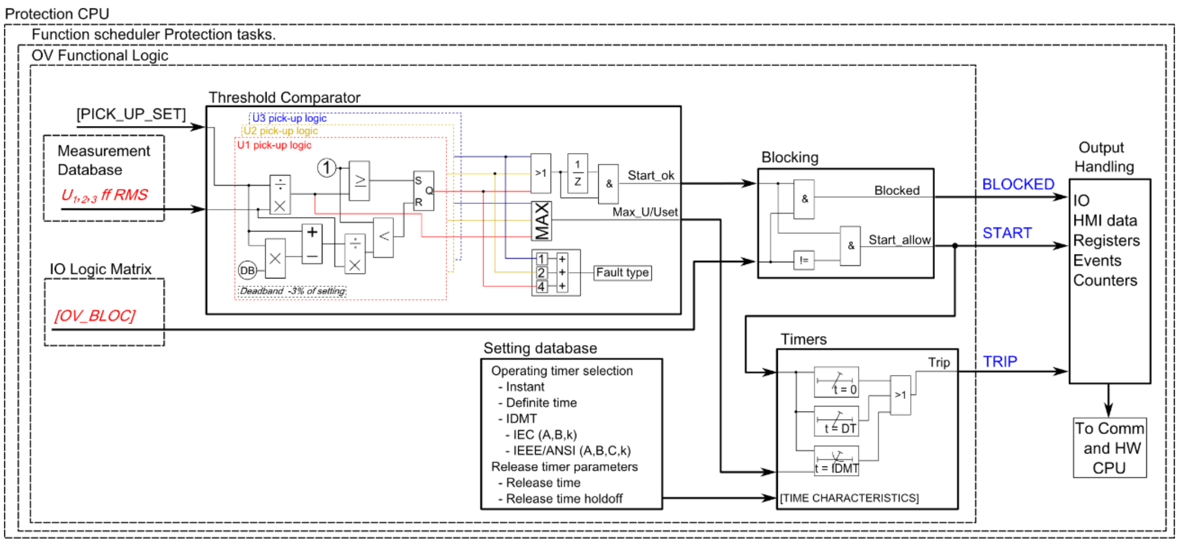
The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed voltage magnitudes.

The function outputs the START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signal. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the overvoltage function.

Figure. 5.4.9. - 53. Simplified function block diagram of the U> function.



Measured input

The function block uses analog voltage measurement values and always uses peak-to-peak measurement from samples. The monitored magnitudes are equal to fundamental frequency RMS values. A -20 ms averaged value of the selected magnitude is used for pre-fault data registering.

Table. 5.4.9. - 94. Measurement input of the U> 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. 5.4.9. - 95. Measured magnitude selection settings.

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

The selection of the AI channel in use is made with a setting parameter. In all possible input channel variations the pre-fault condition is presented with a 20 ms averaged history value from -20 ms from START or TRIP event.

Figure. 5.4.9. - 54. Selectable measurement magnitudes with 3LN+U4 VT connection.

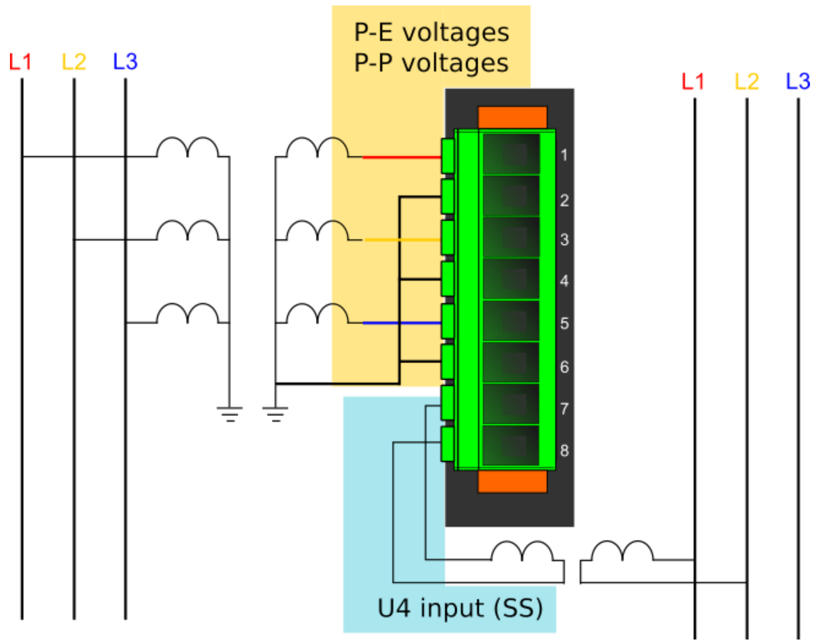


Figure. 5.4.9. - 55. Selectable measurement magnitudes with 3LL+U4 VT connection (P-E voltages not available without residual voltage).

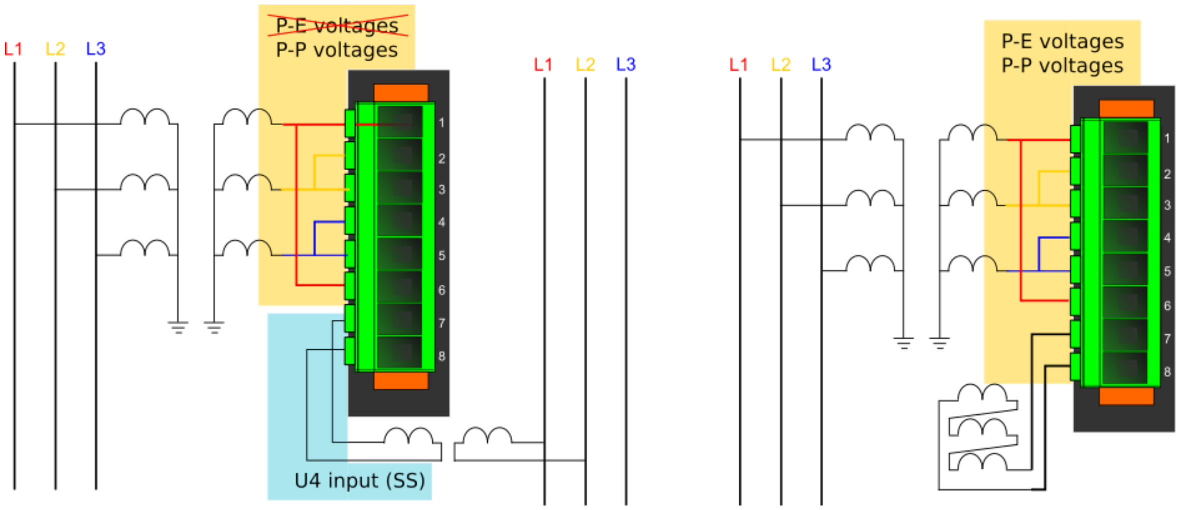
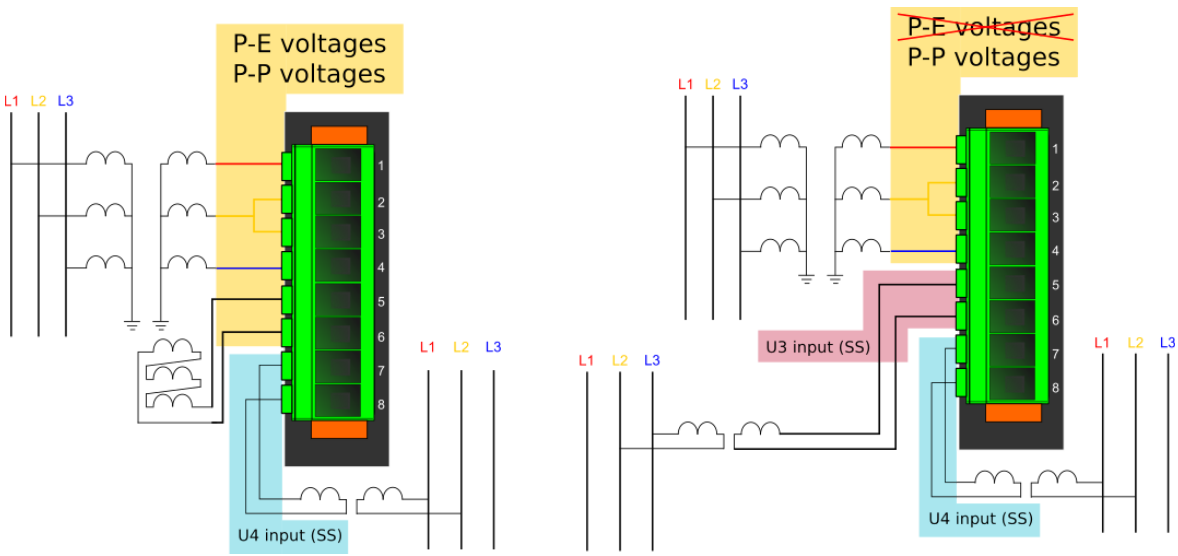


Figure. 5.4.9. - 56. Selectable measurement magnitudes with 2LL+U3+U4 VT connection (P-E voltages not available without residual voltage).



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 the 2LL+U3+U4 mode). *U4 input* selection follows the voltage in Channel 4. *U3Input* selection only follows the voltage in Channel 3 if the 2LL+U3+U4 mode is in use.

Pick-up

The U_{set} setting parameter controls the pick-up of the U> function. This defines the maximum allowed measured voltage before action from the function. The function constantly calculates the ratio between the U_{set} and the measured magnitude (U_m) for each of the three voltages. The reset ratio of 97 % is built into the function and is always relative to the U_{set} value. The setting value is common for all measured amplitudes, and when the U_m exceeds the U_{set} value (in single, dual or all voltages) it triggers the pick-up operation of the function.

Table. 5.4.9. - 96. Pick-up settings.

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
U_{set}	Pick-up setting	50.00…150.00 %U_n	0.1 %U_n	120 %U_n

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

Real-time info displayed by the function

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through AQtivate software when it is connected to the relay and its Live Edit mode is active.

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 when a fault occurs.
Time remaining to trip	s	When the relay has picked up and is counting time towards pick-up.
U_{meas}/U_{set} at the moment	U_m/U_{set}	The ratio between measured voltage and the pick-up value.

Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's 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 the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup voltage values and its fault type to be issued.

The blocking signal can also be tested in the commissioning phase by a software switch signal when the relay's testing mode "Enable stage forcing" is activated (*General* → *Device*).

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

Operating time characteristics for trip and reset

The operating timers’ behavior during a 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 the START signal.

- Definite time operation (DT): gives the TRIP signal after a user-defined time delay regardless of the measured voltage as long as the voltage is above the U_{set} value and thus the pick-up element is active (independent time characteristics).
- Inverse definite minimum time (IDMT): gives the TRIP signal after a time which is in relation to the set pick-up voltage U_{set} and the measured voltage U_m (dependent time characteristics).

The IDMT function follows this formula:

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

Where:

- t = operating time
- k = time dial setting
- U_m = measured voltage
- U_s = pick-up setting
- a = IDMT Multiplier setting

The following table presents the setting parameters for the function's time characteristics.

Table. 5.4.9. - 97. Setting parameters for operating time characteristics.

Name	Range	Step	Default	Description
Delay type	1: DT 2: IDMT	-	1: DT	Selection of the delay type time counter. The selection possibilities are dependent (IDMT, Inverse Definite Minimum Time) and independent (DT, Definite Time) characteristics.
Definite operating time delay	0.000…800.000 s	0.005 s	0.040 s	Definite time operating delay. The setting is active and visible when DT is the selected delay type. 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…60.00 s	0.01 s	0.05 s	This setting is active and visible when IDMT is the selected delay type. Time dial/multiplier setting for IDMT characteristics.
IDMT Multiplier	0.01…25.00 s	0.01 s	1.00 s	This setting is active and visible when IDMT is the selected delay type. IDMT time multiplier in the U_m/U_{set} power.

Table. 5.4.9. - 98. Setting parameters for reset time characteristics.

Name	Range	Step	Default	Description
Release time delay	0.000…150.000 s	0.005 s	0.06 s	Resetting time. The time allowed between pick-ups if the pick-up has not led to a trip operation. During this time the START signal is held on for the timers if the delayed pick-up release is active.
Delayed pick-up release	1: No 2: Yes	-	1: Yes	Resetting characteristics selection either as time-delayed or as instant after the pick-up element is released. If activated the START signal is reset after the set release time delay.
Time calc reset after release time	1: No 2: Yes	-	2: Yes	Operating timer resetting characteristics selection. When active, the operating time counter is reset after a set release time if the pick-up element is not activated during this time. When disabled, the operating time counter is reset directly after the pick-up element is reset.

Continue time calculation during release time	1: No 2: Yes	-	1: No	Time calculation characteristics selection. If activated, the operating time counter is continuing until a set release time has passed even if the pick-up element is reset.

The user can reset characteristics through the application. The default setting is a 60 ms delay; the time calculation is held during the release time.

In the release delay option the operating time counter calculates the operating time during the release. When using this option the function does not trip if the input signal is not re-activated while the release time count is on-going.

Events and registers

The overvoltage function (abbreviated "OV" in event block names) generates events and registers from the status changes in START, TRIP, and BLOCKED. The user can select the status ON or OFF for messages in the main event buffer. The function offers four (4) independent stages; the events are segregated for each stage operation.

The triggering event of the function (START, TRIP or BLOCKED) is recorded with a time stamp and with process data values.

Table. 5.4.9. - 99. Event codes.

Event number	Event channel	Event block name	Event code	Description
5440	85	OV1	0	Start ON
5441	85	OV1	1	Start OFF
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

The function registers its operation into the last twelve (12) time-stamped registers; this information is available for all provided instances separately. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.

Table. 5.4.9. - 100. Register content.

Date and time	Event code	Fault type	Trigger voltage	Fault voltage	Pre-fault voltage	Trip time remaining	Used SG
dd.mm.yyyy hh:mm:ss.mss	5440-5637 Descr.	L1-E… L1-L2-L3	Start average voltage	Trip -20 ms averages	Start -200 ms averages	0 s...1800 s	Setting group 1...8 active

5.4.10. Undervoltage (U<; 27)

The undervoltage function is used for instant and time-delayed undervoltage protection. Each device with a voltage protection module has four (4) available stages of the function (U>, U>>, U>>>, U>>>>). The function constantly measures phase voltage magnitudes or line-to-line voltage magnitudes. Undervoltage protection is based on line-to-line fundamental frequency or to line-to-line neutral fundamental frequency (as the user selects). If the protection is based on line-to-line voltage, undervoltage protection is not affected by earth faults in isolated or compensated networks. Undervoltage protection has two blocking stages: internal blocking (based on voltage measurement and low voltage), or external blocking (e.g. during voltage transformer fuse failure). The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

The outputs of the function are the START, TRIP and BLOCKED signals. The undervoltage function uses a total of eight (8) 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 between definite time (DT) mode and inverse definite minimum time (IDMT).

The operational logic consists of the following:

- input magnitude selection
- input magnitude processing
- threshold comparator
- block signal check
- time delay characteristics
- output processing.

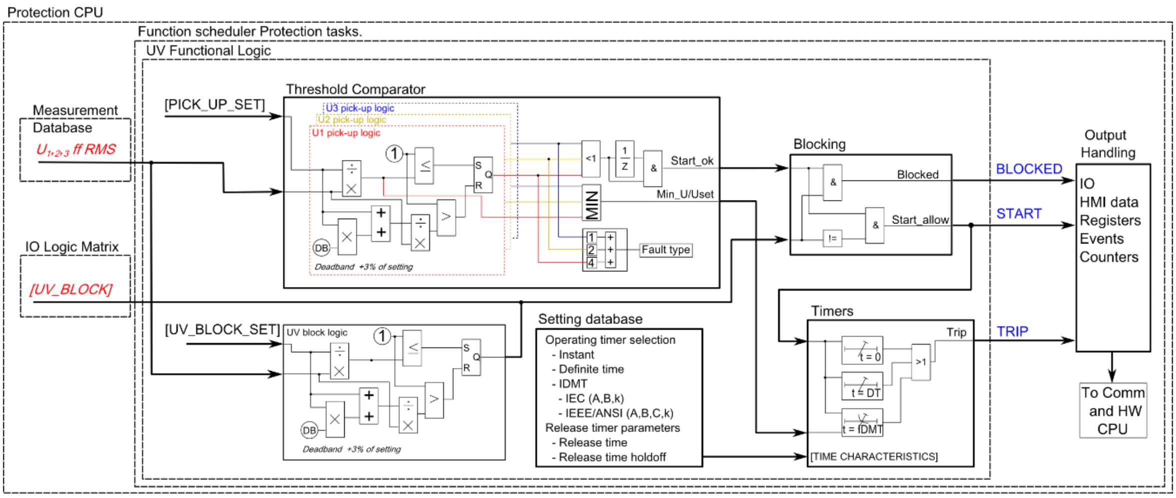
The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed voltage magnitudes.

The function outputs the START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signal. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the undervoltage function.

Figure. 5.4.10. - 57. Simplified function block diagram of the U< function.



Measured input

The function block uses analog voltage measurement values and always uses peak-to-peak measurement from samples. The monitored magnitudes are equal to fundamental frequency RMS values. A -20 ms averaged value of the selected magnitude is used for pre-fault data registering.

Table. 5.4.10. - 101. Measurement inputs of the U< 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. 5.4.10. - 102. Measured magnitude selection settings.

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

The selection of the AI channel in use is made with a setting parameter. In all possible input channel variations the pre-fault condition is presented with a 20 ms averaged history value from -20 ms from START or TRIP event.

Figure. 5.4.10. - 58. Selectable measurement magnitudes with 3LN+U4 VT connection.

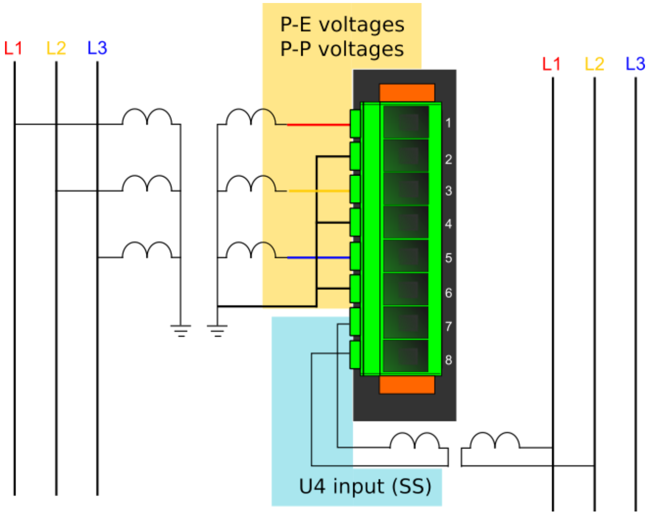


Figure. 5.4.10. - 59. Selectable measurement magnitudes with 3LL+U4 VT connection (P-E voltages not available without residual voltage).

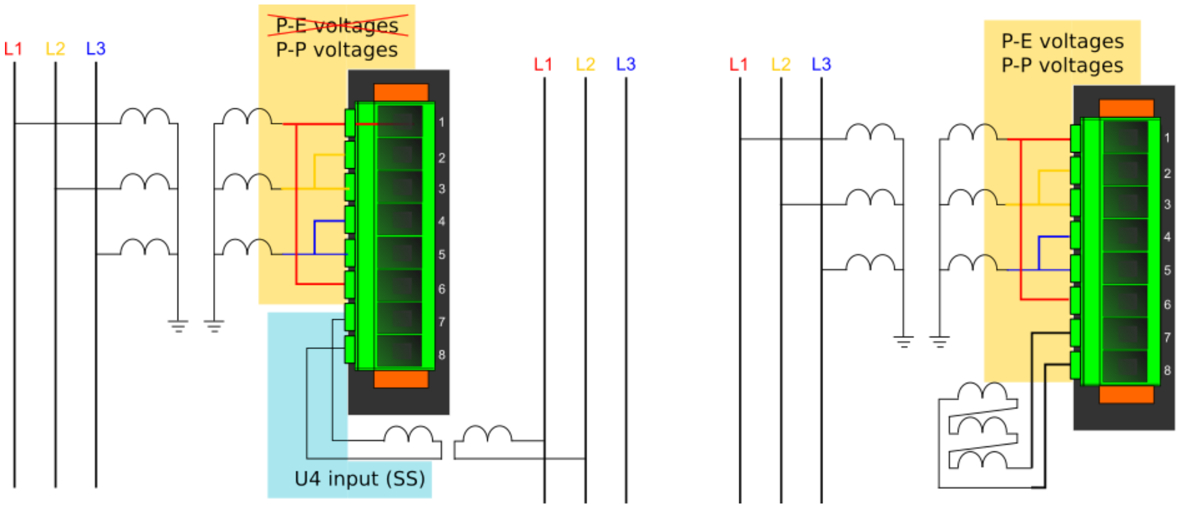
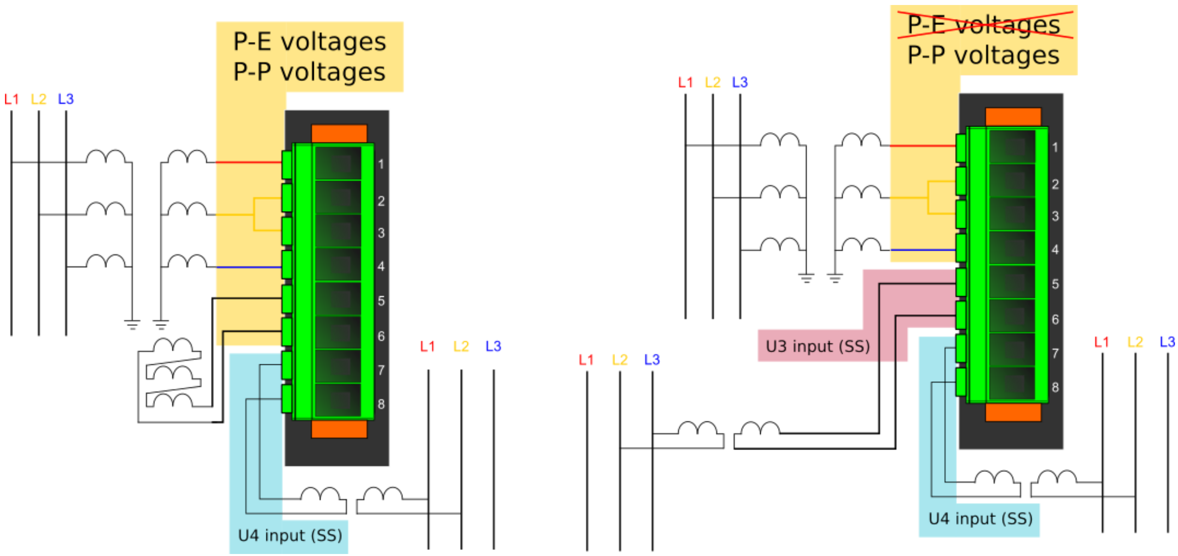


Figure. 5.4.10. - 60. Selectable measurement magnitudes with 2LL+U4 VT connection (P-E voltages not available without residual voltage).



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 the 2LL+U3+U4 mode). *U4 input* selection follows the voltage in Channel 4. *U3Input* selection only follows the voltage in Channel 3 if the 2LL+U3+U4 mode is in use.

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 the voltage in Channel 4. *U3 Input* selection follows only the voltage in Channel 3 if 2LL+U3+U4 mode is in use.

Pick-up

The U_{set} setting parameter controls the pick-up of the U< function. This defines the minimum allowed measured voltage before action from the function. The function constantly calculates the ratio between the U_{set} and the measured magnitude (U_m) for each of the three voltages. The reset ratio of 103 % is built into the function and is always relative to the U_{set} value. The setting value is common for all measured amplitudes, and when the U_m exceeds the U_{set} value (in single, dual or all voltages) it triggers the pick-up operation of the function.

Table. 5.4.10. - 103. Pick-up settings.

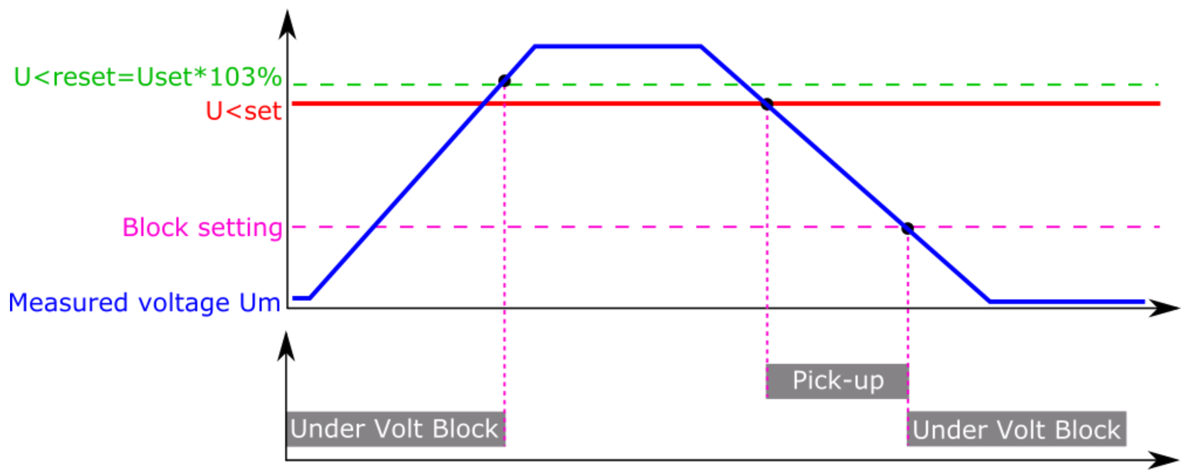
Name	Description	Range	Step	Default
U_{set}	Pick-up setting	0.00…120.00 $\%U_n$	0.01 $\%U_n$	60 $\%U_n$
U Block setting	Block setting. If set to zero, blocking is not in use. The operation is explained in the next chapter.	0.00…100.00 $\%U_n$	0.01 $\%U_n$	10 $\%U_n$

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

Using *Block setting* to prevent nuisance trips

It is recommended to use the *Block setting* parameter to prevent the relay from tripping in a situation where the network is de-energized. When the measured voltage drops below the set value, the relay does not give a tripping signal. If the measured voltage has dropped below the *Block setting* parameter, the blocking continues until all of the line voltages have increased above the U< pick-up setting. Please see the image below for a visualization of this function. If the block level is set to zero (0), blocking is not in use.

Figure. 5.4.10. - 61. Example of the block setting operation.



Real-time info displayed by the function

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through AQtivate software when it is connected to the relay and its Live Edit mode is active.

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 the measured voltage is below this value, the network is considered de-energized and the function will not trip. To deactivate the blocking, the measured voltage must go above the pick-up setting.
Expected operating time	s	Displays the expected operating time when a fault occurs.
Time remaining to trip	s	When the relay has picked up and is counting time towards the pick-up.
U_{meas}/U_{set} at the moment	U_m/U_{set}	The ratio between the measured voltage and the pick-up value.

Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's 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 the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup voltage values and its fault type to be issued.

The blocking signal can also be tested in the commissioning phase by a software switch signal when the relay's testing mode "Enable stage forcing" is activated (*General* → *Device*).

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

Operating time characteristics for trip and reset

The operating timers’ behavior during a 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 the START signal.
- Definite time operation (DT): gives the TRIP signal after a user-defined time delay regardless of the measured voltage as long as the voltage is above the U_{set} value and thus the pick-up element is active (independent time characteristics).

- Inverse definite minimum time (IDMT): gives the TRIP signal after a time which is in relation to the set pick-up voltage U_{set} and the measured voltage U_m (dependent time characteristics).

The IDMT function follows this formula:

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

Where:

- t = operating time
- k = time dial setting
- U_m = measured voltage
- U_s = pick-up setting
- a = IDMT multiplier setting

The following table presents the setting parameters for the function's time characteristics.

Table. 5.4.10. - 104. Setting parameters for operating time characteristics.

Name	Range	Step	Default	Description
Delay type	1: DT 2: IDMT	-	1: DT	Selection of the delay type time counter. The selection possibilities are dependent (IDMT, Inverse Definite Minimum Time) and independent (DT, Definite Time) characteristics.
Definite operating time delay	0.000…1800.000 s	0.005 s	0.040 s	Definite time operating delay. This setting is active and visible when DT is the selected delay type. 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…60.00 s	0.01 s	0.05 s	This setting is active and visible when IDMT is the selected delay type. Time dial/multiplier setting for IDMT characteristics.
IDMT Multiplier	0.01…25.00 s	0.01 s	1.00 s	This setting is active and visible when IDMT is the selected delay type. IDMT time multiplier in the U_m/U_{set} power.

Table. 5.4.10. - 105. Setting parameters for reset time characteristics.

Name	Range	Step	Default	Description
Release time delay	0.000…150.000 s	0.005 s	0.06 s	Resetting time. The time allowed between pick-ups if the pick-up has not led to a trip operation. During this time the START signal is held on for the timers if the delayed pick-up release is active.
Delayed pick-up release	1: No 2: Yes	-	2: Yes	Resetting characteristics selection, either time-delayed or instant after the pick-up element is released. If activated, the START signal is reset after a set release time delay.
Time calc reset after release time	1: No 2: Yes	-	2: Yes	Operating timer resetting characteristics selection. When actived, the operating time counter is reset after a set release time if the 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	1: No 2: Yes	-	1: No	Time calculation characteristics selection. If activated, the operating time counter continues until a set release time even when the pick-up element is reset.

The user can reset characteristics through the application. The default setting is a 60 ms delay; the time calculation is held during the release time.

In the release delay option the operating time counter calculates the operating time during the release. When using this option the function does not trip if the input signal is not re-activated while the release time count is on-going.

Events and registers

The undervoltage function (abbreviated "UV" in event block names) generates events and registers from the status changes in START, TRIP, and BLOCKED. The user can select the status ON or OFF for messages in the main event buffer. The function offers four (4) independent stages; the events are segregated for each stage operation.

The triggering event of the function (START, TRIP or BLOCKED) is recorded with a time stamp and with process data values.

Table. 5.4.10. - 106. Event codes.

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
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

The function registers its operation into the last twelve (12) time-stamped registers; this information is available for all provided instances separately. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.

Table. 5.4.10. - 107. Register content.

Date and time	Event code	Fault type	Pre-trig voltage	Fault voltage	Pre-fault voltage	Trip time remaining	Used SG
dd.mm.yyyy hh:mm:ss.mss	5696-5895 Descr.	A…A-B-C	Start average voltage	Trip -20 ms averages	Start -200 ms averages	0 ms...1800 s	Setting group 1...8 active

5.4.11. Neutral overvoltage (U0>; 59N)

The neutral overvoltage function is used for non-directional instant and time-delayed earth fault protection. Each device with a voltage protection module has four (4) available stages of the function (U0>, U0>>, U0>>>, U0>>>>). The function constantly measures phase-to-earth voltage magnitudes and calculates the zero sequence component. Neutral overvoltage protection is scaled to line-to-line fundamental frequency level. When the line-to-line voltage of a system is 100 V in the secondary side, the earth fault is 100 % of the U_n and the calculated zero sequence voltage reaches 100/√3 V = 57.74 V.

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

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

$$U_{L1...3} = Line\ to\ neutral\ voltages$$

Below are some examples of zero sequence calculation.

Figure. 5.4.11. - 62. Normal situation.

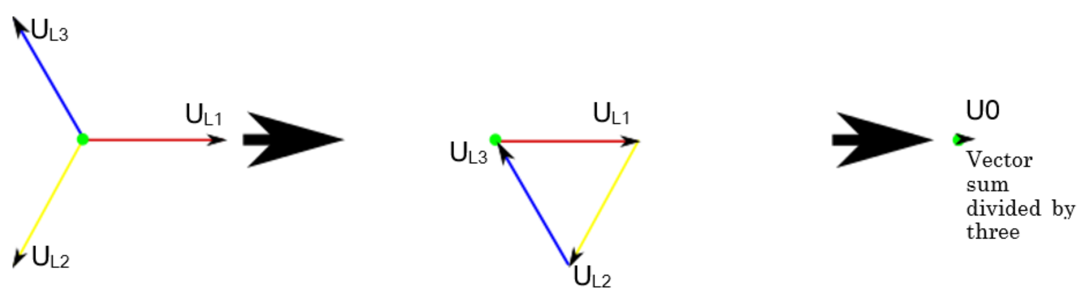


Figure. 5.4.11. - 63. Earth fault in isolated network.

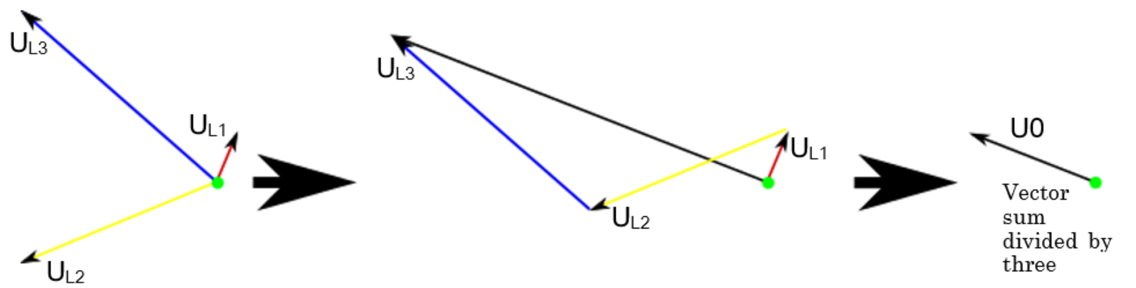
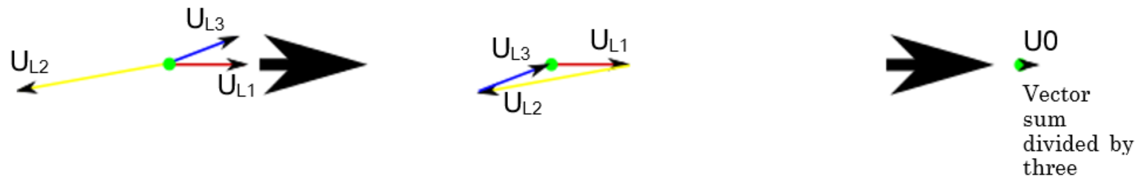


Figure. 5.4.11. - 64. Close-distance short-circuit between phases 1 and 3.



The monitored voltage magnitudes can be selected to be equal to fundamental frequency RMS values, or to TRMS values (including harmonics up to 31^{st}). The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

The outputs of the function are the START, TRIP and BLOCKED signals. The neutral overvoltage function uses a total of eight (8) separate setting groups which can be selected from one common source.

The function can operate on instant or time-delayed mode. In the time-delayed mode the operation can be selected for definite time (DT) or for inverse definite minimum time (IDMT); the IDMT operation supports both IEC and ANSI standard time delays as well as custom parameters.

The operational logic consists of the following:

- input magnitude selection
- input magnitude processing
- threshold comparator
- block signal check
- time delay characteristics
- output processing.

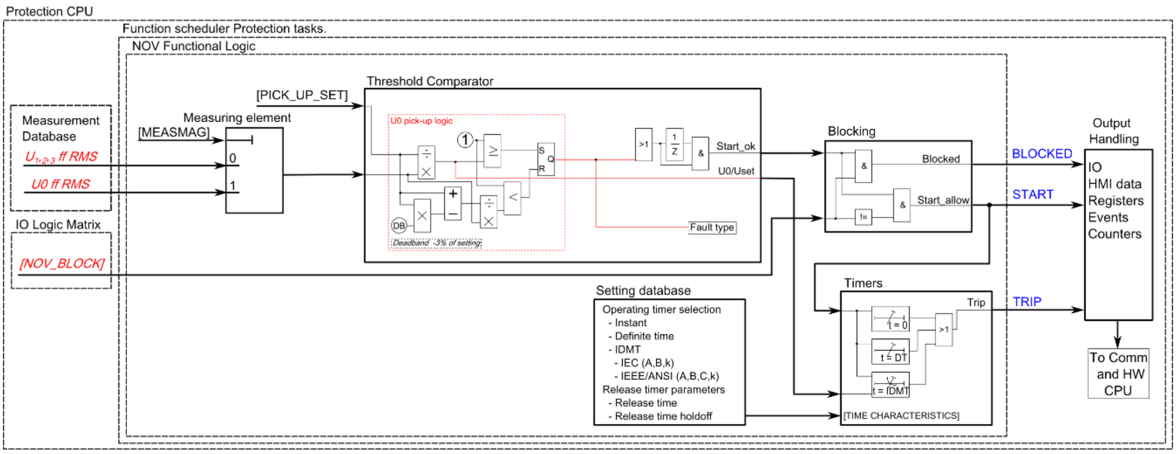
The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed voltage magnitudes.

The function outputs the START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signals. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a cumulative counter for the START, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the neutral overvoltage function.

Figure. 5.4.11. - 65. Simplified function block diagram of the U0> function.



Measured input

The function block uses analog current measurement values and always uses peak-to-peak measurements from samples. The function block uses fundamental frequency RMS values. A -20 ms averaged value of the selected magnitude is used for pre-fault data registering.

Table. 5.4.11. - 108. Measurement inputs of the U0> function.

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

The selection of the AI channel currently in use is made with a setting parameter. In all possible input channel variations the pre-fault condition is presented with a 20 ms averaged history value from -20 ms from a START or TRIP event.

Real-time info displayed by the function

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through AQtivate software when it is connected to the relay and its Live Edit mode is active.

Name	Range	Step	Default	Description
U0> Meas input select	0: Select 1: U0Calc 2: U4 input	-	0: Select	Defines which available measured residual voltage is used by the function.
U0> Pick-up setting	0.0...1 000 000.0 V	0.1 V	-	Primary voltage required for tripping. The displayed pick-up voltage level depends on the chosen U0 measurement input selection, on the pick-up settings and on the voltage transformer settings.
Expected operating time	0.000...1800.000 s	0.005 s	-	Displays the expected operating time when a fault occurs.
Time remaining to trip	0.000...1800.000 s	0.005 s	-	When the relay has picked up and is counting time towards the pick-up.
U_{meas}/U_{set} at the moment	0.00...1250.00	0.01	-	The ratio between the measured or calculated neutral voltage and the pick-up value.

Pick-up

The U_{set} setting parameter controls the pick-up of the U> function. This defines the maximum allowed measured voltage before action from the function. The function constantly calculates the ratio between the U_{set} and the measured magnitude (U_m) for each of the three voltages. The reset ratio of 97 % is built into the function and is always relative to the U_{set} value. The setting value is common for all measured amplitudes, and when the U_m exceeds the U_{set} value (in single, dual or all voltages) it triggers the pick-up operation of the function.

Table. 5.4.11. - 109. Pick-up settings.

Name	Description	Range	Step	Default
Pick-up setting U0set>	Pick-up setting	1.00…99.00 $\%U_n$	0.01 $\%U_n$	20.00 $\%U_n$

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

Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's 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 the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup voltage values and its fault type to be issued.

The blocking signal can also be tested in the commissioning phase by a software switch signal when the relay's testing mode "Enable stage forcing" is activated (*General → Device*).

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

Operating time characteristics for trip and reset

The operating timers' behavior during a 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 the START signal.
- Definite time operation (DT): gives the TRIP signal after a user-defined time delay regardless of the measured or calculated voltage as long as the voltage is above the U_{set} value and thus the pick-up element is active (independent time characteristics).
- Inverse definite minimum time (IDMT): gives the TRIP signal after a time which is in relation to the set pick-up voltage U_{set} and the measured voltage U_m (dependent time characteristics).

The IDMT function follows this formula:

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

Where:

- t = operating time
- k = time dial setting
- U_m = measured voltage
- U_s = pick-up setting
- a = IDMT multiplier setting

The following table presents the setting parameters for the function's time characteristics.

Table. 5.4.11. - 110. Setting parameters for operating time characteristics.

Name	Range	Step	Default	Description
Delay type	1: DT 2: IDMT	-	1: DT	Selection of the delay type time counter. The selection possibilities are dependent (IDMT, Inverse Definite Minimum Time) and independent (DT, Definite Time) characteristics.
Definite operating time delay	0.000…1800.000 s	0.005 s	0.040 s	Definite time operating delay. The setting is active and visible when DT is the selected delay type. When set to 0.000 s, the stage operates as instant (PIOC, 50) 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…60.00 s	0.01 s	0.05 s	The setting is active and visible when IDMT is the selected delay type. Time dial/multiplier setting for IDMT characteristics.
IDMT Multiplier	0.01…25.00 s	0.01 s	1.00 s	The setting is active and visible when IDMT is the selected delay type. IDMT time multiplier in the U_m/U_{set} power.

Table. 5.4.11. - 111. Setting parameters for reset time characteristics.

Name	Range	Step	Default	Description
Release time delay	0.000…150.000 s	0.005 s	0.06 s	Resetting time. Time allowed between pick-ups if the pick-up has not led to a trip operation. During this time the START signal is held on for the timers if the delayed pick-up release is active.
Delayed pick-up release	1: No 2: Yes	-	2: Yes	Resetting characteristics selection either as time-delayed or as instant after the pick-up element is released. If activated, the START signal is reset after a set release time delay.
Time calc reset after release time	1: No 2: Yes	-	2: Yes	Operating timer resetting characteristics selection. When active, the operating time counter is reset after a set release time if the 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	1: No 2: Yes	-	1: No	Time calculation characteristics selection. If activated, the operating time counter continues until a set release time has passed even if the pick-up element is reset.

The user can reset characteristics through the application. The default setting is a 60 ms delay; the time calculation is held during the release time.

In the release delay option the operating time counter calculates the operating time during the release. When using this option the function does not trip if the input signal is not re-activated while the release time count is on-going.

Events and registers

The neutral overvoltage function (abbreviated "NOV" in event block names) generates events and registers from the status changes in START, TRIP, and BLOCKED. The user can select the status ON or OFF for messages in the main event buffer. The function offers four (4) independent stages; the events are segregated for each stage operation.

The triggering event of the function (START, TRIP or BLOCKED) is recorded with a time stamp and with process data values.

Table. 5.4.11. - 112. Event codes.

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
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

The function registers its operation into the last twelve (12) time-stamped registers; this information is available for all provided instances separately. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.

Table. 5.4.11. - 113. Register content.

Date and time	Event code	Fault type	Trigger voltage	Fault voltage	Pre-fault 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 -20 ms averages	Start -200 ms averages	0 ms...1800 s	Setting group 1...8 active

5.4.12. Sequence voltage (U1/U2>/<; 59P/27P/47)

The sequence voltage function is used for instant and time-delayed voltage protection. It has positive and negative sequence protection for both overvoltage and undervoltage (the user selects the needed function). Each device with a voltage protection module has four (4) available stages of the function. The function constantly measures the fundamental frequency of phase-to-earth voltage magnitudes, or line-to-line and neutral voltage magnitudes to calculate the positive or negative sequence voltage. The user can select the voltage used. Sequence voltage is based on the system's line-to-line voltage level. Protection stages can be set to protect against both undervoltage and overvoltage. The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

Positive sequence voltage calculation

Below is the formula for symmetric component calculation (and therefore to positive sequence voltage calculation).

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

$$a = 1\angle 120°$$

$$a^2 = 1\angle 240°$$

$$U_{L1...3} = Line\ to\ neutral\ voltages$$

In what follows are three examples of positive sequence calculation (positive sequence component vector).

Figure. 5.4.12. - 66. Normal situation.

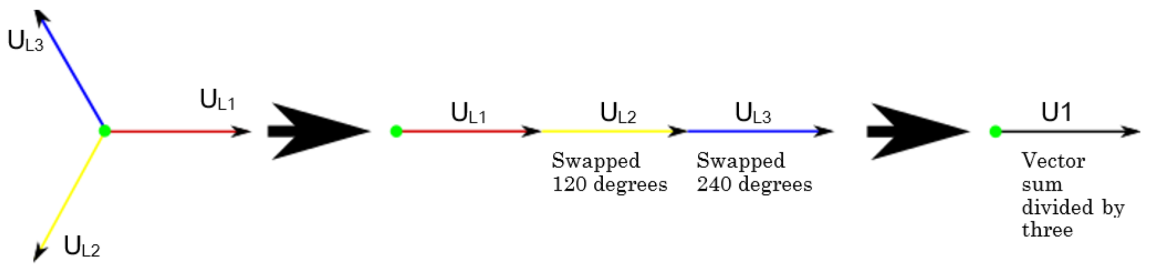


Figure. 5.4.12. - 67. Earth fault in an isolated network.

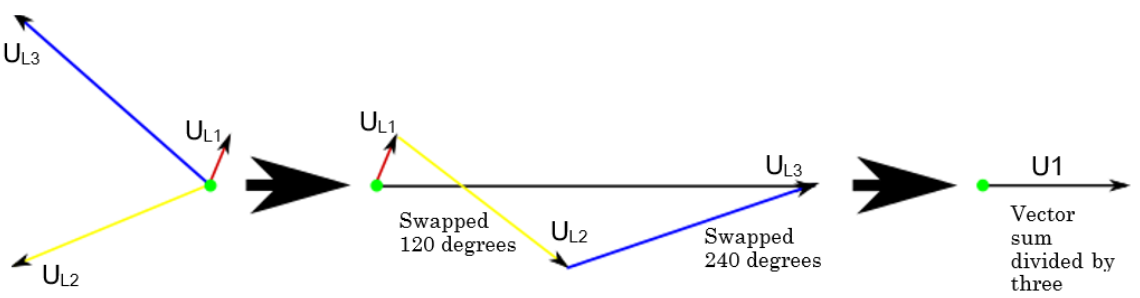
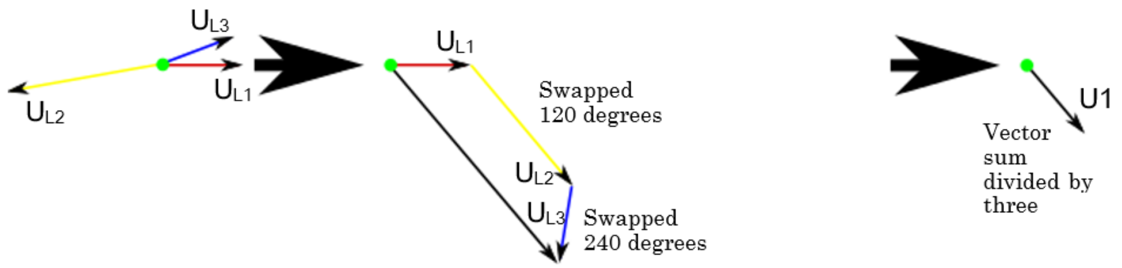


Figure. 5.4.12. - 68. Close-distance short-circuit between phases 1 and 3.



Negative sequence voltage calculation

Below is the formula for symmetric component calculation (and therefore to negative sequence voltage calculation).

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

$$a = 1\angle 120°$$

$$a^2 = 1\angle 240°$$

$$U_{L1...3} = Line\ to\ neutral\ voltages$$

In what follows are three examples of negative sequence calculation (negative sequence component vector).

Figure. 5.4.12. - 69. Normal situation.

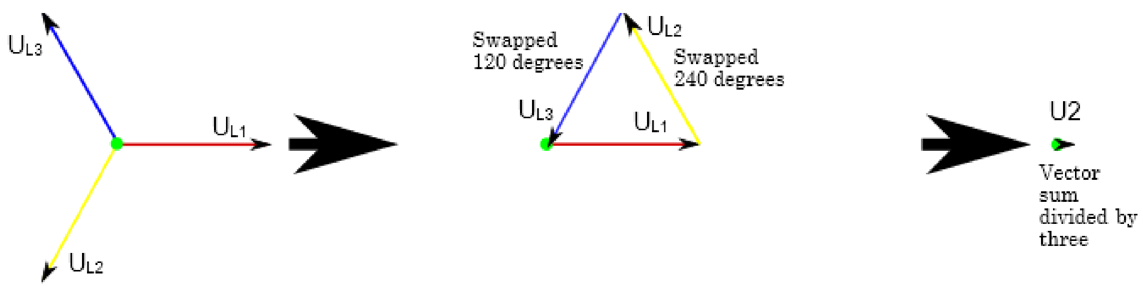


Figure. 5.4.12. - 70. Earth fault in isolated network.

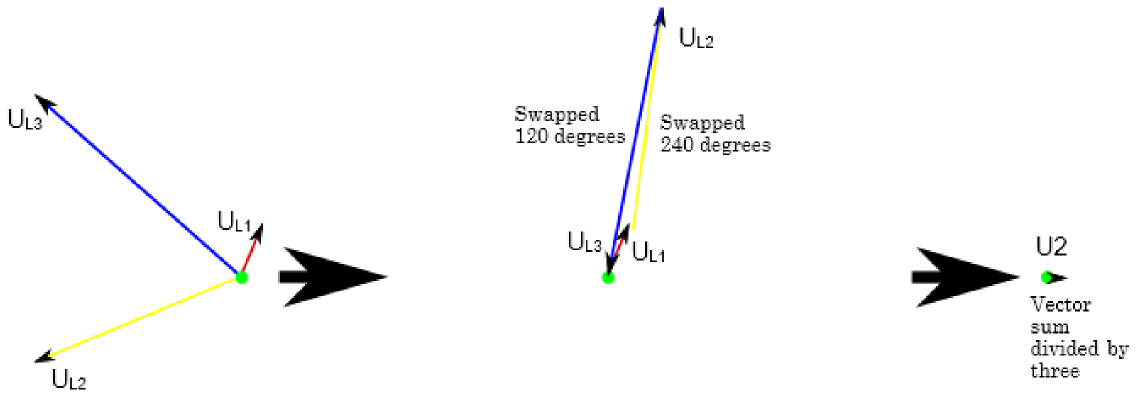
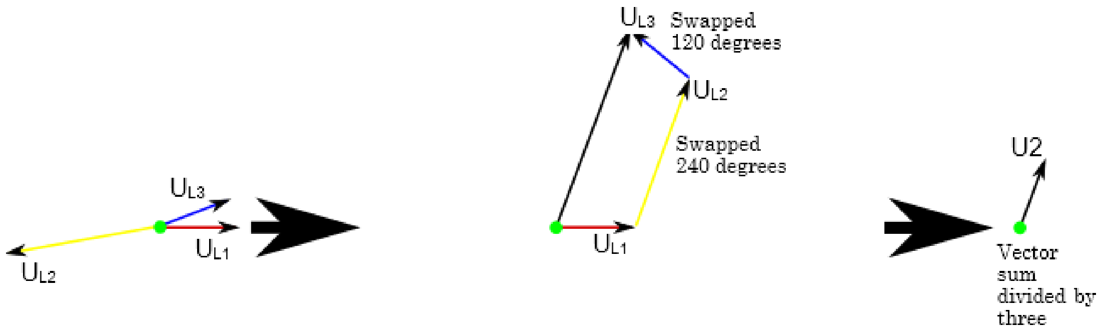


Figure. 5.4.12. - 71. Close-distance short-circuit between phases 1 and 3.



The sequence voltage function uses a total of eight (8) 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 between definite time (DT) mode and inverse definite minimum time (IDMT).

The operational logic consists of the following:

- input magnitude selection
- input magnitude processing
- threshold comparator
- block signal check
- time delay characteristics
- output processing.

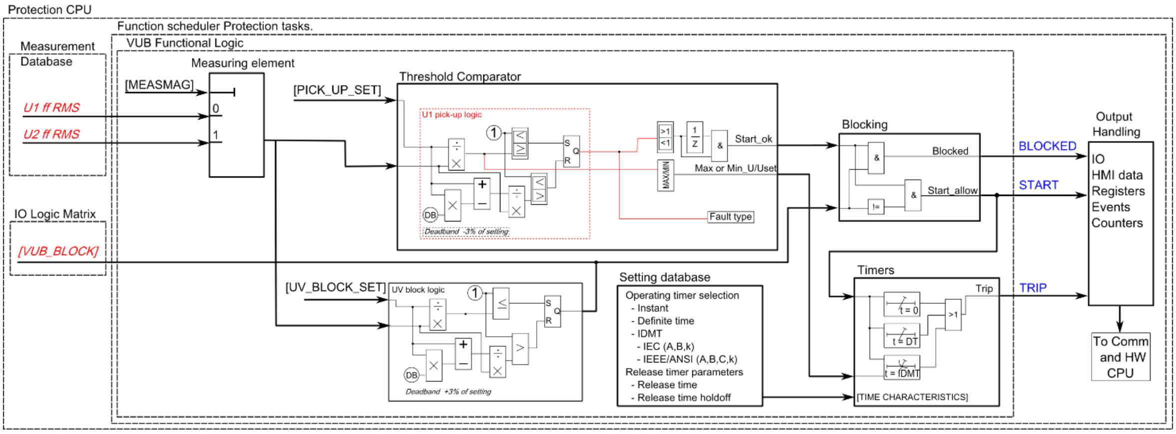
The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed voltage magnitudes.

The function outputs the START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signal. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also a resettable cumulative counter for the START, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the sequence voltage function.

Figure. 5.4.12. - 72. Simplified function block diagram of the U1/U2>/< function.



Measured input

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

Table. 5.4.12. - 114. Measurement inputs of the U1/U2>/< 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

Table. 5.4.12. - 115. Measured magnitude selection.

Name	Description	Range	Default
Measured magnitude	Selects which calculated voltage is supervised.	1: U1 Positive sequence voltage 2: U2 Negative sequence voltage	1: U1 Positive sequence voltage

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

Pick-up

The U_{set} setting parameter controls the pick-up of the U1/U2>/< function. This defines the maximum or minimum allowed calculated U1 or U2 voltage before action from the function. The function constantly calculates the ratio between the U_{set} and the calculated U1 or U2 magnitude (U_c). The monitored voltage is chosen in the *Info* page with the parameter *Measured magnitude*. The reset ratio of 97 % in overvoltage applications is built into the function and is always relative to the U_{set} value. The reset ratio of 103 % in undervoltage applications is built into the function and is always relative to the U_{set} value. When the U_c goes above or below the U_{set} value it triggers the pick-up operation of the function.

Table. 5.4.12. - 116. Pick-up settings.

Name	Description	Range	Step	Default
Pick-up terms	Selects whether the function picks-up when the monitored voltage is under or over the set pick-up value.	Over > Under<	-	Over>

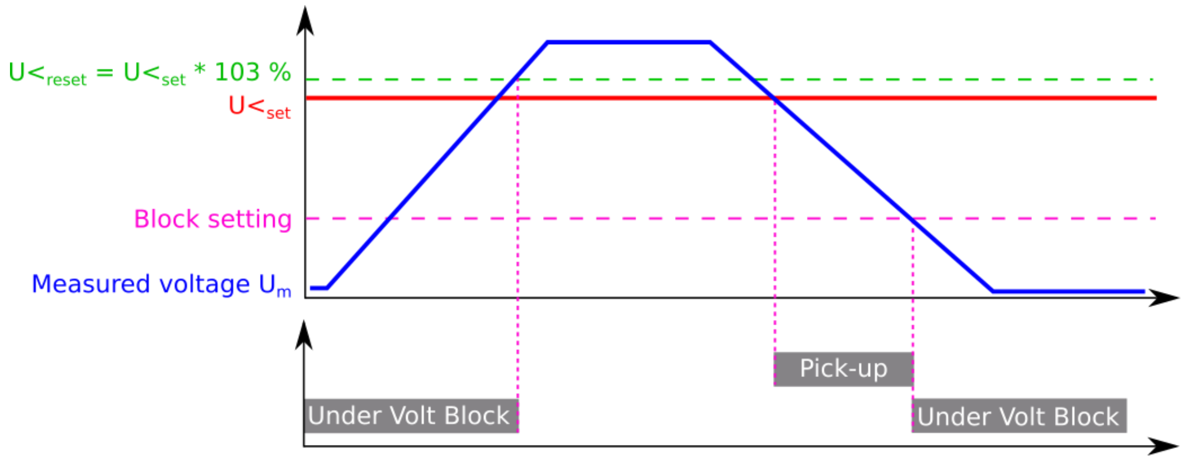
U_{set}	Pick-up setting	5.00…150.00 $\%U_n$	0.01 $\%U_n$	105 $\%U_n$
U_{blk}	Undervoltage blocking (visible when the pick-up term is Under<)	0.00…80.00 $\%U_n$	0.01 $\%U_n$	5 $\%U_n$

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

Using *Block setting* to prevent nuisance trips

It is recommended to use the *Under block setting* U_{blk} parameter when Under< is the chose tripping condition to prevent the relay from tripping in a situation where the network is de-energized. When the measured voltage drops below the set value, the relay does not give a tripping signal. If the measured voltage has dropped below the *Under block setting* U_{blk} parameter, the blocking continues until all of the line voltages have increased above the U< pick-up setting. Please see the image below for a visualization of this function. If the block level is set to zero (0), blocking is not in use.

Figure. 5.4.12. - 73. Example of the block setting operation.



Real-time info displayed by the function

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through AQtivate software when it is connected to the relay and its Live Edit mode is active.

Table. 5.4.12. - 117.

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 when a fault occurs.
Time remaining to trip	s	When the relay has picked up and is counting time towards the next pick-up.
U_{meas}/U_{set} at the moment	U_m/U_{set}	The ratio between the measured voltage and the pick-up value.

Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's 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 the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup voltage values and its fault type to be issued.

The blocking signal can also be tested in the commissioning phase by a software switch signal when the relay's testing mode "Enable stage forcing" is activated (*General → Device*).

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

Operating time characteristics for trip and reset

This function supports definite time delay (DT) and inverse definite minimum time delay (IDMT). For detailed information on these delay types please refer to the chapter "General properties of a protection function" and its section "Operating time characteristics for trip and reset".

Events and registers

The sequence voltage function (abbreviated "VUB" in event block names) generates events and registers from the status changes in START, TRIP and BLOCKED. The user can select the status ON or OFF for messages in the main event buffer. The function offers four (4) independent stages; the events are segregated for each stage operation.

The triggering event of the function (START, TRIP or BLOCKED) is recorded with a time stamp and with process data values.

Table. 5.4.12. - 118. Event codes.

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

The function registers its operation into the last twelve (12) time-stamped registers; this information is available for all provided instances separately. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.

Table. 5.4.12. - 119. Register content.

Date and time	Event code	Trigger voltage	Fault voltage	Pre-fault voltage	Trip time remaining	Used SG
dd.mm.yyyy hh:mm:ss.mss	8320 - 8517 Descr.	Start average voltage	Trip -20 ms averages	Start -200 ms averages	0 ms...1800 s	Setting group 1...8 active

5.4.13. Overfrequency and underfrequency (f>/<; 81O/81U)

The frequency protection function can be used both in overfrequency and in underfrequency situations, and it has four (4) stages for both. Frequency protection can be applied to protect feeder, bus, transformer, motor and generator applications. The difference between the generated power and the 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, overfrequency can occur.

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

Underfrequency and overfrequency protection can be used as an indicator of an accidental island operation in distributed generation and in some consumers (as it is unlikely that the consumed and generated power are the same). Overfrequency is also often used to control power generation to keep the system's frequency consistent.

Each stage can be activated and deactivated individually. After the f>/< mode has been activated (*Protection → Stage activation → Frequency stages*), the user can activate and deactivate the individual stages at will (*Protection → Frequency → Frequency protection f >/< → INFO → Stage operational setup*).

The outputs of the function are the START, TRIP and BLOCKED signals. The frequency protection function uses a total of eight (8) 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 the following:

- input magnitude processing
- threshold comparator
- two block signal check
- time delay characteristics
- output processing.

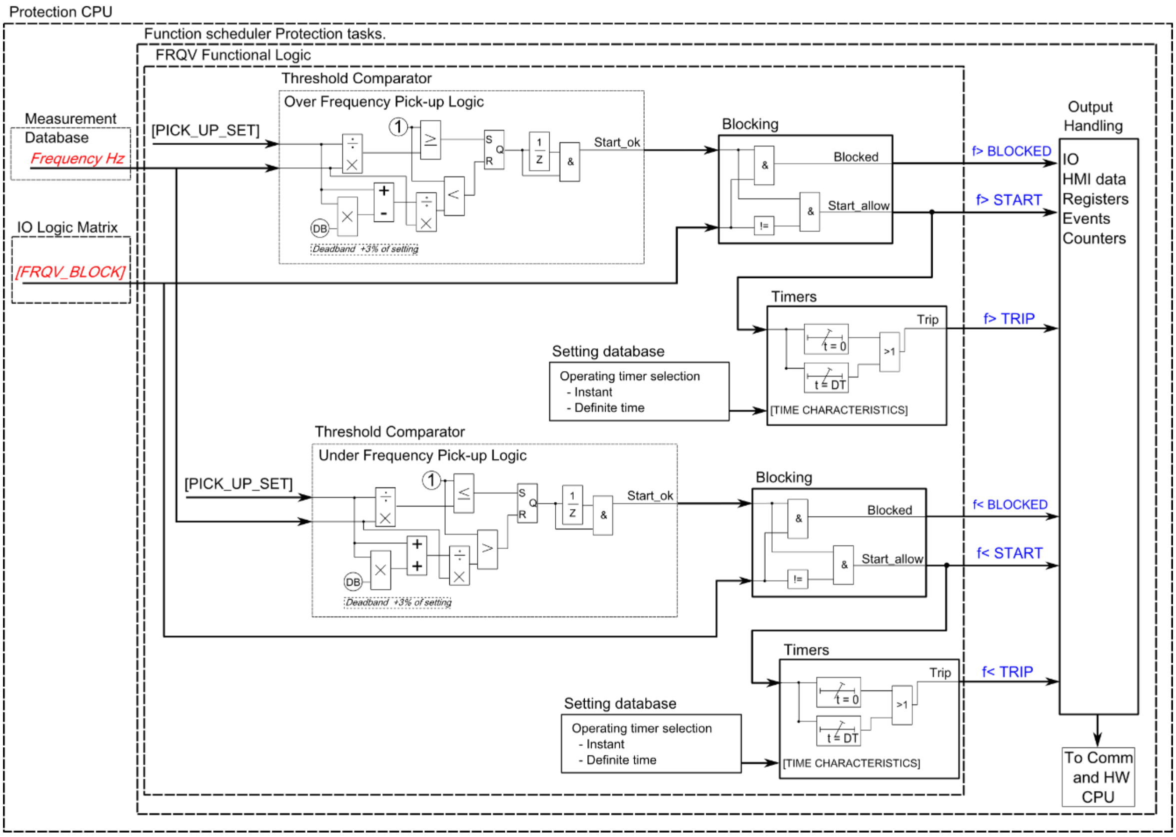
The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed frequency magnitudes.

The function outputs the START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signal. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the frequency function.

Figure. 5.4.13. - 74. Simplified function block diagram of the f>/< function.



Measured input

The frequency protection function compares the measured frequency to the pick-up setting (given in Hz). The source of the measured frequency depends on the factory-defined tracking reference which can be checked from the *Frequency* tab of the *Measurement* menu.

Table. 5.4.13. - 120. Measurement inputs of the f>/< function.

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

Pick-up and time delay

The f_{set}>, f_{set}>>, etc.setting parameters control the pick-up of each stage of the f>/< function. They define the maximum or minimum allowed measured frequency before action from the function. The function constantly calculates the ratio between the pick-up setting and the measured frequency. The reset ratio of 97 % is built into the function and is always relative to the pick-up value.

Table. 5.4.13. - 121. Pick-up settings.

Name	Description	Range	Step	Default
fset> fset>> fset>>> fset>>>>	Pick-up setting	10.00…80.00 Hz	0.01 Hz	51 Hz
fset< fset<< fset<<< fset<<<<	Pick-up setting	5.00…75.00 Hz	0.01 Hz	49 Hz
f> Op.time f>> Op.time f>>> Op.time f>>>> Op.time f< Op.time f<< Op.time f<<< Op.time f<<<< Op.time	Operation time	0.000...1800.00 s	0.005 s	0.1 s

The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the 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 types please refer to the chapter "General properties of a protection function" and its section "Operating time characteristics for trip and reset".

Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's 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 the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup frequency values.

The blocking signal can also be tested in the commissioning phase by a software switch signal when the relay's testing mode "Enable stage forcing" is activated (*General → Device*).

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

Events and registers

The frequency function (abbreviated "FRQV" in event block names) generates events and registers from the status changes in START, TRIP and BLOCKED. The user can select the status ON or OFF for messages in the main event buffer.

The triggering event of the function (START, TRIP or BLOCKED) is recorded with a time stamp and with process data values.

Table. 5.4.13. - 122. Event codes.

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
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

The function registers its operation into the last twelve (12) time-stamped registers. The table below presents the structure of the function's register content.

Table. 5.4.13. - 123. Register content.

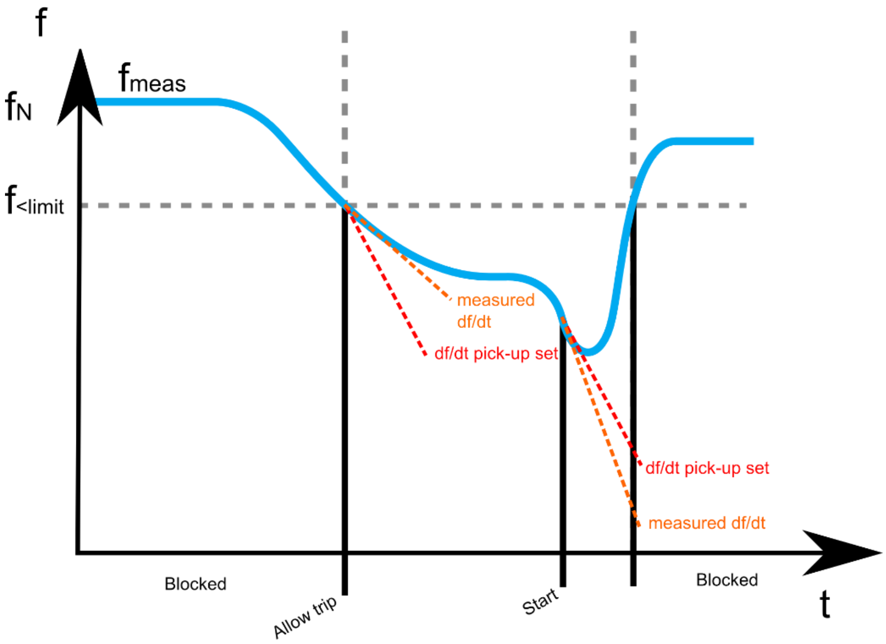
Date and time	Event code	f Pre-trig (Hz)	f Fault (Hz)	Used SG
dd.mm.yyyy hh:mm:ss.mss	6336-6383 Descr.	Start –20 ms averages	Fault frequency	Setting group 1...8 active

5.4.14. Rate of change of frequency (df/dt; 81R)

The rate of change of frequency function is used to detect fast drops or increases in frequency. If the load changes fast this function detects and clears the frequency-based faults faster than conventional underfrequency and overfrequency protections. One of the most common causes for the frequency to deviate from its nominal value is an unbalance between the generated power and the load demand. If the unbalance is big the frequency changes rapidly.

The rate of change of frequency protection can also be applied to detect a loss of mains situation. Loss of mains is a situation where a part of the network (incorporating generation) loses its connection with the rest of the system (i.e. becomes an islanded network). A generator that is not disconnected from the network can cause safety hazards. A generator can also be automatically reconnected to the network, which can cause damage to the generator and the network.

Figure. 5.4.14. - 75. Operation of the df/dt function when the frequency starts but doesn't trip.



The figure above presents an example of the df/dt function's operation when the frequency is decreasing. If the $f<_{limit}$ and/or $f>_{limit}$ is activated, the function does not trip no matter how fast the measured frequency changes if it's over the $f<_{limit}$ or under $f>_{limit}$. As can be seen in the figure above, when the frequency decreases under the $f<_{limit}$, tripping is allowed although the change of frequency is not yet fast enough for the function to trip. Later the frequency makes a fast dip and as a result the change of frequency is faster than the set pick-up value which then causes the relay to operate.

Each stage can be activated and deactivated individually. After the f>/< mode has been activated (*Protection → Stage activation → Frequency stages*), the user can activate and deactivate the individual stages at will (*Protection → Frequency → Frequency protection f >/< → INFO → Stage operational setup*).

The outputs of the function are the START, TRIP and BLOCKED signals. The frequency protection function uses a total of eight (8) 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 the following:

- input magnitude processing
- threshold comparator
- two block signal check
- time delay characteristics
- output processing.

The inputs for the function are the following:

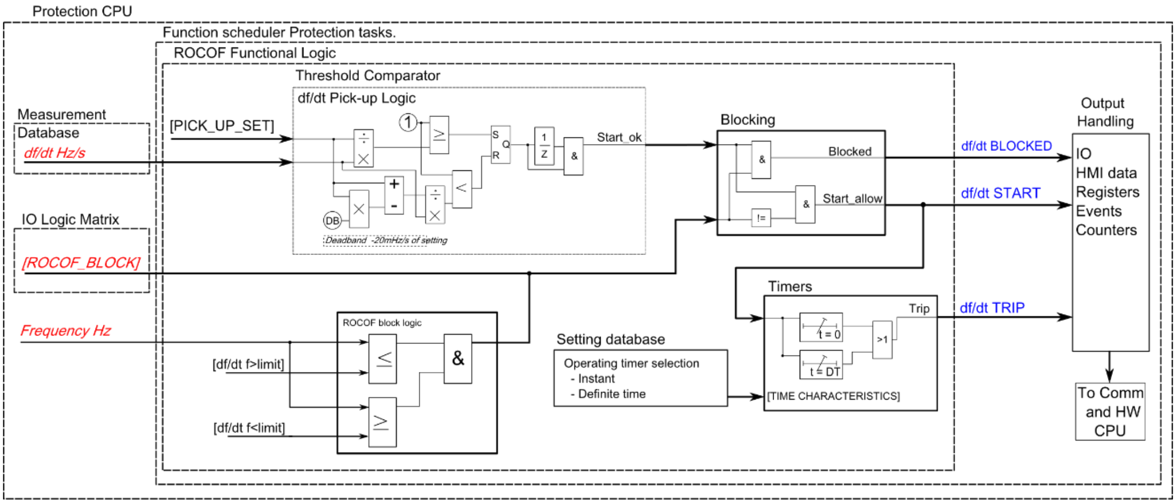
- operating mode selections

- setting parameters
- digital inputs and logic signals
- measured and pre-processed frequency magnitudes.

The function outputs the START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signal. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the df/dt function.

Figure. 5.4.14. - 76. Simplified function block diagram of the df/dt function.



Measured input

The rate of change of frequency protection function compares the measured df/dt ratio to the pick-up setting (given in Hz/s). The source of the measured frequency depends on the factory-defined tracking reference which can be checked from the *Frequency* tab of the *Measurement* menu.

Table. 5.4.14. - 124. Measurement inputs of the df/dt function.

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

Pick-up and time delay

The df/dt>/< (1) pick-up, df/dt>/< (2) pick-up, etc. setting parameters control the pick-up of each stage of the df/dt function. They define the maximum or minimum allowed change of frequency before action from the function. The function constantly calculates the ratio between the pick-up setting and the measured df/dt. The reset ratio of 20 mHz is built into the function and is always relative to the pick-up value. The f>/< limit value is used to block the funtion from operating near the nominal frequency.

Table. 5.4.14. - 125. Pick-up settings.

Name	Description	Range	Step	Default
df/dt>/< (1…8) pick-up	Pick-up setting	0.01…10.00 Hz/s	0.01 Hz/s	0.2 Hz/s
df/dt>/< (1…8) f< limit	f< limit	7.00…65.00 Hz/s	0.01 Hz/s	49.95 Hz/s

df/dt>/< (1…8) f> limit	f> limit	10.00…70.00 Hz/s	0.01 Hz/s	51 Hz/s
df/dt>/< (1…8) Op.time	Operation time	0.000...1800.000 s	0.005 s	0.1 s

The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the 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 types please refer to the chapter "General properties of a protection function" and its section "Operating time characteristics for trip and reset".

Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's 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 the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup frequency values.

The blocking signal can also be tested in the commissioning phase by a software switch signal when the relay's testing mode "Enable stage forcing" is activated (*General* → *Device*).

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

Events and registers

The rate of change of frequency function (abbreviated "DFT" in event block names) generates events and registers from the status changes in START, TRIP and BLOCKED. The user can select the status ON or OFF for messages in the main event buffer.

The triggering event of the function (START, TRIP or BLOCKED) is recorded with a time stamp and with process data values.

Table. 5.4.14. - 126. Event codes.

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
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

The function registers its operation into the last twelve (12) time-stamped registers. The table below presents the structure of the function's register content.

Table. 5.4.14. - 127. Register content.

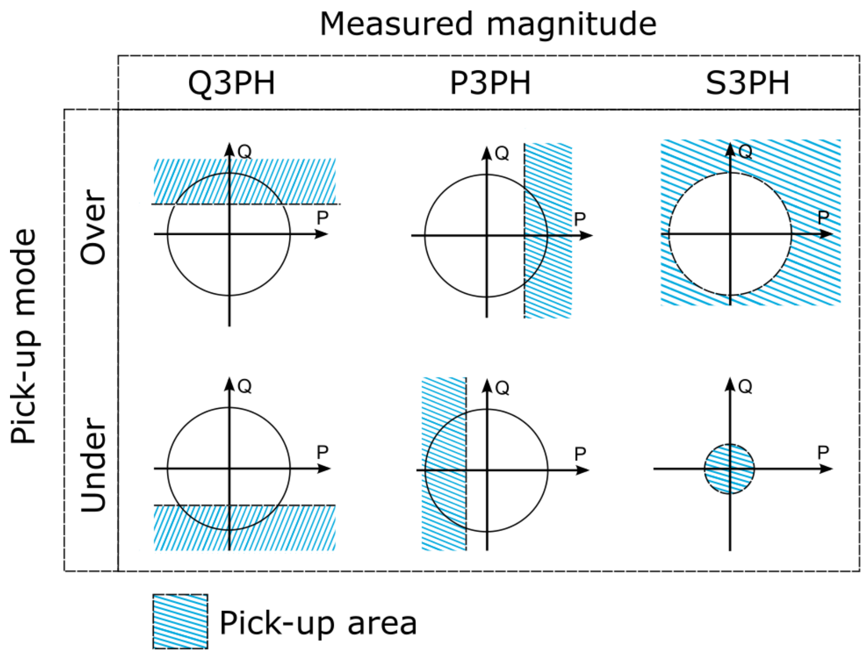
Date and time	Event code	df/dt Pre-trig (Hz/s)	f Pre-trig (Hz)	df/dt Fault (Hz/s)	f Fault (Hz)	Used SG
dd.mm.yyyy hh:mm:ss.mss	6592-6639 Descr.	Start –20 ms averages	Start –20 ms averages	Fault df/dt	Fault frequency	Setting groups 1...8 active

5.4.15. Power protection (P, Q, S; 32)

The power protection function is for instant and time-delayed, three-phase overpower or underpower protection (active, reactive, or apparent). The user can select the operating mode with parameter settings.

The figure below presents the pick-up areas of the function's different modes, displayed in a PQ diagram.

Figure. 5.4.15. - 77. PQ diagram of the pick-up ares in various modes.



The outputs of the function are the START, TRIP and BLOCKED signals. The power protection function uses a total of eight (8) 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 the following:

- input magnitude selection
- input magnitude processing
- threshold comparator
- two block signal checks
- time delay characteristics
- output processing.

The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed power magnitudes.

The function outputs the START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signal. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also a resettable cumulative counter for the START, TRIP and BLOCKED events.

Measured input

The function block uses three-phase power values (active, reactive, or apparent). A -20 ms averaged value is used for pre-fault data registering. The used power measurement value depends on user input. If the protection relay has more than one CT module, the *Measured side* parameter determines which current measurement is used for power measurement.

Table. 5.4.15. - 128. Measurement inputs of the power protection function.

Signal	Description	Time base
3PH active power (P)	Total three-phase active power	5 ms
3PH reactive power (Q)	Total three-phase reactive power	5 ms
3PH apparent power	Total three-phase apparent power	5 ms

Pick-up

The PQS>/< setting parameter controls the pick-up of the power protection function. This defines the maximum or minimum allowed measured three-phase power (active, reactive, or apparent) before action from the function. The function constantly calculates the ratio between the PQS>/< and the measured power magnitude. The reset ratios of 97 % (pick-up mode "Over") and 103 % (pick-up mode "Under") are built into the function and is always relative to the pick-up value.

Table. 5.4.15. - 129. Pick-up settings.

Name	Description	Range	Step	Default
Pick-up mode	Defines whether the function operates in underpower or overpower protection mode.	0: > Over 1: < Under	-	0: Over
Pick-up	Pick-up setting. Related to the nominal power set by the user.	-500.000…500.000 %	0.005 %	0 %

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

Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's 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 the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup voltage values and its fault type to be issued.

The blocking signal can also be tested in the commissioning phase by a software switch signal when the relay's testing mode "Enable stage forcing" is activated (*General* → *Device*).

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

Operating time characteristics for trip and reset

This function supports definite time delay (DT). For detailed information on this delay type please refer to the chapter "General properties of a protection function" and its section "Operating time characteristics for trip and reset".

Events and registers

The power protection function (abbreviated "PQS" in event block names) generates events and registers from the status changes in START, TRIP and BLOCKED. The user can select the status ON or OFF for messages in the main event buffer. The function offers four (4) independent stages; the events are segregated for each stage operation.

The triggering event of the function (START, TRIP or BLOCKED) is recorded with a time stamp and with process data values.

Table. 5.4.15. - 130. Event codes.

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
6406	100	PQS2	0	Start ON
6407	100	PQS2	1	Start OFF
6408	100	PQS2	2	Trip ON
6409	100	PQS2	3	Trip OFF
6410	100	PQS2	4	Block ON
6411	100	PQS2	5	Block OFF
6412	100	PQS3	0	Start ON
6413	100	PQS3	1	Start OFF
6414	100	PQS3	2	Trip ON
6415	100	PQS3	3	Trip OFF
6416	100	PQS3	4	Block ON

6417	100	PQS3	5	Block OFF
6418	100	PQS4	0	Start ON
6419	100	PQS4	1	Start OFF
6420	100	PQS4	2	Trip ON
6421	100	PQS4	3	Trip OFF
6422	100	PQS4	4	Block ON
6423	100	PQS4	5	Block OFF

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.

Table. 5.4.15. - 131. Register content.

Date and time	Event code	Trigger power	Fault power	Pre-fault 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	0 ms...1800 s	Setting group 1...8 active

5.4.16. Transformer status monitoring

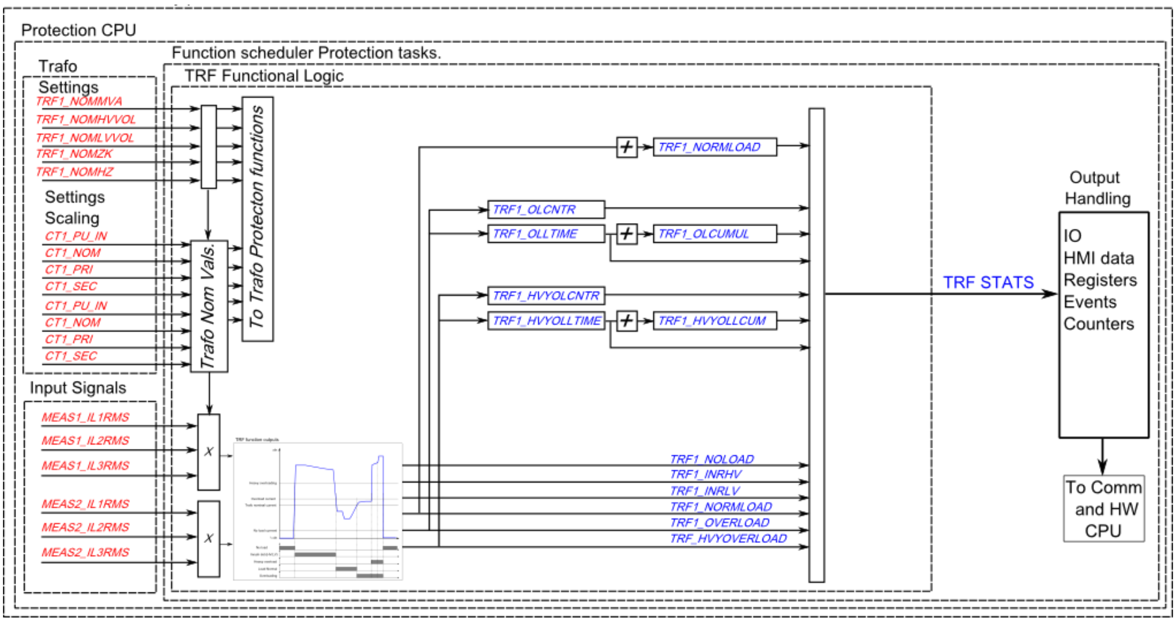
The transformer status monitoring function is designed to be the one place where the user can set up all necessary transformer data and select the used transformer protection functions. Settings related to the protection functions can also be edited inside each function and any changes are updated into this function as well. The function calculates many transformer-related properties which are used in functions that protect and monitor the transformer. Standard transformers require only name plate data and CT scalings to get the relay automatically scale all measurement signals to the transfomer. In special transformers manually set values can be applied to cover the transformer properties that are rarely met. Additionally, the function counts a transformer's cumulative overloading and high overcurrent time.

The function can output the following signals:

- light/no load
- HV side inrush
- LV side inrush
- normal load
- overloading
- heavy overloading.

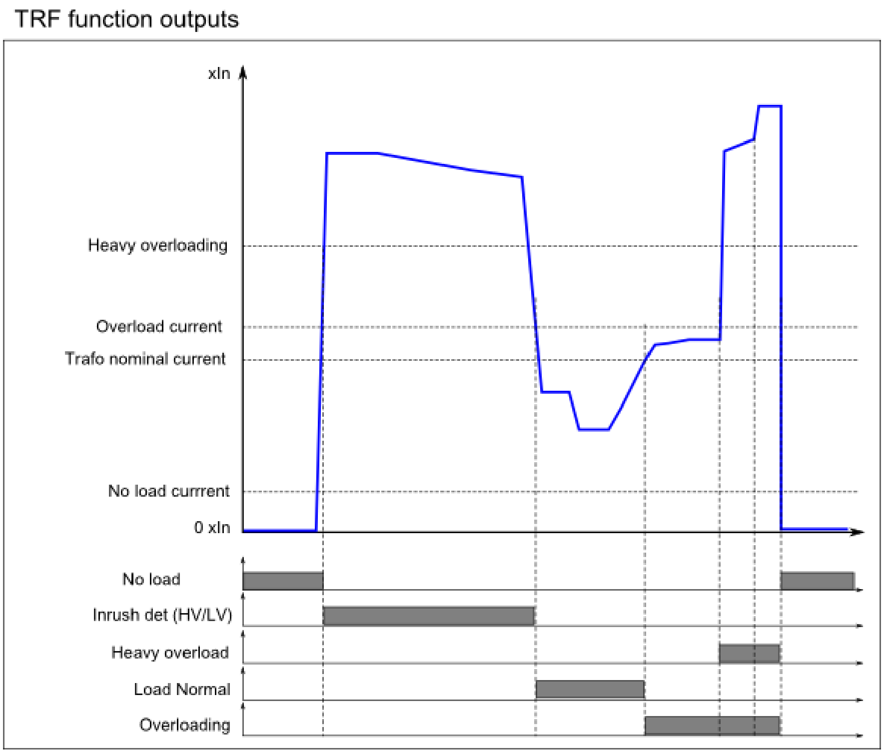
These signals can be used in indication or in logic programming, and they are the basis for the events the function generates (if so chosen).

Figure. 5.4.16. - 78. Simplified function block diagram of the transformer status monitoring function.



The function's outputs are dependent on the set transformer data because the measured currents (in p.u.) are related to the transformer nominal values. The following diagram presents the function's outputs in various situations.

Figure. 5.4.16. - 79. Activation of the function's outputs.



The ***No load*** signal is activated when the current dips below the "No load current" limit (= 0.2 x I_n)" for longer than ten milliseconds. If the current increases from this situation up to the "Heavy overloading" limit (> 1.3 x I_n), the ***HV inrush detection*** and ***LV inrush detection*** signals are activated. If the measured current is between the "No load current" limit and the "Nominal current" limit, the ***Load normal*** signal is activated. If the measured current is between the "Nominal" and the "Heavy overloading" currents, the ***Overloading*** signal is activated.

These signals can be used for multiple purposes: information, transformer-related logics, and monitoring. A constant, long-lasting heavy overloading can cause oil ageing in the transformer, and thus more frequent maintenance is recommended to prevent possible problems in the transformer.

Settings and signals

The settings of the transformer status monitoring function are mostly shared with other transformer protection functions in the transformer module of the device. The following table shows these other functions that also use these settings.

Table. 5.4.16. - 132. Settings of the transformer status monitoring function and how they are shared by other protection functions.

Name	Range	Step	Default	Functions	Description
Transformer nominal	0.1...500.0 MVA	0.1 MVA	1.0 MVA	All	The nominal MVA of the transformer. This value is used to calculate the nominal currents onf both the HV and the LV side.
HV side nominal voltage	0.1…500.0 kV	0.1 kV	110.0 kV	All	The HV side nominal voltage of the transformer. This value is used to calculate the nominal currents of the HV side.
LV side nominal voltage	0.1…500.0 kV	0.1 kV	110.0 kV	All	The LV side nominal voltage of the transformer. This value is used to calculate the nominal currents of the LV side.
Transformer Zk%	0.01…25.00 %	0.01 %	3.00 %	Info	The transformer's short-circuit impedance in percentages. Used for calculating short-circuit current.
Transformer nom. freq.	10…75 Hz	1 Hz	50 Hz	Info	The transformer's nominal frequency. Used for calculating the transformer's nominal short-circuit inductance.
Transf. vect. group	0: Manual set 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	- transformer status monitoring - transformer differential	The selection of the transformer's vector group. The selection values (1–26) are predefined so that the scaling and vector matching are applied in the relay automatically when the correct vector group is selected. The predefinitions assume that the HV side is connected to the CT1 module and that the LV side is connected to the CT2 module. If the protected transformer vector group is not found in the predefined list, it can be manually set by selecting the option "0: Manual set".
HV side Star or Zigzag / Delta	0: Star/Zigzag 1: Delta	-	0: Star/Zigzag	- transformer status monitoring - transformer differential	The selection of the HV side connection. Can be selected between star or zigzag and delta. This selection is visible only if the option "Manual set" is selected for the vector group setting.

HV side earthed	0: Not earthed 1: Earthed	-	0: Not earthed	- transformer status monitoring - transformer differential	The selection of whether or not the zero sequence compensation is applied in the HV side current calculation. The selection is visible only if the option "Manual set" is selected for the vector group setting.
HV side lead or lag LV	0: Lead 1: Lag	-	0: Lead	- transformer status monitoring - transformer differential	The selection of whether the HV side leads or lags the LV side. The selection is visible only if the option "Manual set" is selected for the vector group setting.
LV side Star or Zigzag / Delta	0: Star/Zigzag 1: Delta	-	0: Star/Zigzag	- transformer status monitoring - transformer differential	The selection of the LV side connection. Can be selected between star or zigzag and delta. This selection is visible only if the option "Manual set" is selected for the vector group setting.
LV side earthed	0: Not earthed 1: Earthed	-	0: Not earthed	- transformer status monitoring - transformer differential	The selection of whether or not the zero sequence compensation is applied in the LV side current calculation. The selection is visible only if the option "Manual set" is selected for the vector group setting.
LV side lead or lag HV	0: Lead 1: Lag	-	0: Lead	- transformer status monitoring - transformer differential	The selection of whether the LV side leads or lags the HV side. The selection is visible only if the option "Manual set" is selected for the vector group setting.
HV-LV side phase angle	0.0...360.00 deg	0.1 deg	0.0 deg	- transformer status monitoring - transformer differential	The angle correction factor for HV/LV sides, looked from the HV side. E.g. if the transformer is Dy1, this is set to 30 degrees. The selection is visible only if the option "Manual set" is selected for the vector group setting.
HV-LV side mag correction	0.0…100.0 x I_n	0.1 x I_n	0.0 x I_n	- transformer status monitoring - transformer differential	The magnitude correction for the HV-LV side currents (in p.u.), if the currents are not directly matched through the calculations of the nominal values. The selection is visible only if the option "Manual set" for the vector group setting.
Check online HV-LV configuration	0: - 1: Check	-	0: -	- transformer status monitoring - transformer differential	The selection of whether or not the function checks the current going through the transformer and then compares it to the settings. For this to work, the transformer needs to have a current flowing on both sides and "see" no faults. The selection is visible only if the option "Manual set" is selected for the vector group setting.

Table. 5.4.16. - 133. Calculations of the transformer status monitoring function.

Name	Range	Step	Default	Functions	Description
HV side nominal current (pri)	0.01...50 000.00 A	0.01 A	0.00 A	Info	The calculated primary current of the transformer's HV side primary current.
HV side nominal current (sec)	0.01…250.00 A	0.01 A	0.00 A	Info	The calculated primary current of the transformer's HV side secondary current.
HV CT nom. to TR nom. factor	0.01…250.00 p.u.	0.01 p.u.	0.00 p.u.	Info	The transformer's HV side calculated nominal to the CT primary rate.
LV side nominal current (pri)	0.01…50 000.00 A	0.01 A	0.00 A	Info	The calculated primary current of the transformer's LV side primary current.
LV side nominal current (sec)	0.01…250.00 A	0.01 A	0.00 A	Info	The calculated primary current of the transformer's LV side secondary current.
LV CT nom. to TR nom. factor	0.01…250.00 p.u.	0.01 p.u.	0.00 p.u.	Info	The transformer's LV side calculated nominal to the CT primary rate.
Transformer nom. impedance	0.01… 250.00 Ω	0.01 Ω	0.00 Ω	Info	The calculated nominal impedance of the transformer.
Transformer nom. Zk	0.01…250.00 Ω	0.01 Ω	0.00 Ω	Info	The calculated nominal short-circuit impedance of the transformer.
Transformer nom. SC inductance	0.001… 250.000 µH	0.01 µH	0.000 µH	Info	The calculated nominal short-circuit inductance of the transformer.

Transformer ratio	0.01…250.00	0.01	0.00	Info	The transformer's calculated ratio (= HV/LV).
LV side max. 3ph SC curr.	0.001…500.000 kA	0.001 kA	0.000 kA	Info	The calculated maximum three-phase short-circuit current in the LV poles of the transformer.
LV side 3ph SC to HV side	0.001…500.000 kA	0.001 kA	0.000 kA	Info	Shows how the calculated maximum three-phase short-circuit current in the LV side is seen in the HV side.
LV side max. 2ph SC curr.	0.001…500.000 kA	0.001 kA	0.000 kA	Info	The calculated maximum two-phase short-circuit current in the LV poles of the transformer.
LV side 2ph SC to HV side	0.001...500.000 kA	0.001 kA	0.000 kA	Info	Shows how the calculated maximum two-phase short-circuit current in the LV side is seen in the HV side.

Table. 5.4.16. - 134. Output signals of the transformer status monitoring function.

Name	Range	Step	Default	Description
No/Light load	0: Not active 1: Active	1	0: Not active	The signal is active, when the function detects a current below the "No load current" limit. This signal presents a situation where there is a very light load, or only one or no side of the transformer is energized.
HV side inrush detected	0: Not active 1: Active	1	0: Not active	The signal is active, when the detected current rises above the "High overcurrent" limit in the HV side.
LV side inrush detected	0: Not active 1: Active	1	0: Not active	The signal is active, when the detected current rises above the "High overcurrent" limit in the LV side.
Load normal	0: Not active 1: Active	1	0: Not active	The signal is active when the measured current is below the "Nominal current" but above the "No load current" limit.
Overloading	0: Not active 1: Active	1	0: Not active	The signal is active, when the measured current is between the "Nominal current" and the "High overcurrent" limits.
Heavy overloading (HVY overloading)	0: Not active 1: Active	1	0: Not active	The signal is active, when the measured current is above the "High overcurrent" limit.

Events

The transformer status monitoring function (abbreviated "TRF" in event block names) generates events from the detected transformer energizing status. The data register is available, based on the events.

Table. 5.4.16. - 135. Event codes.

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 transformer data
4621	72	TRF1	13	Calculation finished, possible restart

The function registers its operation into the last twelve (12) time-stamped registers. The table below presents the structure of the function's register content.

Table. 5.4.16. - 136. Register content.

Date and time	Event code	HV L1 current	HV L2 current	HV L3 current	LV L1 current	LV L2 current	LV L3 current
dd.mm.yyyy hh:mm:ss.mss	4608-4621 Descr.	HV side's Phase L1 current x I_n	HV side's Phase L2 current x I_n	HV side's Phase L3 current x I_n	LV side's Phase L1 current x I_n	LV side's Phase L2 current x I_n	LV side's Phase L3 current x I_n

5.4.17. Transformer thermal overload protection (TT>; 49T)

The transformer thermal overload protection function is used for monitoring and protecting thermal capacity in power transformers.

The function constantly monitors the instant values of phase TRMS currents (including harmonics up to 31^{st}) and calculates the set thermal replica status in 5 ms cycles. The function includes a total memory function of the load current conditions according to IEC 60255-8.

The function is based on a thermal replica which represents the protected object's or cable's thermal loading in relation to the current going through the object. The thermal replica includes the calculated thermal capacity that the "memory" uses; it is an integral function which tells this function apart from a normal overcurrent function and its operating principle for overload protection applications.

The thermal image for the function is calculated according to the equation described below:

$$\theta_{t\%} = \left(\left(\theta_{t-1} - \left(\frac{I_{MAX}}{I_N \times k_{SF} \times k_{AMB}} \right)^2 \times e^{-\frac{t}{\tau_1/\tau_2}} \right) + \left(\frac{I_{MAX}}{I_N \times k_{SF} \times k_{AMB}} \right)^2 \right) \times 100\%$$

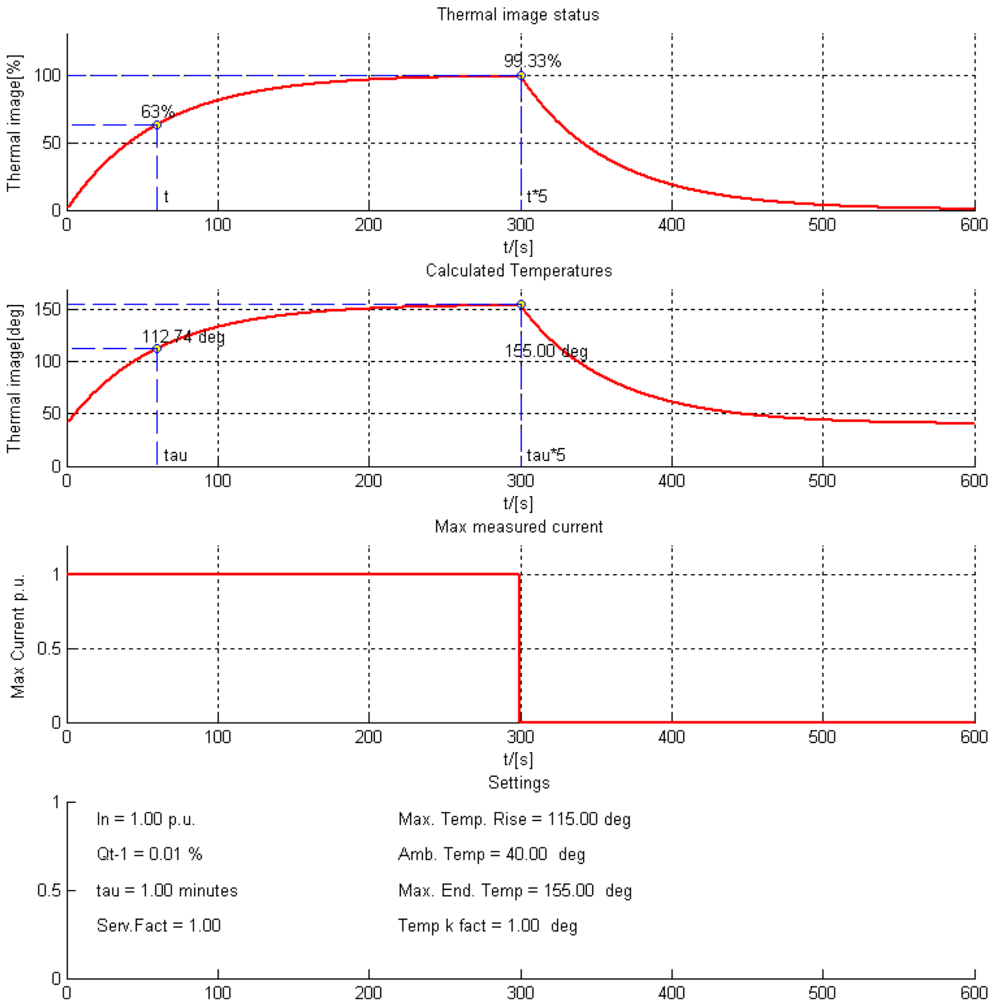
Where:

- $\theta_{t\%}$ = Thermal image status, percentage of the maximum available thermal capacity
- θ_{t-1} = Thermal image status, 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., t_{max} achieved in τ x 5)
- k_{SF} = Loading factor (service factor), maximum allowed load current (in p.u.) value, dependent on the protected object or cable/line installation
- k_{amb} = Temperature correction factor, either from a linear approximation or from a settable ten-point thermal capacity curve
- t = Calculation time step (0.005 s)
- e = Euler's number

- τ_1 = Thermal heating time constant of the protected object (in minutes)
- τ_2 = Thermal heating time constant of the protected object (in minutes)

The basic operating principle of the thermal replica is based on the nominal temperature rise, which is achieved when the protected object is loaded with a nominal load in a nominal ambient temperature. When the object is loaded with a nominal load for a time equal to 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 approaches 100 % indefinitely but never exceeds it. With a single time constant model the cooling of the object follows this same behavior, the reverse of the heating when the current feeding is zero.

Figure. 5.4.17. - 80. Example of thermal image calculation with nominal conditions.



The described behavior is based on the assumption that the monitored object (whether a cable, a line or an electrical device) has a homogenous body which generates and dissipates heat with a rate proportional to the temperature rise caused by the current squared. This is usually the case with cables and other objects while the heat dissipation of overhead lines is dependent on the weather conditions. Weather conditions considering the prevailing conditions in the thermal replica are compensated with the 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. underground cables).

The ambient temperature compensation takes into account the set minimum and maximum temperatures and the load capacity of the protected object as well as the measured or set ambient temperature. The calculated coefficient is a linear correction factor, as the following formula shows:

$$t_{Amb<t_{min}} = k_{min}$$

$$t_{Amb<t_{ref}} = \left(\frac{1-k_{min}}{t_{ref}-t_{min}} \times (t_{AMB}-t_{min})\right) + k_{min}$$

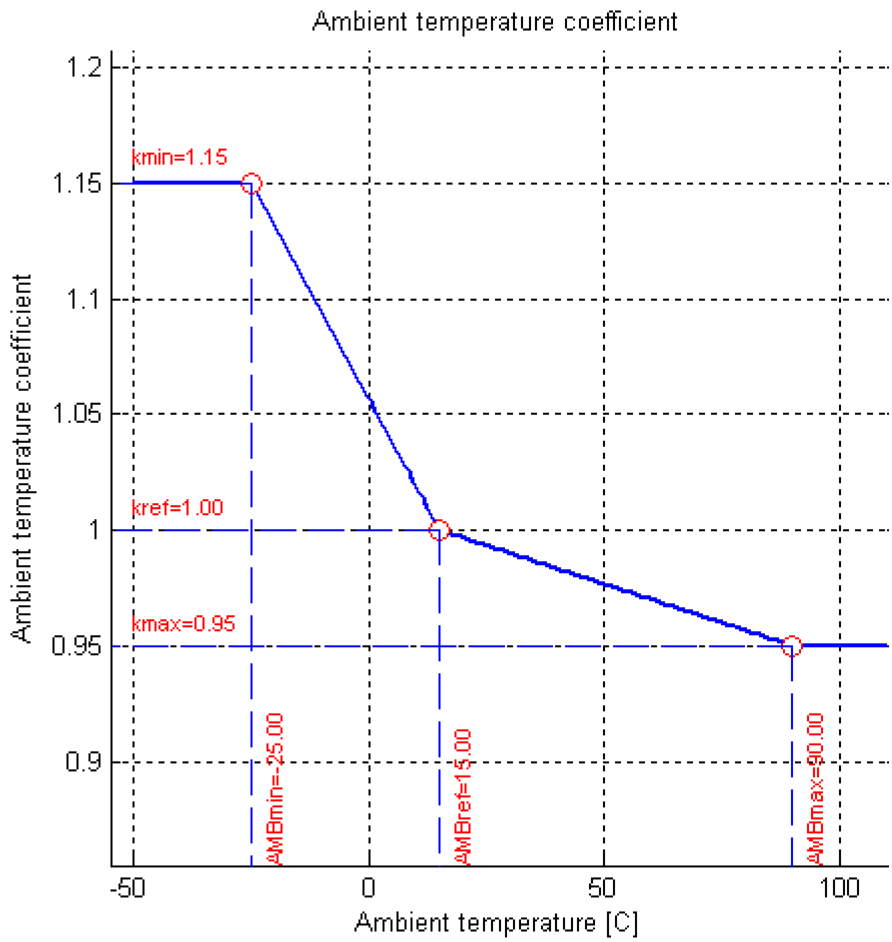
$$t_{Amb>t_{ref}} = \left(\frac{k_{max}-1}{t_{max}-t_{ref}} \times (t_{AMB}-t_{ref})\right) + 1.0$$

$$t_{Amb>t_{max}} = k_{max}$$

Where:

- t_{amb} = Measured (set) ambient temperature (can be set in ℃ or ℉)
- t_{max} = Maximum temperature (can be set in ℃ or ℉) for the protected object
- k_{max} = Ambient temperature correction factor for the maximum temperature
- t_{min} = Minimum temperature (can be set in ℃ or ℉) for the protected object
- k_{min} = Ambient temperature correction factor for the minimum temperature
- t_{ref} = Ambient temperature reference (can be set in ℃ or ℉, the temperature in which the manufacturer's temperature presumptions apply, the temperature correction factor is 1.0)

Figure. 5.4.17. - 81. Ambient temperature coefficient calculation (a three-point linear approximation and a settable correction curve).



Function inputs and outputs

The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

The outputs of the function are the TRIP and BLOCKED signals. The overvoltage function uses a total of eight (8) separate setting groups which can be selected from one common source. Additionally, the function's operating mode can be changed via the setting group selection.

The operational logic consists of the following:

- input magnitude processing
- thermal replica
- comparator
- block signal check
- output processing.

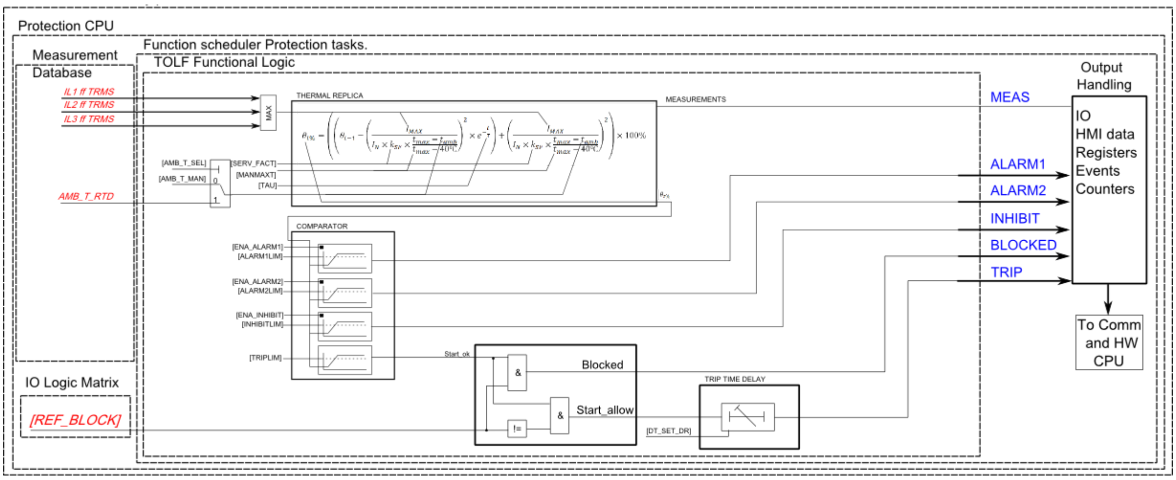
The inputs for the function are the following:

- setting parameters
- measured and pre-processed current magnitudes.

The function's output signals can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the two (2) output signal. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the TRIP, ALARM 1, ALARM 2, INHIBIT and BLOCKED events.

The following figure presents a simplified function block diagram of the transformer thermal overload protection function.

Figure. 5.4.17. - 82. Simplified function block diagram of the TT> function.



Measured input

The function block uses analog current measurement values as well as the fundamental frequency magnitude of the current measurement inputs and the calculated residual current with residual current measurement. The user can select channel I01 or I02 for residual current measurement.

Table. 5.4.17. - 137. Measurement inputs of the TT> 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. 5.4.17. - 138. General settings (not selectable under setting groups)

Name	Range	Step	Default	Description
TT> mode	0: Disabled 1: Activated	-	0: Disabled	The selection of the function is activated or disabled in the configuration. By default it is not in use.
Temp C or F deg	0: C 1: F	-	0: C	The selection of whether the temperature values of the thermal image and RTD compensation are shown in Celsius or in Fahrenheit.

Table. 5.4.17. - 139. Settings for thermal replica.

Name	Range	Step	Default	Description
IN thermal cap current	0.10…40.00 x I_n	0.01 x I_n	1.00 x I_n	The current for the 100 % thermal capacity to be used (the pick-up current in p.u., with t_{max} achieved in time τ x 5).

tau h (t const)	0.1…500.0 min	0.1 min	10.0 min	The τ_h time constant setting. This time constant is used for the heating of the protected object.
tau c (t const)	0.1…500.0 min	0.1 min	10.0 min	The τ_c time constant setting. This time constant is used for the cooling of the protected object.
k_{SF} (service factor)	0.01…5.00	0.01	1.00	The service factor which corrects the value of the maximum allowed current according to installation and other conditions varying from the presumptive conditions.
Cold reset default theta	0.0…150.0 %	0.1 %	60.0 %	The thermal image status in the restart of the function or the device. The value is given in percentages of the used thermal capacity of the protected object. It is also possible to reset the thermal element. This parameter can be used when testing the function to manually set the current thermal cap to any value.

Table. 5.4.17. - 140. Environmental settings

Name	Range	Step	Default	Description
Object max. temp. (t_{max} = 100%)	0…500 deg	1 deg	90 deg	The maximum allowed temperature for the protected object. The default suits for Celsius range and for PEX-insulated cables.
Ambient temp. sel.	0: Manual set 1: RTD	-	0: Manual set	The selection of whether fixed or measured ambient temperature is used for the thermal image biasing.
Man. amb. temp. set	0…500 deg	1 deg	15 deg	The manual fixed ambient temperature setting for the thermal image biasing. Underground cables usually use 15 °C. This setting is visible if "Manual set" is selected for the "Ambient temp. sel." setting.
RTD amb. temp. read.	0…500 deg	1 deg	15 deg	The RTD ambient temperature reading for the thermal image biasing. This setting is visible if "RTD" is selected for the "Ambient temp. sel." setting.
Ambient lin. or curve	0: Linear est. 1: Set curve	-	0: Linear est.	The selection of how to correct the ambient temperature, either by internally calculated compensation based on end temperatures or by a user-settable curve. The default setting is "0: Linear est." which means the internally calculated correction for ambient temperature.
Temp. reference (t_{ref}) k_{amb}=1.0	-60…500 deg	1 deg	15 deg	The temperature reference setting. The manufacturer's temperature presumptions apply and the thermal correction factor is 1.00 (rated temperature). For underground cables the set value for this is usually 15 ℃ and for cables in the air it is usually 25 ℃. This setting is visible if "Ambient lin. or curve" is set to "Linear est."
Max. ambient temp.	0…500 deg	1 deg	45 deg	The maximum ambient temperature setting. If the measured temperature is more than the maximum set temperature, the set correction factor for the maximum temperature is used. This setting is visible if "Ambient lin. or curve" is set to "Linear est."
k at max. amb. temp.	0.01…5.00 x I_n	0.01 x I_n	1.00 x I_n	The temperature correction factor for the maximum ambient temperature setting. This setting is visible if "Ambient lin. or curve" is set to "Linear est."
Min. ambient temp.	-60…500 deg	1 deg	0 deg	The minimum ambient temperature setting. If the measured temperature is below the minimum set temperature, the set correction factor for minimum temperature is used. This setting is visible if "Ambient lin. or curve" is set to "Linear est."
k at min. amb. temp.	0.01…5.00 x I_n	0.01 x I_n	1.00 x I_n	The temperature correction factor for the minimum ambient temperature setting. This setting is visible if "Ambient lin. or curve" is set to "Linear est."
Amb. temp. ref. 1...10	-50.0…500.0 deg	0.1 deg	15 deg	The temperature reference points for the user-settable ambient temperature coefficient curve. This 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	The coefficient value for the temperature reference point. The coefficient and temperature reference points must be set as pairs. This 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	The selection of whether or not the curve temperature/coefficient pair is in use. The minimum number to be set for the temperature/coefficient curve is two pairs and the maximum is ten pairs. If the measured temperature is below the set minimum temperature reference or above the maximum set temperature reference, the used temperature coefficient is the first or last value in the set curve. This setting is visible if "Ambient lin. or curve" is set to "Set curve".

Operation characteristics

The operating characteristics of the machine thermal overload protection function are completely controlled by the thermal image. The thermal capacity value calculated from the thermal image can set the I/O controls with ALARM 1, ALARM 2, INHIBIT and TRIP signals.

Table. 5.4.17. - 141. Pick-up settings.

Name	Range	Step	Default	Description
Enable TT> Alarm 1	0: Disabled 1: Enabled	-	0: Disabled	Enabling/disabling the ALARM 1 signal and the I/O.
TT> Alarm 1 level	0.0…150.0 %	0.1 %	40 %	ALARM 1 activation threshold.
Enable TT> Alarm 2	0: Disabled 1: Enabled	-	0: Disabled	Enabling/disabling the ALARM 2 signal and the I/O.
TT> Alarm 2 level	0.0…150.0 %	0.1 %	40 %	ALARM 2 activation threshold.
Enable TT> Rest Inhibit	0: Disabled 1: Enabled	-	0: Disabled	Enabling/disabling the INHIBIT signal and the I/O.
TT> Inhibit level	0.0…150.0 %	0.1 %	80 %	INHIBIT activation threshold.
Enable TT> Trip	0: Disabled 1: Enabled	-	0: Disabled	Enabling/disabling the TRIP signal and the I/O.
TT> Trip level	0.0…150.0 %	0.1 %	100 %	TRIP activation threshold.
TT> Trip delay	0.000…3600.000 s	0.005 s	0.000 s	The trip signal's additional delay. This delay delays the trip signal generation by a set time. The default setting is 0.000 s which does not give an added time delay for the trip signal.

Function blocking

he block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's 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 the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and processes the release time characteristics similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup current values and its fault type to be issued.

The blocking signal can also be tested in the commissioning phase by a software switch signal when the relay's testing mode "Enable stage forcing" is activated (*General → Device*).

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

Measurements and indications

The function outputs measured process data from the following magnitudes:

Table. 5.4.17. - 142. General status codes.

Name	Range	Description
TT> Condition	0: Normal 1: Alarm 1 ON 2: Alarm 2 ON 3: Inhibit ON 4: Trip ON 5: Blocked	The function's operating condition at the moment considering binary IO signal status. No outputs are controlled when the status is "Normal".
Thermal status	0: Light/No load 1: High overload 2: Overloading 3: Load normal	The function's thermal image status. When the measured current is below 1 % of the nominal current, the status "Light/No load" is shown. When the measured current is below the trip limit, the status "Load normal" is shown. When the measured current is above the pick-up limit but below 2 x I_n , the status "Overloading" is shown. When the measured current is above 2 x I_n, the status "High overload" is shown.
TT> Setting alarm	0: SF setting ok 1: Service factor set fault. Override to 1.0	Indicates if SF setting has been set wrong and the actually used setting is 1.0. Visible only when there is a setting fault.
TT> Setting alarm	0: Ambient setting ok 1: Ambient t set fault. Override to 1.0	Indicates if ambient temperature settings have been set wrong and actually used setting is 1.0. Visible only when there is a setting fault.
TT> Setting alarm	0: Nominal current calc ok 1: Nominal current set fault. Override to 1.0	Indicates if nominal current calculation is set wrong and actually used setting is 1.0. Visible only when there is a setting fault.
TT> Setting alarm	0: Ambient setting ok 1: Inconsistent setting of ambient k	Indicates if ambient k setting has been set wrong. Visible only when there is a setting fault.

Table. 5.4.17. - 143. Measurements.

Name	Range	Description/values

Currents	0: Primary A 1: Secondary A 2: Per unit	The 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 the 100 % thermal cap - TT> Rreference T curr.: reference/pick-up value (IEQ) - TT> Active meas. curr.: the measured maximum TRMS current at a given moment - TT> T est. with act. curr.: estimation of the used thermal capacity including the current at a given moment - TT> T at a given moment: the thermal capacity used at that moment
	1: Temp. estimates	- TT> Used k for amb. temp: the ambient correction factor at a givenmoment - TT> Max. temp. rise all.: the maximum allowed temperature rise - TT> Temp. rise atm: the calculated temperature rise at a given moment - TT> Hot spot estimate: the estimated hot spot temperature including the ambient temperature - TT> Hot spot max. all.: the maximum allowed temperature for the object
	2: Timing status	- TT> Trip delay remaining: the time to reach 100% theta - TT> Trip time to rel.: the time to reach theta while staying below the trip limit during cooling - TT> Alarm 1 time to rel.: the time to reach theta while staying below the Alarm 1 limit during cooling - TT> Alarm 2 time to rel.: the time to reach theta while staying below the Alarm 2 limit during cooling - TT> Inhibit time to rel.: the time to reach theta while staying below the Inhibit limit during cooling

Table. 5.4.17. - 144. Counters.

Name	Description / values
Alarm1 inits	The number of times the function has activated the Alarm 1 output
Alarm2 inits	The number of times the function has activated the Alarm 2 output
Restart inhibits	The number of times the function has activated the Restart inhibit output
Trips	The number of times the function has tripped
Trips Blocked	The number of times the function trips has been blocked

Events and registers

The line thermal overload protection function (abbreviated "TOLT" in event block names) generates events and registers from the status changes in TRIP and BLOCKED signals. The user can select the status ON or OFF for messages in the main event buffer.

The triggering event of the function (TRIP or BLOCKED) is recorded with a time stamp and with process data values.

Table. 5.4.17. - 145. Event codes.

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

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data for TRIP, BLOCKED, etc. signals. The table below presents the structure of the function's register content.

Table. 5.4.17. - 146. Register content.

Name	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event code	4672-4681 Descr.
Time to reach 100 % theta	seconds
Ref. T current	x I_n
Active meas. current	x I_n
T at a given moment	%
Max. temp. rise allowed	degrees
Temp. rise at a given moment	degrees
Hot spot estimate	degrees
Hot spot maximum allowed	degrees
Trip delay rem.	seconds
Used SG	Setting group 1...8 active

5.4.18. Transformer differential (Idb>/Idi>/I0dHV>/I0dLV>; 87T/87N)

The transformer differential function is used for protecting the following power transformers: two-winding transformers, and to some extent three-winding and two-winding transformers that have double outputs and a summing application.

Power transformers are seen in electric power generation, transmission, and distribution. They are also part of applications network in wide range considering of the power, voltage levels and usage purposes. The most common use for a transformer is (as the name implies) to transform alternating voltage from one voltage level to another. What is common for all transformers is that they are a crucial and one of the most important single components in a network because a transformer's failure affects a wide area in the network. While transformers do not have many moving parts (apart from tap changers), their electric and mechanical properties are far from being simple.

When designing transformer protection it is usual to consider the transformer's usage as well as the power level it transforms. This is because the economical aspect becomes more significant as the size of the transformer increases, and the applied protection should be in line with the cost of the transformer. For example, there is little point in installing a highh-level multifunction transformer device into a distribution transformer of a few kVA that feeds a handful of farms in a rural area network. Similarly, it is pointless to have nothing but fuses protecting a transmission transformer of a few hundred MVA that feeds entire cities.

When designing transformer protection one should consider which protection elements are needed to apply sufficient protection. The following table gives a rough idea what protection methods and elements as well as risks exist for the different types of transformers. Overlooking these points when designing transformers increase the risk of costly problems with the transformer.

Transformer	Risks	Protection

Pole-mounted <100 kVA transformer Distribution.	Risks are mostly environmental; the most common issue is a lightning hitting an overhead line. A broken device can be switched to a new one within hours. Relatively cheap.	Protection includes feeder overcurrent and earth fault protection. No separate protection devices are normally applied.
<500 kVA transformer in industrial use, installation indoors. Distribution, applications.	The biggest risk is overloading; cooling can be an issue if the environmental conditions are difficult. A broken device can be replaced with a new one within hours. Possible fault extension to other parts of the network or to building should be reduced. Relatively cheap.	Protection includes feeder overcurrent and earth fault protection. Fuses are used to limit the possible short-circuit current.
500kVA...2 MVA Distribution, applications, motors, small generators.	Risks include overloading, overvoltage, transients, and cooling. Replacing a broken device is costly, so fixing might be the better option if a fault occurs. It is important to monitor the device as the cost of fixing failures is probably higher than the cost of monitoring.	Protection includes overcurrent and earth fault protection, a dedicated pressure guard (Buchholz gas relay), overloading protection with winding temperature monitors. Fuses could be considered for limiting the short-circuit current. If the transformer is oil-insulated, oil level monitoring should be applied.
2MVA...100 MVA Distribution, generation, sub transmission <130 kV.	Risks include overloading, overvoltage, transients, cooling, and environmental issues. Replacing a broken device is problematic as the process is difficult and normally takes the network off-line for a long time. The device is relatively expensive. Its failure affects a wide area regardless of where it is installed (transmission, distribution, generation). Monitoring, clearing faults quickly, and limiting the device's internal fault time are all very important.	Includes the following protections: differential overcurrent and earth fault protection, back-up overcurrent and earth fault protection, tap changer protection, a dedicated pressure guard (Buchholz gas relay), overloading protection with numerical and winding temperature monitors. If the transformer is oil-insulated, oil level monitoring should be applied in addition to monitoring of loading and oil-ageing estimations. If the transformer has forced cooling, monitoring and protection for cooling systems should be applied. Multifunction relays need protections and monitoring; dedicated relays require back-up overcurrent and earth fault protections.
>100 MVA Transmission > 130 kV	Risks include overloading, overvoltage, transients, cooling, and environmental issues. Replacing a broken device is problematic as the process is difficult and normally takes the network off-line for a long time. The device is extremely expensive. Its failure affects a wide area regardless where it is installed (transmission, distribution, generation). Monitoring, clearing faults quickly, and limiting the device's internal fault time are all very important.	Includes the following protections: redundant differential overcurrent and earth fault protection, redundant back-up overcurrent and earth fault protection, tap changer protection, a dedicated pressure guard (Buchholz gas relay), overloading protection with numerical and redundant winding temperature monitors. Oil level monitor should be applied, as well as monitoring of loading and oil-ageing estimations. If the transformer has forced cooling, monitoring and protection for cooling systems should be applied. Separated relays for control, monitoring and protection.

There are many transformer faults, e.g. dirty, watered or old transformer oil, oil leakage from the tank, as well as multiple, prolonged heavy overloading and other faults in the cooling systems. These can cause earth faults, interturn faults or even phase-to-phase faults in the windings of the transformer.

Why is differential protection needed in transformer protection?

The transformer differential function is based on calculating the difference between the ingoing and outgoing currents. If the operating status is normal, all power that comes in also goes out. If this is not the case, the transformer has an internal fault and the device should be de-energized as soon as possible to avoid extensive damage to the transformer. An operating differential function takes a faulty transformer off-line for a long time. A quick de-energizing of the fault saves money because in most cases the transformer can still be repaired which is significantly cheaper than replacing the broken device with a new one. However, there are some exceptions to this. Faults that occur within the differential protection zone but without the transformer itself (such as in the bus or in the cables connected to the transformer). Faults of this type are easily repaired and the transformer can be re-energized soon after the fault has bee cleared.

If a transformer is protected only by conventional overcurrent and earth-fault protections, the operating time should be set in coordination with the low-voltage side protection relays to ensure selectivity. This means that transformer protection should not be set to instant operation but to delayed operation instead in order for the low-voltage side relays to operate before transformer protection. This is because under normal conditions the transformer's energizing and its short-circuit supply to the high or low voltage side is seen directly on both sides of the transformer. An overcurrent during instant operation causes problems with timing coordination or sensitivity, if the instant protection is set on high-current starting criteria. In smaller transformers this is not a siginificant problem as the installation and maintenance of various differential protections is considered more expensive than not having a full coverage of protection.

Differential protection is very sensitive and it is scaled internally to the loading and fault current flowing through the transformer. For example, an interturn fault in the transformer's windings could go entirely unnoticed by an overcurrent relay while a differential relay could trip it in the very first power cycle. The same goes for internal earth faults: they can be impossible for conventional earth fault protection to notice until the fault causes heavier fault currents (such as when the fault location is close to the neutral side inside the star winding).

These are the main arguments for using differential protection: they are sensitive, their operation in internal in-zone faults is fast, and they have a high stability for out-zone faults. These guarantee a minimum of unwanted power outages as well as minimized and reduced damage to the transformer itself. On the other hand, differential protection has its negative properties: it is not very easy to set up to operate correctly, and it requires a second set of current transformers which increases installation costs. operate correctly and second set of current transformers are required thus increasing the installation cost. However, this cost is marginal in larger scale power transformers.

The following chapter explains the principles of transformers. It also shows how how to set the differential protection correctly for the example application.

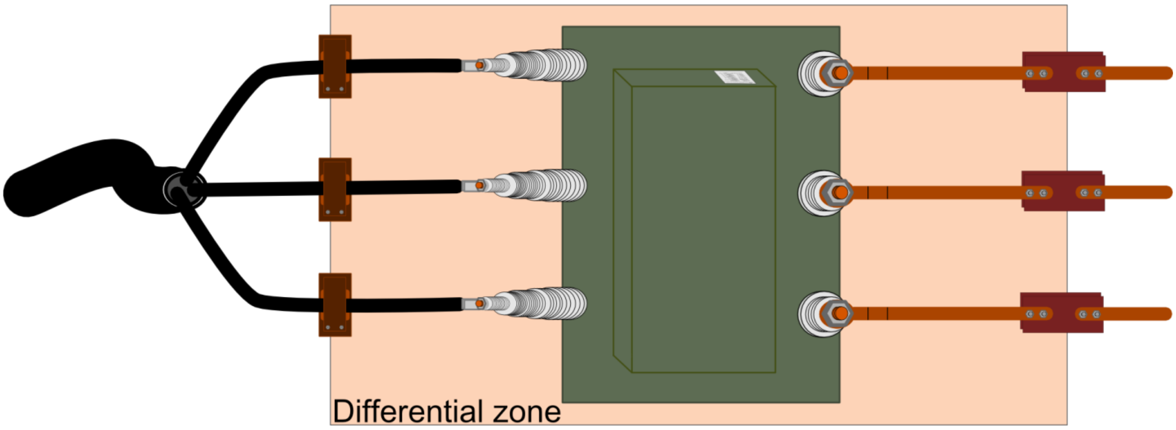
Transformer properties and basic concepts for differential protection

Setting the differential protection requires some intial data of the transformer to be known. At minimum, the following data needs to be available:

- the transformer's nominal power
- the nominal voltages of both the HV and LV sides
- the transformer's special properties, such as tap changer and auxiliary windings
- the transformer's vector group (for matching the transformer vectors in p.u.)
- the ratios and properties of the transformers HV and LV sides.

This chapter shows the setting and the principle of transformer differential protection step by step.

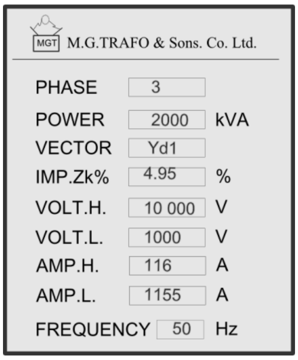
Figure. 5.4.18. - 83. Transformer and its components forming the differential zone.



The working area is the area between the current transformers. This is called the differential zone which means that the currents going in from one side must come out from the other side. This is true whether the signal is scaled higher or lower, or whether the phase angle is shifted. Unless both side currents match there is a problem within the protected zone which either blocks or keeps the current inside the zone.

The image below shows what a typical transformer name plate looks like, what data it includes and what to do with it.

Figure. 5.4.18. - 84. Transformer name plate data.



According to the data on this example name plate, this transformer is designed for three-phase usage and therefore it has two windings. The nominal power of the transformer is 2 MVA. Its vector group is Yd1: this means that the high-voltage side is connected to the Y and the low-voltage side to the delta, resulting in the LV side having a 30-degree lag in relation to the HV side. Additionally, the HV side's nominal voltage is 10 kV and its amperage is 116 A, on the LV side the nominal voltage is 1kV and its amperage is 1.155 kA. The transformer's short-circuit impedance is 4.95 %; it is based on the transformer's final test and presents how much short-circuit current the transformer is able to feed. The transformer's frequency is 50 Hz. This kind of information is usually available in a transformer's name plate and documentation. If the transformer has a tap changer, its information is usually also available in the name plate data.

Nominal current matching is the first thing to consider in differential protection. Usually a modern numerical protection relay can calculate these factors itself as long as the transformer's nominal power and voltage levels are known. However, if one feels inclined to calculate the amplitude matching factor, they can do so with the formulas presented below.

For this example, let us say we want to do these calculation for the transformer whose name plate we have in the image above. Let us further say the HV side current transformers are 150/5 A and the LV side current transformers are 1200/5 A. The primary side factor (p.u.) and current are then calculated as follows:

$$I_{n,HV} = \frac{S_n}{\sqrt{3} \times U_{HV}} = \frac{2\ 000\ 000\ \text{VA}}{\sqrt{3} \times 10\ 000\ \text{V}} = 115.47\ \text{A}$$

$$I_{pu,pri,HV} = \frac{I_{n,HV}}{CT_{pri,HV}} = \frac{115.47\ \text{A}}{150\ \text{A}} = 0.77$$

$$I_{pu,sec,HV} = I_{pu,pri,HV} \times CT_{sec,HV} = 0.77 \times 5\ \text{A} = 3.85\ \text{A}$$

Then, the secondary side factor (p.u.) and current are calculated as follows:

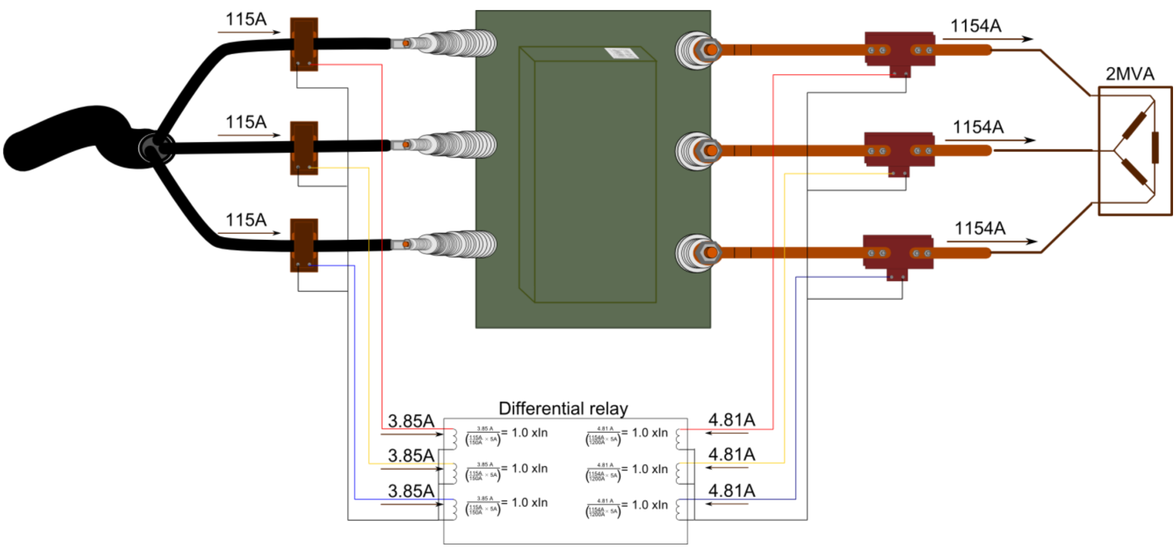
$$I_{n,LV} = \frac{S_n}{\sqrt{3} \times U_{LV}} = \frac{2\ 000\ 000\ \text{VA}}{\sqrt{3} \times 1\ 000\ \text{V}} = 1154.7\ \text{A}$$

$$I_{pu,pri,LV} = \frac{I_{n,LV}}{CT_{pri,LV}} = \frac{1154.7\ \text{A}}{1200\ \text{A}} = 0.96$$

$$I_{pu,sec,LV} = I_{pu,pri,LV} \times CT_{sec,LV} = 0.96 \times 5\ \text{A} = 4.81\ \text{A}$$

The calculations show that if 2 MVA of power go through the transformer the CT's secondary current on the high-voltage side will be 3.85 A and the CT secondary current on the low-voltage side will be 4.81 A. The differential function uses these values to change them into measured currents in per unit. Therefore, it would show 1.0 · I_n for both HV and LV side measurements, eventhough the measured currents are different. This is called amplitude matching of the HV and LV sides. In modern differential relays this is done automatically when the nominal values and CT ratings are set for the transformer. Thus, these calculations only have nice-to-know informational value.

Figure. 5.4.18. - 85. Amplitude scaling to match the nominal currents and CTs in the differential relay.

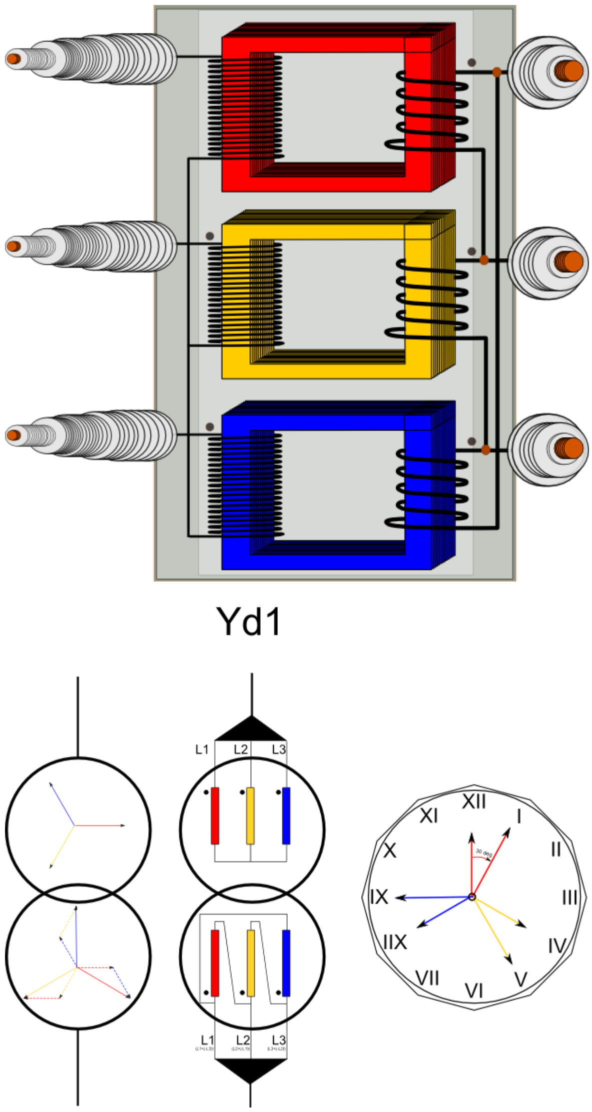


Nominal current matching is only part of the differential protection settings. The vector group of the transformer is also important, since the differential function is interested in the angle difference of the measured current vectors. In this example the transformer's vector group is Yd1, which means that the transformer's HV side is connected to the Y and the LV side to the delta. Therefore, the LV side is in 30-degree lag in relation to the HV side vectors.

The number '1' in the vector group's name comes from the angle in the phase current difference between the HV and the LV side. If one imagines the HV side current's Y placed upside down on the face of a clock (with the Y's leg pointing at 12), the LV side's delta would be pointing at 1. Likewise, '11' means that the LV side is leading 30 degrees; '5' and '7' are just the other ends of the windings thus causing a 180-degree difference between the '1' and '11' clock numbers.

The following example explains transformer current vectors and what a connection might look like.

Figure. 5.4.18. - 86. Yd1 transformer's internal connection (in theory).



In modern relays these standard vector groups (Y or delta, lead or lag) are defined by a setting selection and there is no need for interposing transformers. Even if the transformer's vector group is not standard it should still be settable within the relay (such as with zigzag transformers).

In this example, the function translate the delta side currents. The correction applies not only to the angles but also to the amplitudes because the delta side (in p.u.) is relative to the amplitude difference with the Y-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 process is called vector group matching for the currents (in p.u.) of the transformer. This matching is necessary whenever one side is connected to the delta and another to the Y. Previously in non-numerical relays, this matching was done by interposing CTs which connected the power transformer's Y side to the delta, and the transformer's delta side to the Y. This got the HV and LV side vectors to match each other. Then the currents in the relay inputs are summed up. If there is no difference (as the HV and LV side currents negate each other), the pick-up is not triggered. If the currents do have a difference, the current flows to the relay input and with enough difference causes a pick-up and a trip. However, as modern differential relays do this transformation by calculating the corrected vector internally, this is also just nice-to-know information not related to the actual operation of the relay.

Figure. 5.4.18. - 87. Expected phase shifts from HV side to LV side (a 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

The direction of the CTs' Y legs on the HV and LV sides affects how the differential calculation method is set. The setting options are "add" and "subtract" which is why the CTs' currenct direction has to be taken into account. The "add" mode is used when the CT's starpoints are either pointing towards each other or away from each other. The "subtract" mode is used when those points are pointing in the same direction. In this example the correct setting would be the "add" mode because the CTs in the main circuit are connected to the opposite and thus the measured currents from the CTs are also opposite. The user selects how they want the signals shown: the CTs' currents can be negated with the "subtract" option, resulting in a one Y-connected vector diagram.

The images below present the differential algorithm itself (one calculating formula for each phase difference); first the "subtract" formulas, then the "add" formulas. Selection is based on the CT connections.

Figure. 5.4.18. - 88. "Subtract" formula.

$$L1DIFF_{Subt} = |\overline{IL1_{HV}} - \overline{IL1_{LV}}|$$

$$L2DIFF_{Subt} = |\overline{IL2_{HV}} - \overline{IL2_{LV}}|$$

$$L3DIFF_{Subt} = |\overline{IL3_{HV}} - \overline{IL3_{LV}}|$$

Figure. 5.4.18. - 89. "Add" formula.

$$L1DIFF_{Add} = |\overline{IL1_{HV}} + \overline{IL1_{LV}}|$$

$$L2DIFF_{Add} = |\overline{IL2_{HV}} + \overline{IL2_{LV}}|$$

$$L3DIFF_{Add} = |\overline{IL3_{HV}} + \overline{IL3_{LV}}|$$

Figure. 5.4.18. - 90. CTs' starpoints requiring the "Add" mode.

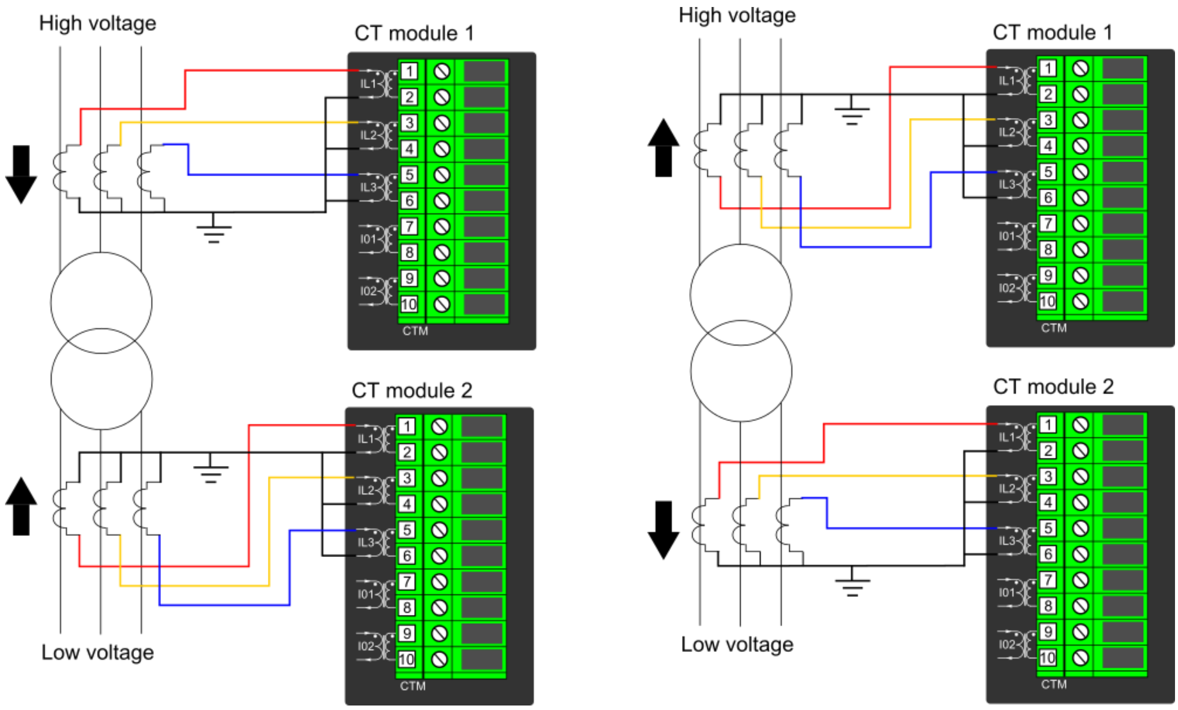
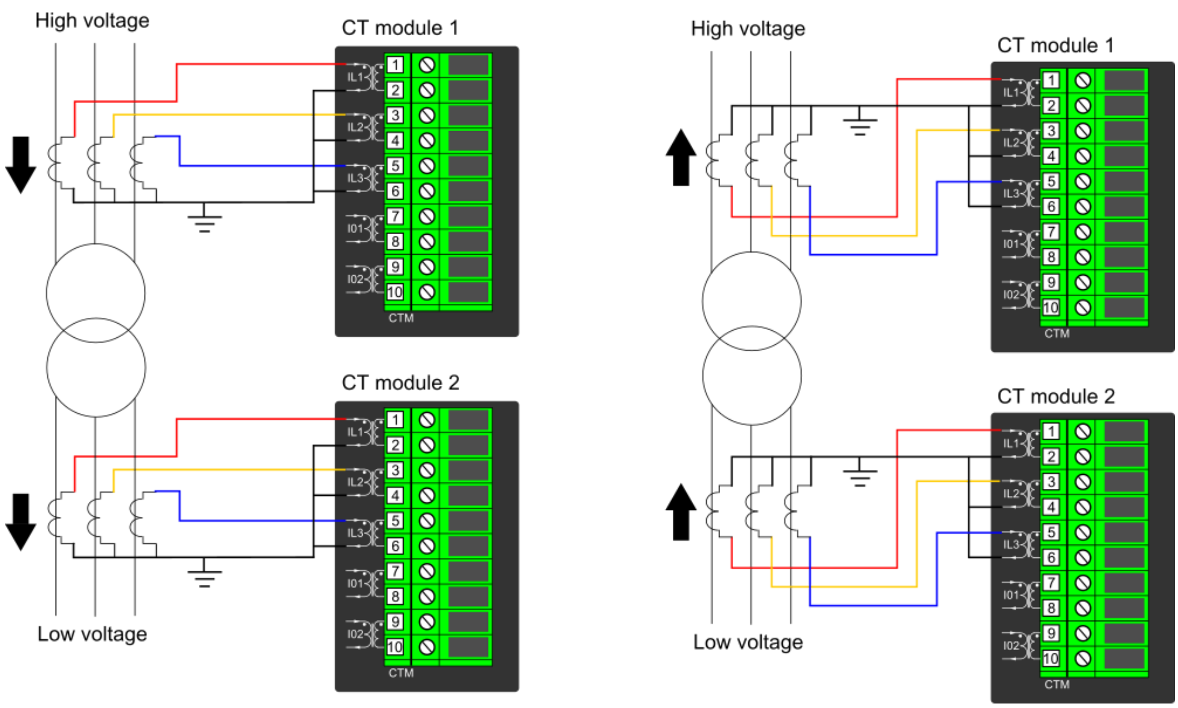


Figure. 5.4.18. - 91. CTs' starpoints requiring the "Subtract" mode.



The differential function has two (2) separate stages built into the function. Non-restraint characteristics use only these formulas as the comparison base. Restraint characteristics also make a so-called bias calculation for each of the phases in order to adjust the differential stage towards the measured currents. Bias calculation can be sensitive or coarse (see the following formulas).

Figure. 5.4.18. - 92. Average mode (sensitive biasing).

$$L1BIAS_{AVG} = \frac{|IL1_{HV}| + |IL1_{LV}|}{2}$$

$$L2BIAS_{AVG} = \frac{|IL2_{HV}| + |IL2_{LV}|}{2}$$

$$L3BIAS_{AVG} = \frac{|IL3_{HV}| + |IL3_{LV}|}{2}$$

Figure. 5.4.18. - 93. Max mode (coarse biasing).

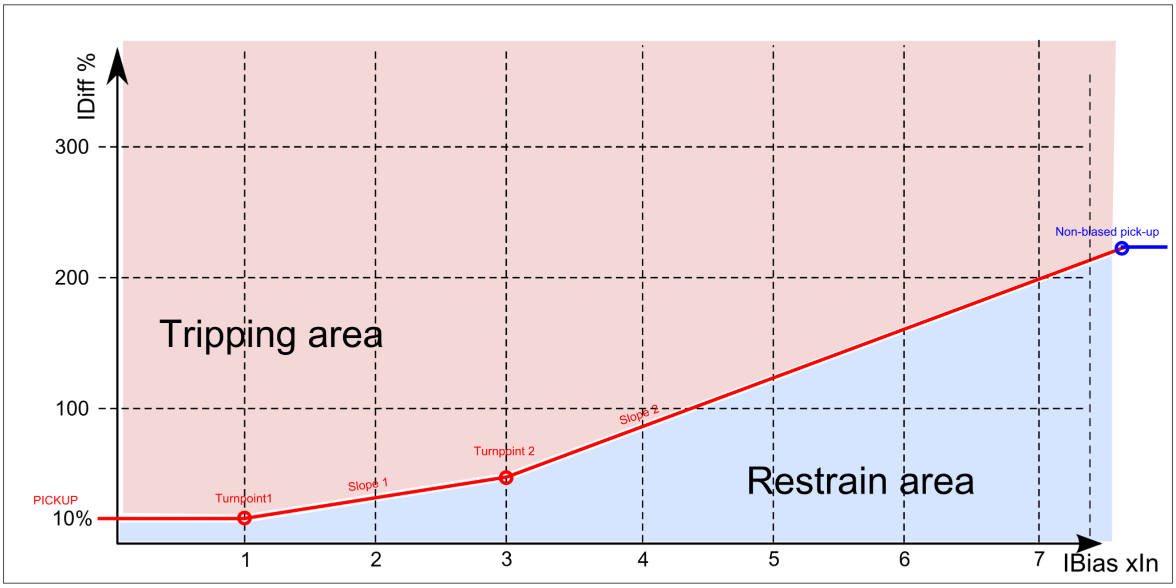
$$L1BIAS_{MAX} = \max(|\mathrm{IL1_{HV}}|, |\mathrm{IL1_{LV}}|)$$

$$L2BIAS_{MAX} = \max(|\mathrm{IL2_{HV}}|, |\mathrm{IL2_{LV}}|)$$

$$L3BIAS_{MAX} = \max(|\mathrm{IL3_{HV}}|, |\mathrm{IL3_{LV}}|)$$

Next, these two formulas are combined in a graph: the x-axis presents the measured differential current, and the y-axis presents the calculated bias current. The following graph shows the differential function characteristic, both biased and non-biased.

Figure. 5.4.18. - 94. Differential function characteristic, biased and non-biased.



The graph is the function of measured biasing current and the differential protection current. The red line presents the allowed differential current in percentages. In this example the non-biased pick-up is set lower than in a normal transformer application. The settings and the ranges of the differential protection function are presented in the "Settings and signals" section of this topic.

The biasing characteristic is formed with the following formulas:

$$Diff_{bias<TP1} = I_{d>pick-up}$$

$$Diff_{bias\,TP1...TP2} = SL1 \times (Ix - TP1) + I_{d>pick-up}$$

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

These form a straight line from zero current to Turnpoint (TP1). From TP1 to TP2 is the first slope (Slope 1) which causes the set biasing to be coarser when the measured current amplitude increases. When the measured current is higher that the TP2 set value, the second slope (Slope 2) is used.

Differential characteristics settings

Characteristics parts

One needs to understand what the various parts of the characteristics mean in order to set the characteristics for the transformer application.

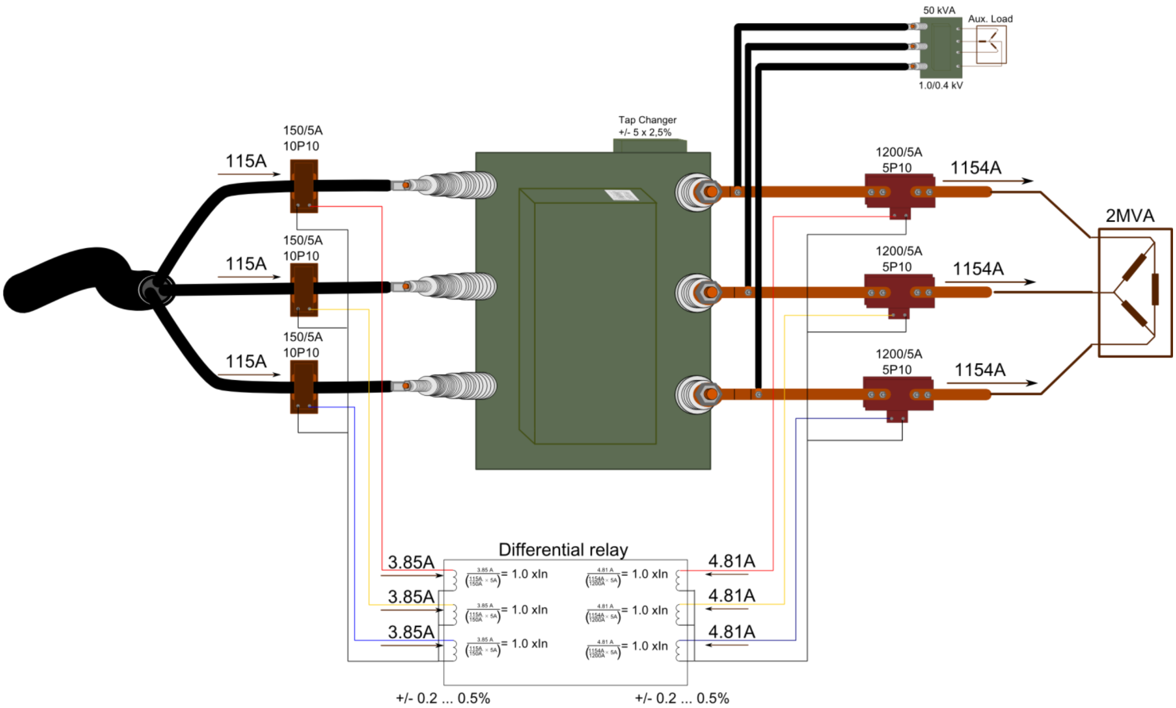
$Diff_{bias<TP1} = I_{d>pick-up}$

This is the first straight line which represents the differential current created by the transformer's normal operation. It takes into account measurement errors, possible variations caused by the transformer's tap changer (if available), and the various reasons why the application might have caused a different load inside the protected differential zone. In differential relays this is known as the pick-up current ($I_{d>pick-up}$). It is the basic sensitivity limit: when the measured differential current is below this limit, the transformer still operates normally and the protection does not trigger. In other words, the pick-up current setting must be higher than the combination of all the normal operation factors that cause differential currents.

Differential current sources (normal operation)

When calculating the differential current in a basic situation, it is strongly recommended to consider the following transformer component errors (the illustrated parts in the image below).

Figure. 5.4.18. - 95. Differential current sources (normal operation).



There seven (7) differential current sources for normal operation:

1) Primary side CT measurement accuracy (CTE_{pri})
In this example the primary side CTs are Class 10P, which means the measurement error is 10 %.

2) Secondary side CT measurement accuracy (CTE_{sec})
In this example the secondary side CTs are Class 5P, which means the measurement error is 5 %.

3) Relay measurement accuracy (primary and secondary) (RE_m)
The relay measurement error is below 0.5 %, its optional accuracy below 0.2 % per measurement channel: the combined value for both sides is either 1 % or 0.4 %.

4) Possible auxiliary transformer or auxiliary winding, currents not measured separately (AUTE)
In this example a 50 kVA auxiliary transformer is connected to the LV side output before the CTs, and this needs to be noted in the calculations. The same is true when the transformer itself is connected to auxiliary power output and those currents are not measured. The auxiliary power output's effect can be calculated by calculating the percentage of the auxiliary transformer/winding VA in relation to the transformer nominal VA (see formula below; assumes the auxiliary load to be nominal):

$$AUTE = \frac{AUX}{NOM} \times 100\ \% = \frac{50\ 000\ \text{VA}}{2\ 000\ 000\ \text{VA}} \times 100\ \% = 2.5\ \%$$

5) Transformer core magnetizing current (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 in the settings calculations. The approximate magnetizing current value can be calculated according to the following formula:

$$I_{TM} = \frac{U_{PRI}}{j\omega L_P}$$

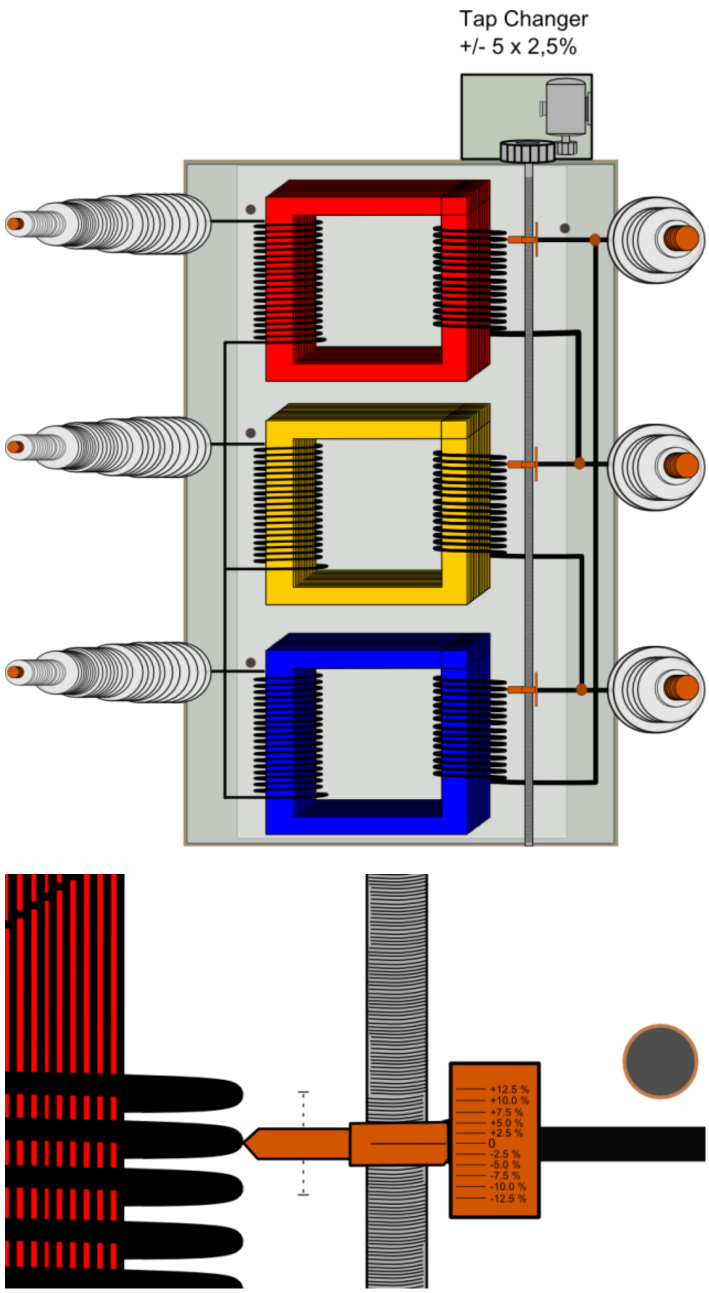
When the primary inductance is known, the magnetizing current value is compared to the HV side's nominal current and the resulting percentage is directly the TME value. If the transformer's primary inductance is unknown, one can use a conservative estimate of 3 % as the TME value.

6) Safety margin (SME)
Conservative settings typically use a safety margin up to 5 %.

7) Tap changer on load side (TCE)
This example transformer has a tap charger with the rating of +/- 5 × 2.5 %. This means that the secondary side windings can be set +/- 5 × 2.5 % from the nominal center position, causing a maximum deviation of 5 × 2.5 % from the nominal conditions. Therefore the TCE is 12.5 % in this case. Please note that the tap position is not always in the nominal center position: check the application and calculate the maximum effect to the worst side.

Generally the tap changer means that the transformer transformation ratio can be adjusted in order to receive the nominal voltage more accurately to the secondary side of the transformer. There a multiple reasons for voltage varioations, e.g. heavy or light loading in the HV side. In practice this means that if the secondary side needs more or less voltage, the secondary side uses more or less winding rounds. This causes a difference in the nominal current condition, which can be noticed as a differential current in the relay. Usually tap changer positions are presented as deviation steps for the secondary voltage to both positive and negative direction from the center (see the second image below).

Figure. 5.4.18. - 96. Transformer tap changer.



Calculating the generated differential current — The biased settings

Now we have all the necessary data to calculate a naturally generated differential current based on the known errors and possible variables.

First we need to calculate the maximum uncertainty ($I_{meas,\ unc}$) from the various magnitudes inside the transformer. In this example, the transformer has a tap changer that affects the internal currents; however, its effects cannot be estimated reliably and the current's maximum uncertainty needs to be calculated. If there is no tap changer, the maximum uncertainty can be calculated sufficiently enough by summing the maximum inaccuracies of the CTs on the HV and LV sides.

$$I_{meas,unc} = \frac{absolute\ uncertainty}{absolute\ measurement} \times 100$$

Looking at the formula above, one can see that the absolute maximum uncertainty as well as the absolute measurement are needed. The former is the sum of the primary CT error (CTE_{pri}), the secondary CT error (CTE_{sec}), the tap changer maximum error (TCE) and the product of multiplying the secondary CT error with the tap changer maximum error (CTE_{sec} × TCE). The latter is the sum of the so-called expected value (1 × I_n) and the tap changer maximum error (TCE). The images below show the full formula (on the left) as well as the formula and its result when filled with the figures from our example configuration (on the right):

$$I_{meas,unc} = \frac{CTE_{pri} + CTE_{sec} + \mathrm{TCE} + (CTE_{sec} + \mathrm{TCE})}{1 + TCE} \times 100 \qquad I_{meas,unc} = \frac{0.1 + 0.05 + 0.125 + (0.05 \times 0.125)}{1 + 0.125} \times 100 = 25\ \%$$

The calculation result (25 %) presents the maximum caused differential current to nominal that can be caused by the transformer's properties. If we know other uncertainties, they can now be added to $I_{meas,\ unc}$ to get the following operation:

$$I_{db>pick-up} = I_{meas,unc} + (2 \times RE_m) + AUTE + TME = 25\ \% + (2 \times 0.5\ \%) + 2.5\ \% + 3\ \% = 31.5\ \%$$

This means that in the worst case scenario, the differential current flows while the transformer's operation is normal. This is why the final result usually gets an added safety margin: the stable operation of the differential protection must be ensured and possible calculation errors negated. The following image shows the base sensitivity (i.e. the minimum setting for the differential current that the relay operation requires) given to 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 the base sensitivity takes into account the starting situation (no load to Turnpoint 1) in the caharacteristics. Next, it needs to b edecided where to set **Turnpoint 1**. In most of differential relays this point is either fixed or automatically defined based on the base sensitivity and Slope 1; however, in this type of differential relay this point can be set by the user. If the user wants a high sensitivity, TP1 can be set to 1 × I_n since the calculated base sensitivity already factors in the tap changer effect and all other differential current sources that normal operating causes. If the user prefers coarse settings, TP1 can be set to 0.5 × I_n, even 0.01 × I_n. The limit is determined by the sum of the protection principle the user wants. A smaller value results in a conservative and stable operation, while a larger value results in a highly sensitive but possibly unstable protection.

Please note that if TP 1 is set to 0.01 × I_n, Slope 1 starts directly from the setting and no unbiased sensitive section is available. This is useful when the user does not want base sensitivity to include the tap changer effect, but instead have it be accounted for in Slope 1 directly. This can lead to optimal sensitivity and stable settings for a differential relay even if there are no non-biased sensitive section in the characteristics. In this case, the formula to calculate the base sensitivity is as follows:

$$I_{db>Pick-up} = \mathrm{CTEpri} + \mathrm{CTEsec} + 2 \times REm + AUTE + TME + \mathrm{SME}$$

$$I_{db>Pick-up} = 10\% + 5\% + 2 \times 0.5\% + 2.5\% + 3\% + 5\% = 26\%$$

Next are the **Slope 1** settings, which present the relay's restrain characteristics over the transformer's load current range. This slope should be effective up to the maximum transformer loading. This value for power transformers is usually around 1.0 to 2.0 × I_n; for large power transformer a typical value is 1.5 × I_n. The purpose is to compensate the measurement errors caused by a relatively high current, including the tap changer effect. 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 the Slope 1 setting is calculated as follows:

$$Slope\ 1 = \frac{Idiff\ TP2}{Ibias\ TP2} \times 100\%$$

Now the calculation of the maximum differential current in **Turnpoint 2** includes the previously calculated correction factors for the 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 (*TR_{corr}*) due to the tap changer position on the maximum voltage position (usually this generates the highest differential current).

$$TR_{CORR} = \frac{U_{HV\_VOLTSMIN}}{U_{HV}} \times \left(\frac{U_{HV}}{U_{LV}}\right)$$

To get the HV volts minimun value the user needs to apply the calculation on a situation when the tap changer on the secondary side is at maximum output voltage and the output is nominal. In this example we had a maximum of +12.5% increasing effect from the tap changer, resulting in the following calculation:

$$TR_{CORR} = \frac{U_{HV\_VOLTSMIN}}{U_{HV}} \times \left(\frac{U_{HV}}{U_{LV}}\right)$$

Next we calculate the the currents that flow in the HV and LV sides, when the loading of the transformer is e.g. 1.5 times its rated power.

Therefore, the LV side currents are as follows:

$$I_{LV} = \frac{\left(\frac{I_{NLV} \times 1.5}{\left(\frac{CT_{LVPRI}}{CT_{LVSEC}}\right)}\right)}{CT_{LVSEC} \times IpuPRI_{LV}} = \frac{\left(\frac{1154.7A \times 1.5}{\left(\frac{1200A}{5A}\right)}\right)}{5A \times 0.96} = 1.5xIn$$

The currents of the HV side are as follows:

$$I_{HV} = \frac{\left(\frac{\left(\frac{I_{NLV} \times 1.5}{TR_{CORR}}\right)}{\left(\frac{CT_{HVPRI}}{CT_{HVSEC}}\right)}\right)}{CT_{HVSEC} \times IpuPRI_{HV}} = \frac{\left(\frac{\left(\frac{1154.7A \times 1.5}{8.75}\right)}{\left(\frac{150A}{5A}\right)}\right)}{5A \times 0.77} = 1.7xIn$$

These currents present the worst-case scenario that the tap changer effect can cause to the differential relay's measured currents.

Next, we need to calculate the differential current. In theory there are two ways to use biasing calculation to do this, but in practice only one: the results of add and subtract modes are the same because they just compensate the connected CTs differently (starpoint towards or away from the transformer). Thus, the differential current is always calculated as follows:

$$|I_{HV} - I_{LV}|$$

This gives the absolute difference in the measured currents.

If the user wants more sensitive settings, the Average mode is selected and the Slope 1 calculation is as follows:

$$LxBIAS_{AVG} = \frac{|ILx_{HV}| + |ILx_{LV}|}{2}$$

$$Slope\ 1 = \frac{Idiff\ TP2}{LxBIAS_{AVG}} \times 100\% = \frac{|I_{LV} - I_{HV}|}{\left(\frac{I_{LV} + I_{HV}}{2}\right)} \times 100\% = \frac{1.5 - 1.7}{\left(\frac{1.5 + 1.7}{2}\right)} \times 100\% = 12.5\%$$

If the user wants more stable settings, the Maximum mode is selected and the Slope 1 calculation is as follows:

$$LxBIAS_{MAX} = \max\left(|\mathrm{ILx_{HV}}|, |\mathrm{ILx_{LV}}|\right)$$

$$Slope\ 1 = \frac{Idiff\ TP2}{LxBIAS_{max}} \times 100\% = \frac{|I_{LV} - I_{HV}|}{\max\left(\lfloor I_{LV} \rfloor, \lfloor I_{HV} \rfloor\right)} \times 100\% = \frac{1.5 - 1.7}{1.7} \times 100\% = 11.7\%$$

If the user wants to be on the safe side, yet another safety margin (in addition to the 5 % already in the base sensitivity settings) can be added to ensure stability.

At this point the only setting still missing is that of **Slope 2.** This setting is used for biasing the differential characteristics against heavy faults outside the differential zone that can cause heavy saturation on one or both sides of the CTs causing heavy differential current in the measurements even though the transformer itself does not have a fault. Please note that if there is a heavy end fault causing the biasing current to increase, this setting should not be set to maximum as the biasing may block the differential characteristics. This makes the trip not applicable even if there is an end fault.

When the transformer is fed from the HV side and the differential current is direct, the fault that feeds the end current can be accounted in the Slope 2 setting.

If the Average mode is used for biasing (due to a single end fault), the bias current is calculated as follows:

$$LxBIAS_{AVG} = \frac{|ILx_{HV}| + |0|}{2}$$

Therefore, the differential current is the following:

$$|ILx_{HV}|$$

$$Slope\ 2 = \frac{|ILx_{HV}|}{\frac{|ILx_{HV}|}{2}} \times 100\% = \frac{|1|}{\left(\frac{1}{2}\right)} \times 100\% = 200\%$$

If the Maximum mode is used for biasing (due to a single end fault), the bias current is the same as the differential current. Therefore, the Slope 2 setting is calculated as follows:

$$Slope\ 2 = \frac{|ILx_{HV}|}{|ILx_{HV}|} \times 100\% = \frac{|1|}{|1|} \times 100\% = 100\%$$

Calculating the generated differential current — The non-biased settings

Now that the biased characteristic is set, we consider the settings for the non-biased stage $I_{di>Pick\text{-}up}$.

The purpose of this stage is to ensure fast and selective tripping of faults inside the differential zone, and also to ensure a stable operation on heavy outside faults. This stage operates only on the measured absolute differential current and is not blocked by harmonics or bias restraints. The setting of the stage should be based on the weakest full saturation of the CT under worst-case fault conditions because then only the other side current is measured and all current seen is differential current.

Let us calculate the maximum three-phase short-circuit current on the LV side in our example case from earlier:

$$I_{3phSC\_LV} = \frac{S_N}{\sqrt{3} \times Z_k} = \frac{S_N}{\sqrt{3} \times \left(\frac{{U_{LV}}^2}{S_N} \times \frac{Z_{k\%}}{100\%}\right)} = \frac{2000000\,VA}{\sqrt{3} \times \left(\frac{10000V^2}{2000000VA} \times \frac{4.95\%}{100\%}\right)} = 23327A$$

On the HV side this current is seen as:

$$I_{3phSC_{LV}\rightarrow HV} = \frac{I_{3phSC\_LV}}{\left(\frac{U_{HV}}{U_{LV}}\right)} = \frac{23327A}{\left(\frac{10000V}{1000V}\right)} = 2332A$$

Next, let us remind ourselves of the given CT ratings for our example:
$CT_{pri,HV}$ = 150/5A (10P10)
$CT_{pri,LV}$ = 1200/5A (5P10)

Now we can calculate the secondary currents:

$$I_{HVMAX} = \frac{I_{3phSC_{LV}\rightarrow HV}}{CT_{HVPRI}} = \frac{2332A}{\frac{150A}{5A}} = 77.7A_{SEC}\ (20.18\ xIn)$$

$$I_{LVMAX} = \frac{I_{3phSC_{LV}}}{CT_{HVPRI}} = \frac{23327A}{\frac{1200A}{5A}} = 97.2A_{SEC}\ (20.2\ xIn)$$

This is the theoretical maximum of the current flowing in the CTs, when a bolted and symmetrical three-phase fault occurs in the LV side of the transformer. Based on the previous calculations, we can see that the HV side maximum current is approximately 15 times higher than the CT rating, and the LV side appr. 19 times higher. No full CT saturation should be seen in either side even though the accuracy limit factor for both CTs is ten times the nominal. The protection class information in the CT ratings tell us that the CT output is for both CTs ten times the rated current in their given measurement class (5 % and 10 %, respectively). However, this is related to the nominal burden that is normally very high compared to the CT input in modern protection relays.

Next, the real CT accuracy limit factor needs to be checked in both CTs, in both sides. This check has much important initial data: the VA of the CTs on both sides, the length of the wiring between the relay and the CTs, the connection between the CTs, as well as the cross-section and material of the wires. Let us begin with the burden the wiring causes to the relay, and calculate the resistance in a conductor:

$R_{Cond} = \frac{\rho \times l}{A}$,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

When designing the CTs and their wiring, please keep in mind the following: the resistance of the wire doubles when the length is doubled, and the resistance halves when the wire's cross-section are doubles. When 1 A secondary is used (instead of 5 A secondary), all burdens drop to a level smaller to portion of $5A^2$, e.g. 1/25.

Although copper cables are normally used to connect CTs to a relay, the table below also presents the resistivity (rho) and conductivity (sigma) properties of aluminum (at +20 °C):

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

You can use the following formula to calculate the resistivity in temperatures other than +20 °C:

Change in resistivity:

$$\Delta_\rho = ((\alpha \times \Delta T) \times \rho_0, \text{where}$$

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, the resistivity of copper at +75 °C is calculated like this:

$$\rho_0 + \Delta_\rho = \rho_0 + (\alpha \times \Delta T \times \rho_0)$$

$$1.68 \times 10^{-8} + \left((0.003862 \times (75°C - 20°C)) \times 1.68 \times 10^{-8}\right) = 0.0203\ \mu\Omega/m$$

With this value we can calculate the resistances (per meter) of the most commonly used copper wires given value most common used copper wires at +75 °C by using the above-mentioned formula for R_{cond}:

Cross-section (mm^2)	Resistance (Ω/m)
1.5	0.0135
2.5	0.00812
4.0	0.00508

6.00	0.00338

It is recommended that you use the worst-case scenario as the basis for calculating the CT burden. In most cases these +75 ºC values are sufficient. If the ambient temperature in your application is higher than +75 ºC, the resistance should be calculated for that specific temperature.

It is also Important to know the wiring of the CTs: do the CTs have a common return wire or are both ends of both CTs wired to the terminal connector? Usually there are four wires coming from the CTs to the terminal: in these cases the length per phase is the sum of the distance from the CT to the relay and the distance from the relay OR from the CTs to the common coupling point. When both sides of all CTs are wired to the relay or to the terminal, the length of the wiring is double the distance from the CTs to the relay. If the connection is a combination of these two wiring types, the length can be estimated by increasinf the distance in proportion to the six-wire or four-wire connection. For example, if six wires connecting the CTs to the terminal account for 30 % of the wiring (in addition to the four wires connecting the and the terminal), the estimated length of the wire is 1.3 times the distance between the relay and the CTs.

The next loading factor is the resistance of the relay's measuring input. In this relay type the resistance is 0.0005 for the current input, which gives approximately 0.001 VA with a current of 1 A. Then we need to calculate the accuracy limit factor (ALF). This requires the CT nominal ALF value and we can get that from the above-mentioned CT rating: the figure after P gives the current overload as a factor of the nominal rated value and therefore gives the ALF applicable at that overload of the CT. The actual ALF can be calculated with the following 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

The main issue with this equation is the S_{CTRN}, the internal burden of the CT secondary. The internal resistance is related to the CT rating, to the winding length as well as to the dimensions of the wire used in the winding. Some CT manufacturers include the SCTRN value in their product documentation. However, as the value is only a small portion of the CT burden as a whole (the wirings cause most of it in typical relay applications), one should not worry if the value is unknown.

For example, let us assume that the internal resistance of the CT's HV side is 0.05 Ω and is rated 5 VA, and that the internal resistance of the CT's LV side 0.09 Ω, also rated 5 VA. The wiring from the HV side to the relay is 10 m and from the LV side to the relay 5 m; both sides have 30% of the wiring made with a six-wire connection and 70% of the wiring with a four-wire connection. The wirings on both sides are made with 4 mm^2 wires. The HV side is 150/5 A, with the protection class 10P10; the LV side is 1200/5 A, with the protection class 5P10. Therefore, the actual accuracy limit factor on both sides is as follows (the HV side on the left, the LV side on the right):

$ALF_{RATED} = 10$ $S_{Rated} = 5\text{VA}$ $S_{CTRN} = {I_{NS}}^2 \times CT_{RS} = 5^2 A \times 0.05\Omega = 1.25\text{VA}$ $R_{Wire} = (10m \times 1.3) \times 0.00508\frac{\Omega}{\text{m}} = 0.066\Omega$ $S_{Actual} = {I_{NS}}^2 \times (R_{Wire} + R_{Relay}) = 5^2 A \times (0.066\Omega + 0.0005\ \Omega) = 1.65\text{ VA}$ $ALF_{ACT} = ALF_{RATED} \times \left\|\frac{S_{CTRN} + S_{Rated}}{S_{CTRN} + S_{Actual}}\right\| = 10 \times \left\|\frac{1.25VA + 5\text{VA}}{1.25VA + 1.65VA}\right\| = 21.55$	$ALF_{RATED} = 10$ $S_{Rated} = 5\text{VA}$ $S_{CTRN} = {I_{NS}}^2 \times CT_{RS} = 5^2 A \times 0.09\Omega = 2.25\text{VA}$ $R_{Wire} = (5m \times 1.3) \times 0.00508\frac{\Omega}{\text{m}} = 0.033\Omega$ $S_{Actual} = {I_{NS}}^2 \times (R_{Wire} + R_{Relay}) = 5^2 A \times (0.033\Omega + 0.0005\ \Omega) = 0.838\text{ VA}$ $ALF_{ACT} = ALF_{RATED} \times \left\|\frac{S_{CTRN} + S_{Rated}}{S_{CTRN} + S_{Actual}}\right\| = 10 \times \left\|\frac{2.25VA + 5\text{VA}}{2.25VA + 0.838VA}\right\| = 23.5$

When comparing the corrected CT accuracy limit factors to the estimated maximum through fault currents, we can see that the current will not saturate the CTs. The HV side can repeat the current 21.6 × I_n, while the calculated HV through fault current is at maximum 20.2 × I_n. The same is true for the LV side where the maximum output is 20.2 × I_n when the LV side CT is able to repeat 23.5 × I_n. From this we can expect that through faults will not cause problems with this power transformer and CT combination. It also shows us that the non-biased differential stage can be set to operate sensitively during in-zone faults. If the CTs have the possibility to saturate (that is, the calculated through fault current is bigger than the ALF on either CT side), the setting of the instant stage must be set high enough so that it does not operate on through fault saturation.

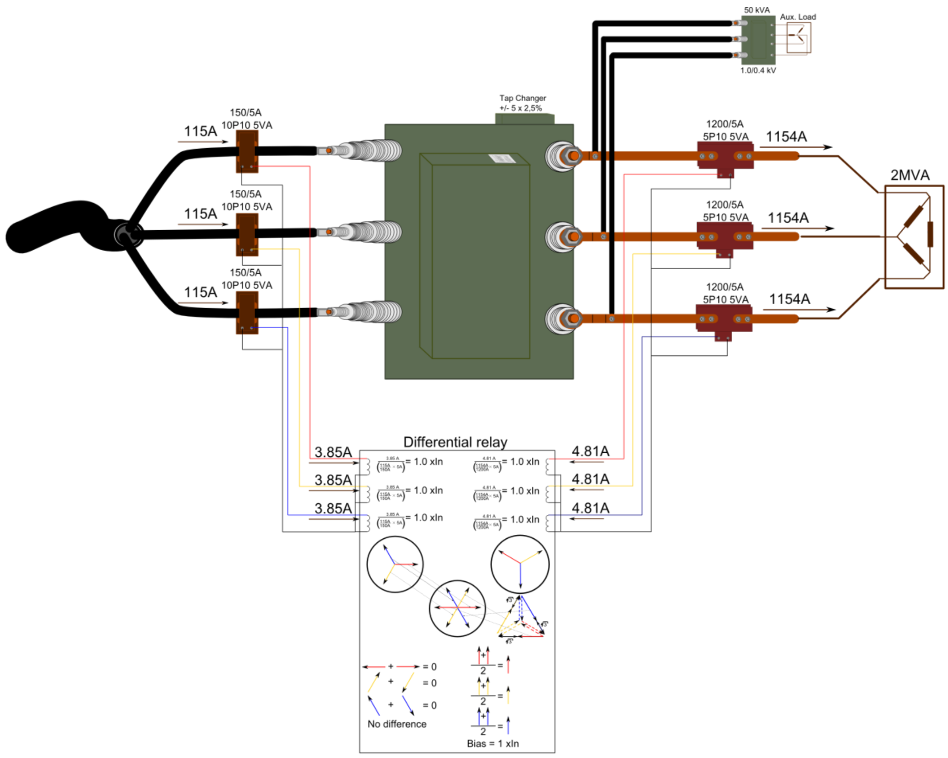
The inrush peak current should also be considered when setting the instant stage. In normal-power transformers the energizing inrush current may be 10 × I_n, while the measured current is FFT-filtered for the fundamental frequency which is used for differential calculation. Typically, the found differential current is half of the maximum peak current. The instant stage should be 5 × I_n if the setting should be according to the theoretical maximum and the margin. Conservative settings should use the 10 × I_n. The setting value should never cause trips for energizing, but still operate fast during energizing fault cases. This stage is usually never blocked in applications, and therefore the stage settings should consider the absolute differential current that is possible in normal operations while keeping the settings sensitive enough for inrush currents (especially in energiszing cases).

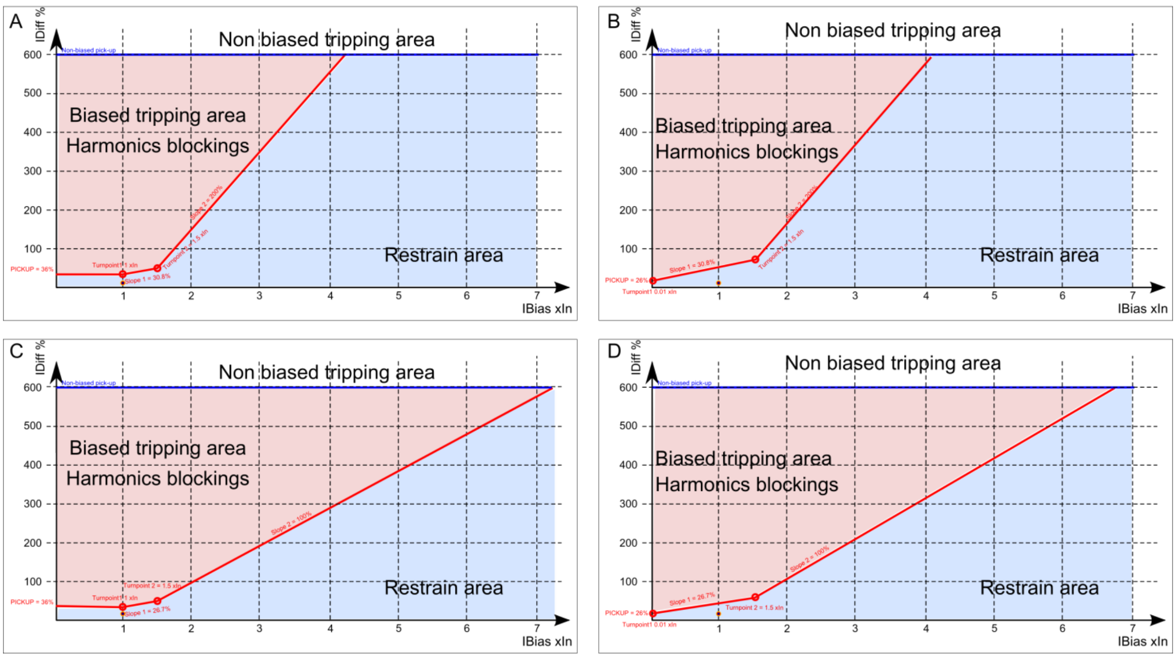
Thus, the setting suggestion for this $I_{di>Pick\text{-}up}$ stage is 6.0 × I_n…10 × I_n for sensitive and conservative operations respectively.

Finalising the settings

Now the basic settings for the differential stages are applied and the differential protection is ready to operate. Our example transformer is very small but the formulas presented in this manual can be applied to transformers of all sizes. If so selected, the relay automatically calculates these settings (using these same formulas) in the Transformer status monitoring (TRF) module. 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 the following example configuration when the example settings and transformer are used.

Figure. 5.4.18. - 97. Example configuration for the transformer differential function.



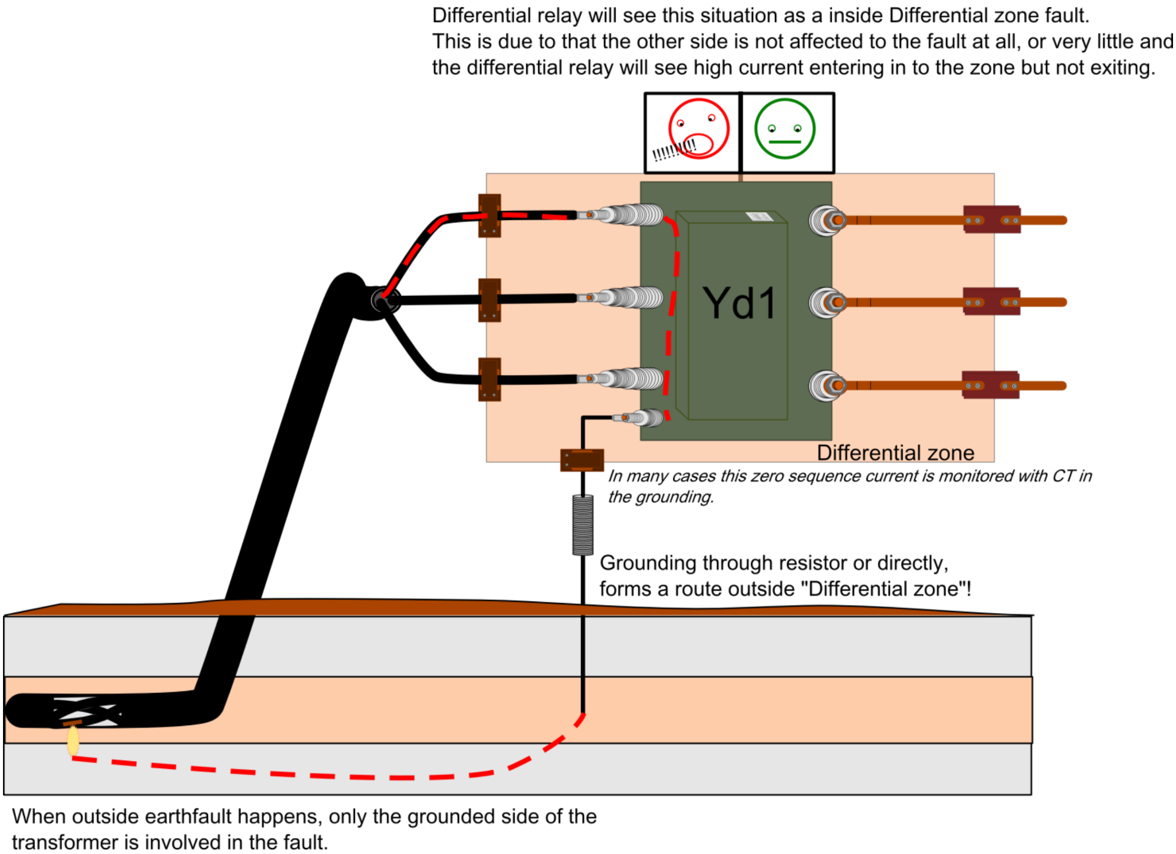


The four characteristics (the image above) present the setting variations based to the Average restraint calculation mode (figures A and B) and the Maximum restraint calculation modes (figures C and D). The characteristics are set to be equally sensitive in each of them. You can also see the variations in Turnpoint 1 settings: in Figures A and C it is set at 1.0 × I_n, whereas in Figures B and D it is set at 0.01 × I_n.

Zero sequence compensation for external earth faults

Our example presented only one type of transformer and its properties. Another very common variation is the type of transformer where the star side (HV, LV, or both) is earthed and thus forms a route outside the differential zone (see the image below).

Figure. 5.4.18. - 98. Transformer earthing settings that do not compensate for external earth faults.



The differential relay looks at this situation and sees a fault inside the differential zone. This is because the other side is not affected at all by the fault (or only very little), and the relay sees a high current entering but not exiting the zone.

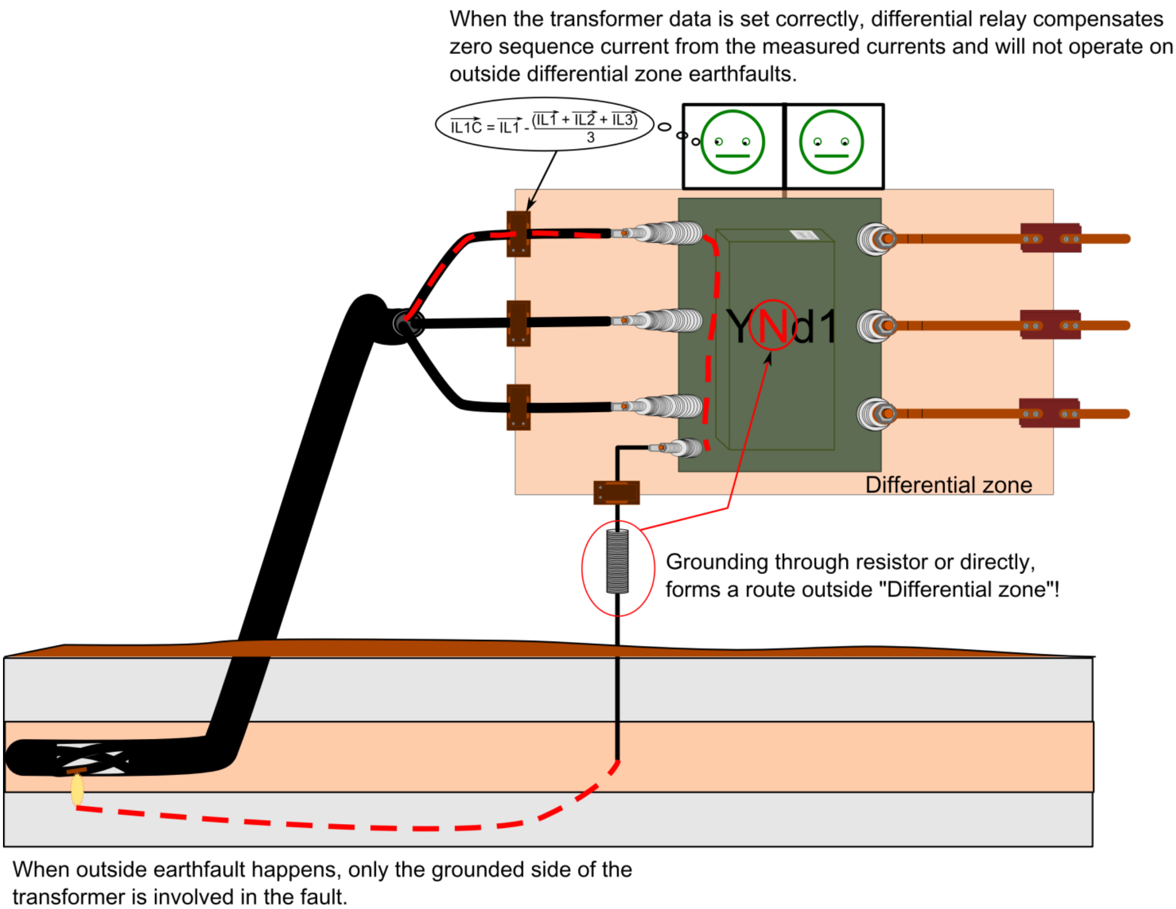
In many cases the zero sequence current is monitored by the CT in the earthing.

Earthing (directly or via a resistor) forms a route outside the differential zone.

When an external earth fault happens, only the earthed side of the transformer is involved in the fault.

The differential earthing requires the earthing to be known: if not compensated, any low-impedance earth fault outside the differential zone causes a differential current and possibly trips the differential protection. This is why the calculated zero sequence compensation is used. The vector group selection has either "N" or "n" to signify either HV side or LV side earthing. The selection then deducts the calculated zero sequence current from the currents (in p.u.) before differential calculation and thus negates the effect of an external earth fault. Correctly selected transformer settings prevent the differential function from being tripped by out-of-zone earth faults (see the image below).

Figure. 5.4.18. - 99. Transformer earthing settings that compensates for external earth faults.



When the transformer settings are correct, the differential relay compensates the zero sequence current and does not trip due to earth faults outside the differential zone.

Earthing (directly or via a resistor) forms a route outside the differential zone.

When an external earth fault happens, only the earthed side of the transformer is involved in the fault.

The "N" or "n" selection applies the correction and eliminates the zero sequence effect with the following formulas:

$$\overrightarrow{IL1}_{Corr} = \overrightarrow{IL1} - \frac{\overrightarrow{IL1} + \overrightarrow{IL2} + \overrightarrow{IL3}}{3}$$

$$\overrightarrow{IL2}_{Corr} = \overrightarrow{IL2} - \frac{\overrightarrow{IL1} + \overrightarrow{IL2} + \overrightarrow{IL3}}{3}$$

$$\overrightarrow{IL3}_{Corr} = \overrightarrow{IL3} - \frac{\overrightarrow{IL1} + \overrightarrow{IL2} + \overrightarrow{IL3}}{3}$$

Note! When you enable the zero sequence compensation by selecting the "N" or "n" in the transformer vector group, the sensitivity to single phase one end fault decreases by a third simultaneously. This is why restricted earth fault protection (I0>, REF) should be enabled for the side where the zero sequence is compensated. However, enabling the REF protection requires that both the phase current measurements and the starpoint current are available and can be connected to the relay's residual current channel on the corresponding (HV/LV) side measurement.

Restricted earth fault

When the transformer's earthed side is compensated with afore-mentioned zero sequence compensation, that side will be a third (appr. 33 %) less sensitive in detecting single-phase faults inside the differential zone. For this reason it is advised that the restricted earth fault (REF) stage is activated on the transformer side that compensates the zero sequence current. Additionally, it should be enabled whenever the Y side of the starpoint is earthed; normal phase differential protection cannot be set to provide the maximum sensitivity to detect single-phase (earth) faults within the differential are because the properties dependant on the transformer and the application that were described in the previous section. This differential stage monitors the incoming calculated residual current and compares it to the outgoing starpoint current. If the single-phase (earth) fault occurs outside the differential zone, this function does not operate; if the fault occurs inside the differential zone, this function operates quickly. This protection's sensitivity to earth faults only within the protection zone is referred to as the "restricted earth fault protection".

The transformer differential functions offers two stages of low-impedance, restricted earth fault protection.

The operating characters of the restricted earth fault function (I0d>) on both the high voltage and the low voltage side are more similar to each other than to the percentage characteristics presented by the Idb> function, even though both sides are independent and can be set freely. The calculation of differential and biasing currents on both sides is as follows (the HV side on the left, the LV side on the right).

$HV_{I0d\_Bias\_AVG} = \frac{\left\|(\overrightarrow{IL1}_{HV} + \overrightarrow{IL2}_{HV} + \overrightarrow{IL3}_{HV}) + \overrightarrow{I0}_{HVMEAS}\right\|}{2}$ $HV_{I0d\_Bias\_MAX} = \max\left((\overrightarrow{IL1}_{HV} + \overrightarrow{IL2}_{HV} + \overrightarrow{IL3}_{HV}), \overrightarrow{I0}_{HVMEAS}\right)$ $HV_{I0d>\_diff\_add} = \left\|(\overrightarrow{IL1}_{HV} + \overrightarrow{IL2}_{HV} + \overrightarrow{IL3}_{HV}) + \overrightarrow{I0}_{HVMEAS}\right\|$ $HV_{I0d>\_diff\_substract} = \left\|(\overrightarrow{IL1}_{HV} + \overrightarrow{IL2}_{HV} + \overrightarrow{IL3}_{HV}) - \overrightarrow{I0}_{HVMEAS}\right\|$	$LV_{I0d\_Bias\_AVG} = \frac{\left\|(\overrightarrow{IL1}_{LV} + \overrightarrow{IL2}_{LV} + \overrightarrow{IL3}_{LV}) + \overrightarrow{I0}_{LVMEAS}\right\|}{2}$ $LV_{I0d\_Bias\_MAX} = \max\left((\overrightarrow{IL1}_{LV} + \overrightarrow{IL2}_{LV} + \overrightarrow{IL3}_{LV}), \overrightarrow{I0}_{LVMEAS}\right)$ $LV_{I0d>\_diff\_add} = \left\|(\overrightarrow{IL1}_{LV} + \overrightarrow{IL2}_{LV} + \overrightarrow{IL3}_{LV}) + \overrightarrow{I0}_{LVMEAS}\right\|$ $LV_{I0d>\_diff\_subtract} = \left\|(\overrightarrow{IL1}_{LV} + \overrightarrow{IL2}_{LV} + \overrightarrow{IL3}_{LV}) - \overrightarrow{I0}_{LVMEAS}\right\|$

Similarly to the phase differential stages, both sides with the restricted earth fault stages have options between the average and the maximum bias current calculation, as well as the option between the add and the subtract current calculation. The use of these stages depends on the CTs' installation directions and the desired sensitivity for bias calculation.

In the transformer differential stage the reference current for the REF protection is always the protected side nominal current, which is calculated in the relay's Transformer status monitoring (TRF) module.

The transformer REF stage (regardless of the side) may be set to be a lot more sensitive than the phase differential. The setting sensitivity should be defined by whether or not one expects CT saturation (transformer's maximum single-phase output compared to the neutral point CT ratings). The tripping characteristics may be set differently when the network is earthed either directly or through impedance, and therefore the fault current may be expected to saturate the CTs even during external faults. For this reason there are three sections also in the REF function characteristics (non-biased, slightly biased, and heavily biased). For high-impedance or close-to-neutral winding faults the first (non-biased) section should consider the CTs' possible measurement errors as well as the desired sensitivity for internal faults close-to-neutral. The Turnpoint 1 setting should be twice the CT's nominal current. Normally the setting calculation is guided by the primary-to-maximum current rating because the CTs' neutral point has a lower primary current rating than the phase current. The first biased section (that is, Slope 1) should consider how a possible saturation in the CTs' neutral point affects normal (external) earth faults, and the how a heavy fault going fully through the second biased section (Slope 2) can cause saturation in the CTs' phase currents.

The recommended base settings:

- Pick-up (base sensitivity): typically 5 % to 10 % of the phase current CT error (Px)
- Turnpoint 1: double the neutral current CT nominal primary to transformer nominal current ratio
- Slope 1: calculate the 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 (typically 5 or 10); if the single-phase overcurrent fault exceeds this value, set Turnpoint 2 to that value
- Slope 2: set the maximum restraint calculation mode to 100 % and the average mode to 200 %.

Blockings from harmonics (2nd and 5th)

In transformer protection harmonics are always present in energizing situations: they are generated by the high current in the transformer inductances when the coils are energized. They are also preent in the currents during overfluxing and overvoltage situations. Energizing situations generate even harmonics: the 2nd harmonic is the most commonly used harmonic in inrush blocking. Overvoltage (and overexcitation) situations generate odd harmonics: the 5th harmonic is mainly used for blocking (the 3rd harmonic is also present in Y windings but absent in delta windings which is why the 5th harmonic has been chosen for overfluxing and excitation detection). In this chapter 'blocking' refers to the Idb> (the biased differential) stage and it has both these blocking (2nd and 5th) applied internally. If the Idi> stage (the non-biased differential) needs to be blocked, external blocking must be used.

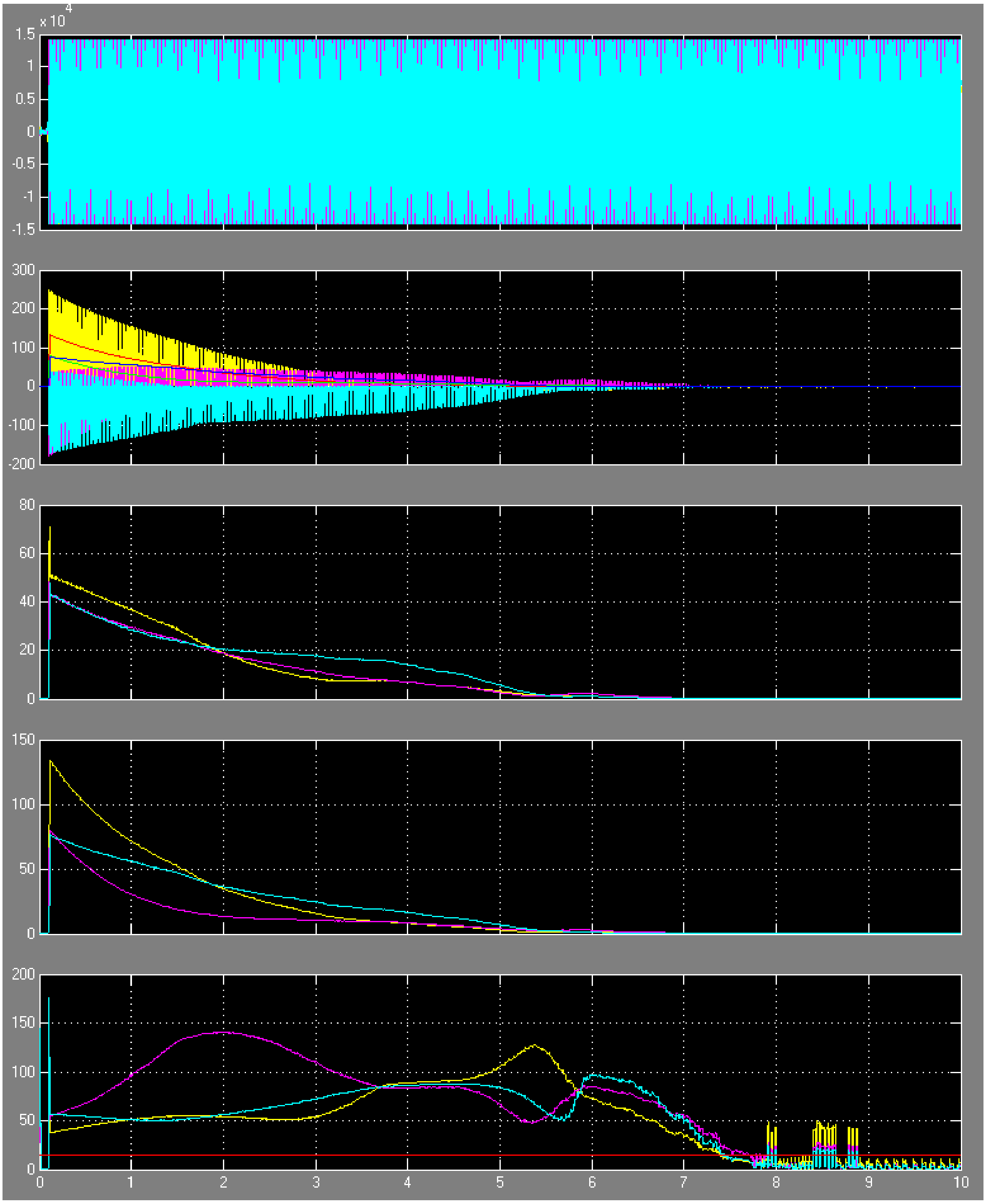
2nd harmonic for magnetizing inrush blocking (principle and usage)

When the primary side of a power transformer is energized (secondary side open), the transformer acts as a simple inductance. During normal operation the flux produced in the transformer core lags behind the fed voltage by 1.58 radians (90 degrees). This means that when the voltage is in zero crossing, the steady state value of the flux is in its negative or positive maximum value. In energizing situations there is no flux available at the instant the winding is energized because there is no (live) magnetic flux linked to the transformer core prior to switching on the supply (however, remanence flux may still exist). The flux reaches its steady state operation some time after energization (depends on the transformer's properties such as its size, its R/X ratio, etc.). In practice this means that the flux in the transformer core starts from zero, as does the voltage in the winding; when energizing the transformer's primary side, the flux ends up 90 degrees behind the winding voltage and the system is in a steady state.

This start-up transition in the transformer has the effect of making the flux value be double the nominal flux value in the first half of the cycle after energization. The transformer core is generally saturated just above the steady state value of the flux and because of this the transformer core is decreasingly saturated during the transition time. During this saturation time the transformer's primary side draws a very high current with a heavy amount of even harmonics (the highest being the 2nd). This current is called the "magnetizing inrush current in transformer". The inrush current can be up to ten times higher than the nominal rated current of a transformer. The energizing characteristics of a transformer depend on the ratings of the transformer as well on the transformer's design (limb constructions, etc.).

The differential relay sees the energization current as a differential current since it only flows through the primary side winding only. The saturation of the transformer core generates the 2nd harmonic component which can be used to block the biased sensitive differential stage during energization.

Figure. 5.4.18. - 100. Energizing behavior of a small transformer.



The figure above presents the energizing behavior of a small transformer. The first graph depicts the applied voltage, the second graph depicts the phase currents' peak and FFT values (as mentioned earlier, the calculated FFT value is about 50% of the peak value), the third graph depicts the 2nd harmonic absolute values (in amperes), the fourth graph depicts the fundamental (50 Hz) FFT-calculated currents (in amperes), and fifth graph depicts the 2nd harmonic components relative to the corresponding fundamental component currents (with the 15 % setting limit).

The magnetizing inrush current in a 2 MVA transformer is over quickly, in about seven seconds. Afterwards there is still the nominal measurable current (seen only in the transformer's primary side) which would cause the differential relay to trip if energized without magnetizing the inrush blocking. Looking at the currents more closely one can see that the input values of the fundamental frequency currents (used for differential calculations) are roughly as follows:

$$IL1peak = 140\ A = 1.2xIn$$

$$IL2peak = 75\ A = 0.65xIn$$

$$IL3peak = 70\ A = 0.60xIn$$

In our previous example the transformer's nominal current on the HV (primary) side was 115.5 A; with it we can count the following:

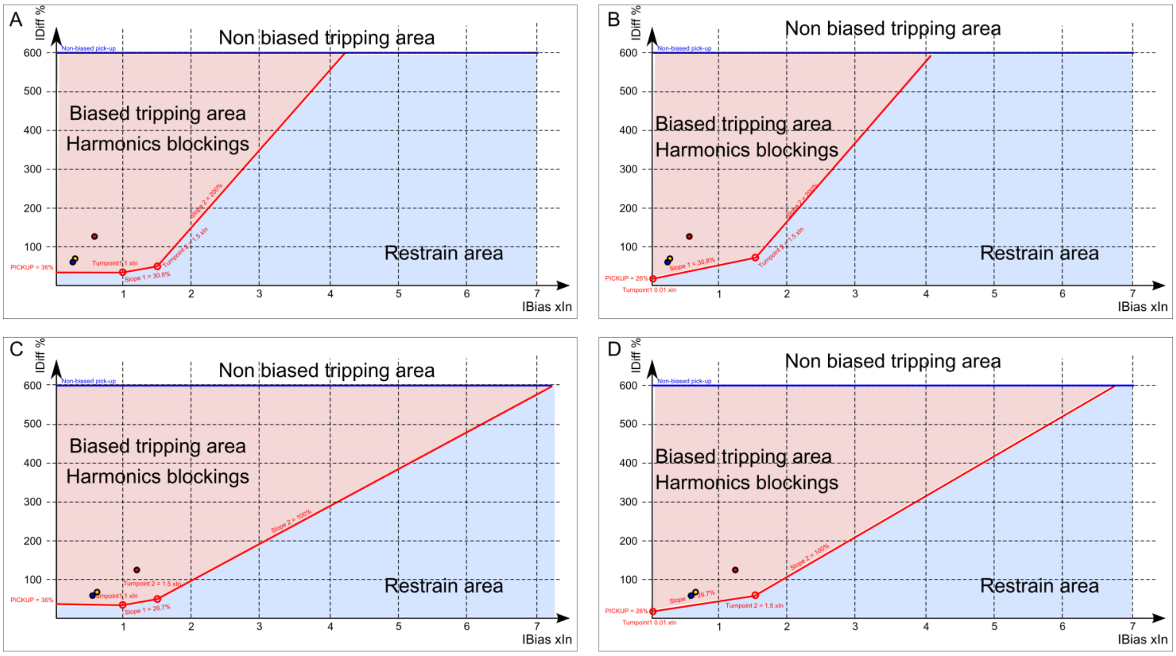
$$IL1_{diff} = 120\%,\ IL1_{biasAVG} = \frac{1.2xIn}{2} = 0.6xIn,\ IL1_{biasMAX} = 1.2xIn$$

$$IL2_{diff} = 65\%,\ IL2_{biasAVG} = \frac{0.65xIn}{2} = 0.33xIn,\ IL2_{biasMAX} = 0.65xIn$$

$$IL3_{diff} = 60\%,\ IL3_{biasAVG} = \frac{0.60xIn}{2} = 0.30xIn,\ IL3_{biasMAX} = 0.60xIn$$

The graph below shows how the differential currents look like when used in the set characteristics.

Figure. 5.4.18. - 101. Differential currents in the energization of a 2 MVA transformer.



While the results are very low compared to the magnetizing inrush current magnitudes, the differential relay would still definitely trip without the 2nd harmonic blocking. The situation is the same with all of the calculted setting variations.

The following figure presents the principle operation of the harmonic blocking in the transformer differential. When the transformer is energized, both the fundamental frequency and the 2nd harmonic increase significantly. In this example the harmonic blocking limit was set to 15 % (the ratio between the 2nd harmonic and the fundamental frequency, all phases), which seems more than sufficient for this transformer. The pick-up in the example is set to 30 %. Now, when the flux in the transformer core starts to catch up, the saturation in the core is reduced and the current for magnetizing is reduced as well. The blocking remains active until the setting is reached after which the blocking is released for each phase separately. With our example transformer the harmonic blocking limit could be set to 30 % and the energizing would still be successful because the 2nd harmonic is still heavily present by the time the fundamental currents are reduced below the differential stage's pick-up limit.

Figure. 5.4.18. - 102. Inrush blocking by using the 2nd harmonic (relative to fundamental frequency).

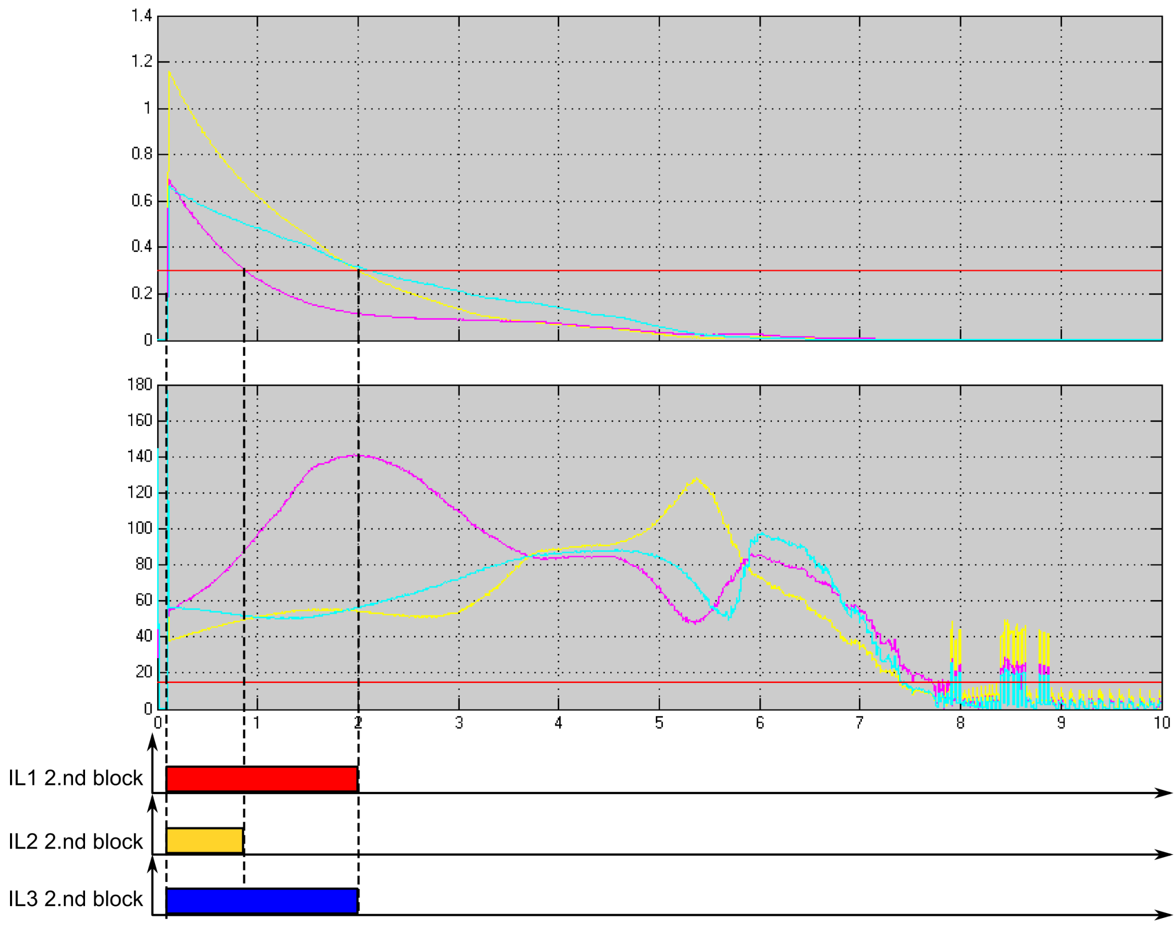
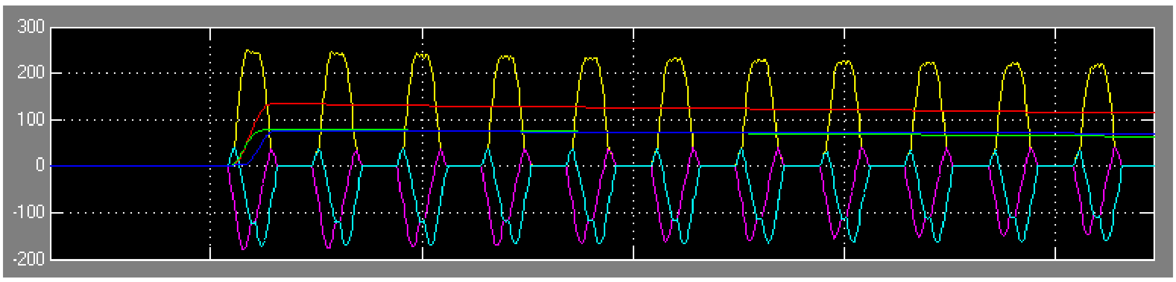


Figure. 5.4.18. - 103. Example of transformer magnetizing inrush currents.



A conservative setting recommendation for standard type transformers:

- enabling the 2nd harmonic blocking
- sensitivity appr. 15...20 %

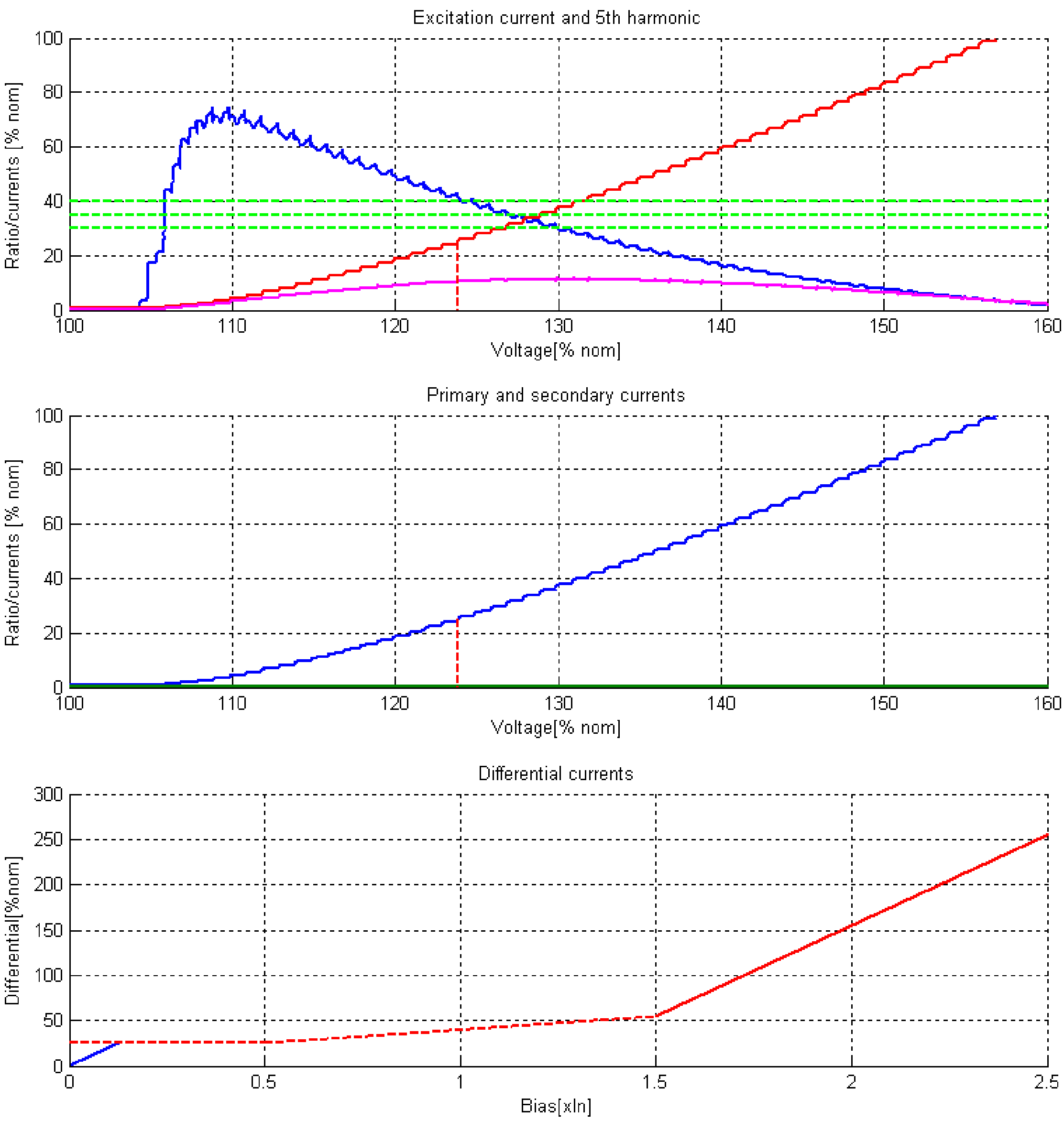
- harmonic content compared to the fundamental frequency.

The user can fine-tune the transformer settings during the commissioning phase if there are any issues with the transformer energization.

5th harmonic for overexcitation blocking (principle and usage)

When the transformer's primary side voltage increases for some reason, the voltage-frequency (V/f) ratio exceeds the desing limits and the transformer overexcited very quickly. This may be caused by two things: a fault in the LV side can throw off the loading and cause a temporary overvoltage, or the frequency in the network decreases for some reason (e.g. overloading or generation drop). The differential relay should not trip in either of these cases even though the overexcitation in the transformer's core result in the primary side measured currents being higher than those on the secondary side.

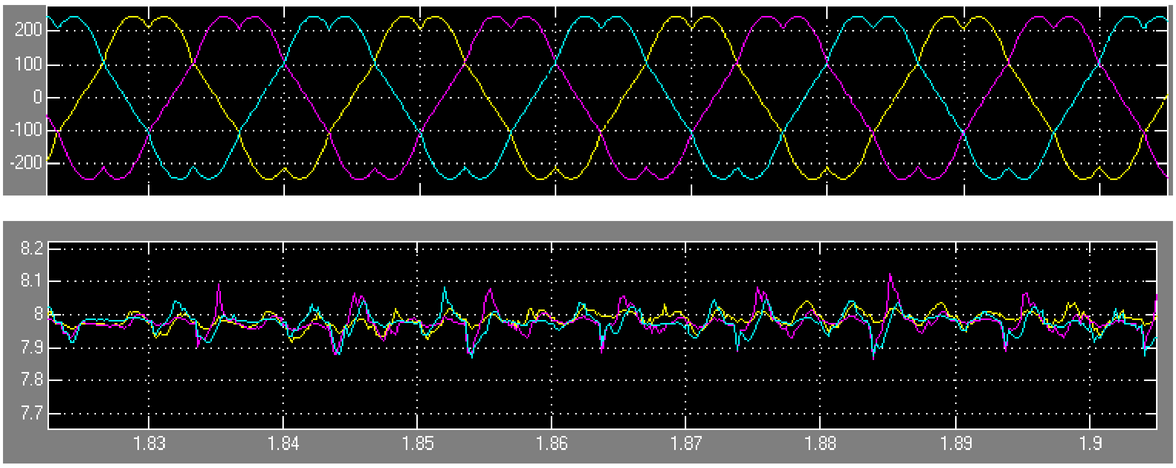
Figure. 5.4.18. - 104. Transformer behavior in case of overvoltage caused by overexcitation.



The figure above presents the simulated behavior of a power transformer when overvoltage occurs. In the simulation the transformer was unloaded on the secondary side while the voltage on the primary side was increased with a ramp. The first graph depicts the excitation current, the 5th harmonic component and their relation (which is used in the blocking); the green lines represents the suggested setting limits for 5th harmonic detection (30 %, 35 %, and 40 %). The second graph depicts the primary and secondary currents, plotted as a function of the voltage. The third graph depicts the differential characteristics and the differential and bias currents.

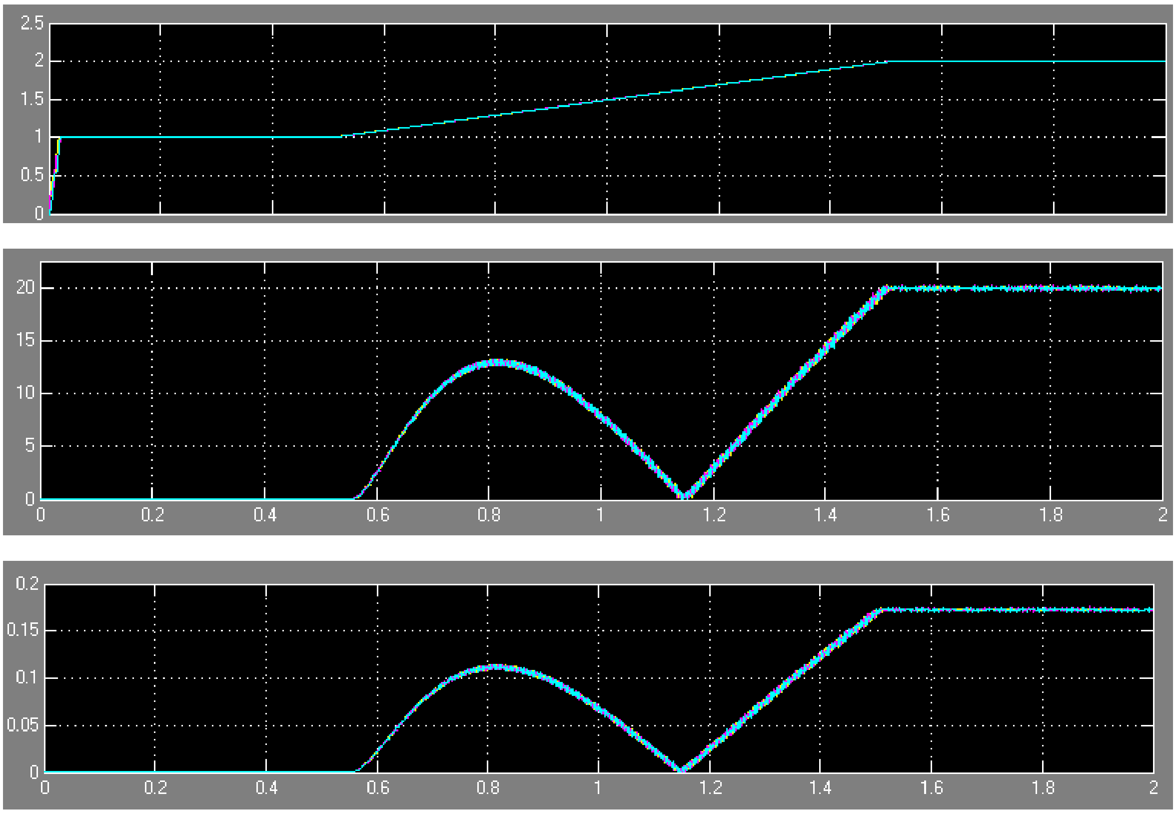
As can be noted from the first graph, the 5th harmonic component begins increasing rapidly (compared to the fundamental) in the start situation when the voltage is about 120 % of the nominal (depends entirely on the transformer properties and its saturation characteristics). This behavior is common to all transformers: when the core starts to be saturated there is a heavy amount of the 5th harmonic in the magnetizing current. When the overvoltage exceeds a certain point in the magnetizing characteristics, the 5th harmonic remains; however, the fundamental component of the current starts to grow very rapidly and as a result the relation of the 5th harmonic to fundamental decreases rapidly as a function of the primary side voltage. The growing magnetizing current is only seen on the transformer's primary side and the differential relay sees it as pure differential current. From the third graph we can see that the differential pick-up setting is reached when the voltage is approximately 125 % of the nominal value. This means that the differential current generated by the overexcitation could trip the transformer, as the ratio between the 5th harmonic and the fundamental magnitude decreases. If the overvoltage were, for example, 130 % of the nominal value, no blocking would be available; even the differential current would be greatly over the setting limit (appr. 40 % vs. the set 25 %). Nevertheless, this behavior can still be considered to be correct for the power transformer because an overvoltage like this can cause many serious problems and therefore tripping is desired.

Figure. 5.4.18. - 105. Example waveforms of transformer running with 200 % rated voltage with corresponding 5th-harmonic-to-fundamental- ratio.



Traditionally, the ratio between the 5th harmonic and the fundamental has been used in blocking the differential relay from tripping in overvoltage and overexcitation situations. However, the ratio is not a reliable method because you need to know the magnetizing properties and the hysteresis values exactly in order to set it correctly and for it to be of any use.

Figure. 5.4.18. - 106. Per unitized system voltage and magnitude of the 5th harmonic component, absolute and scaled to transformer nominal.

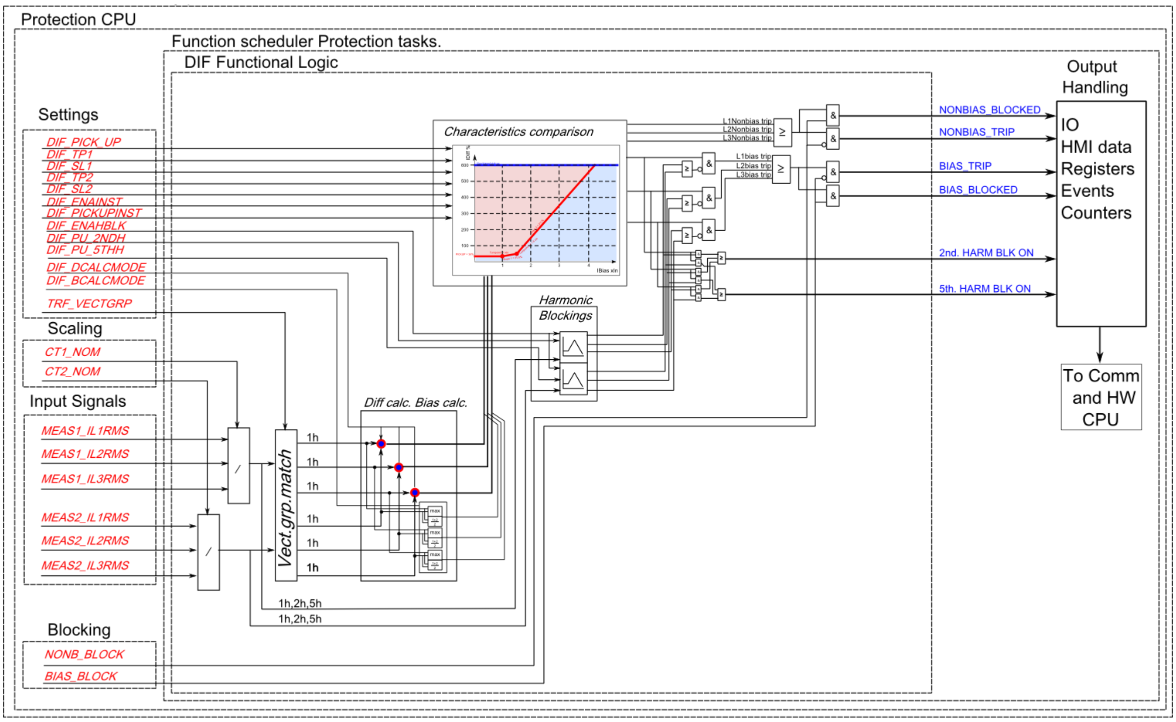


As can be seen in the figure above the 5th harmonic component increases, decreases and then increases again in the function of rising system voltage, in this case about with overvoltage of 160% the 5th harmonic seems to disappear completely. In this kind of behavior the previously mentioned blocking can be used as it automatically blocks on a smaller overvoltage (in case there is any differential current) and releases when the overvoltage is too heavy and the differential current is most probably over the tripping limit.

However, one should note that the behavior of this blocking is very unpredictable if the exact saturation characteristic and the transformer design are not known. If there is a chance that the overexcitation can cause problems (that is, no overvoltage relays are available), this blocking can be enabled with the setting of 30...40 % with the disturbance recorder enabled. If a trip occurs as a result of overexcitation, the settings can be adjusted based on the data captured by the disturbance recorder.

Differential function details

Figure. 5.4.18. - 107. Simplified function block diagram of the transformer differential function.



The transformer differential function outputs TRIP and BLOCKED signals from the biased and non-biased functions as well as the 2nd and 5th harmonic block activation signals. These signals can be used in protection applications.

Settings and signals

The settings of the differential function are a combination of transformer monitor and differential stage function settings. The following table shows the function's settings, including the general settings (in p.u.) used for pre-calculations.

Table. 5.4.18. - 147. Settings related to the differential function's pre-calculation.

Name	Range	Step	Default	Function	Description
Transformer nominal	0.1...500.0 MVA	0.1 MVA	1.0 MVA	All	The nominal MVA of the transformer. This value is used to calculate the nominal currents onf both the HV and the LV side.
HV side nominal voltage	0.1…500.0 kV	0.1 kV	110.0 kV	All	The HV side nominal voltage of the transformer. This value is used to calculate the nominal currents of the HV side.
LV side nominal voltage	0.1…500.0 kV	0.1 kV	110.0 kV	All	The LV side nominal voltage of the transformer. This value is used to calculate the nominal currents of the LV side.
Transformer Zk%	0.01…25.00 %	0.01 %	3.00 %	Info	The transformer's short-circuit impedance in percentages. Used for calculating short-circuit current.
Transformer nom. freq.	10…75 Hz	1 Hz	50 Hz	Info	The transformer's nominal frequency. Used for calculating the transformer's nominal short-circuit inductance.

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	- transformer status monitoring - transformer differential	The selection of the transformer's vector group. The selection values (1–26) are predefined so that the scaling and vector matching are applied in the relay automatically when the correct vector group is selected. The predefinitions assume that the HV side is connected to the CT1 module and that the LV side is connected to the CT2 module. If the protected transformer vector group is not found in the predefined list, it can be manually set by selecting the option "0: Manual set".
HV side Star or Zigzag / Delta	0: Star/Zigzag 1: Delta	-	0: Star/Zigzag	- transformer status monitoring - transformer differential	The selection of the HV side connection. Can be selected between star or zigzag and delta. This selection is visible only if the option "Manual set" is selected for the vector group setting.
HV side grounded	0: Not grounded 1: Grounded	-	0: Not grounded	- transformer status monitoring - transformer differential	The selection of whether or not the zero sequence compensation is applied in the HV side current calculation. The selection is visible only if the option "Manual set" is selected for the vector group setting.
HV side lead or lag LV	0: Lead 1: Lag	-	0: Lead	- transformer status monitoring - transformer differential	The selection of whether the HV side leads or lags the LV side. The selection is visible only if the option "Manual set" is selected for the vector group setting.
LV side Star/Zigzag or Delta	0: Star/Zigzag 1: Delta	-	0: Star/Zigzag	- transformer status monitoring - transformer differential	The selection of the LV side connection. Can be selected between star or zigzag and delta. This selection is visible only if the option "Manual set" is selected for the vector group setting.
LV side grounded	0: Not grounded 1: Grounded	-	0: Not grounded	- transformer status monitoring - transformer differential	The selection of whether or not the zero sequence compensation is applied in the LV side current calculation. The selection is visible only if the option "Manual set" is selected for the vector group setting.
LV side lead or lag HV	0: Lead 1: Lag	-	0: Lead	- transformer status monitoring - transformer differential	The selection of whether the LV side leads or lags the HV side. The selection is visible only if the option "Manual set" is selected for the vector group setting.
HV-LV side phase angle	0.0...360.00 deg	0.1 deg	0.0 deg	- transformer status monitoring - transformer differential	The angle correction factor for HV/LV sides, looked from the HV side. E.g. if the transformer is Dy1, this is set to 30 degrees. The selection is visible only if the option "Manual set" is selected for the vector group setting.
HV-LV side mag correction	0.0...100.0 × I_n	0.1 × I_n	0.0 × I_n	- transformer status monitoring - transformer differential	The magnitude correction for the HV-LV side currents (in p.u.), if the currents are not directly matched through the calculations of the nominal values. The selection is visible only if the option "Manual set" for the vector group setting.

Check online HV-LV configuration	0: - 1: Check	-	0: -	- transformer status monitoring - transformer differential	The selection of whether or not the function checks online the energized trafo the configuration success. For this to work, the transformer needs to have a current flowing on both sides and "see" no faults. The selection is visible only if the option "Manual set" is selected for the vector group setting.
Enable I0d> (REF) HV side	0: Disabled 1: Enabled	-	0: Disabled	- transformer status monitoring - transformer differential	The selection of whether the restricted earth fault stage on the HV side is enabled or disabled.
HV side starpoint meas.	0: IO1 1: IO2	-	0: IO1	- transformer status monitoring - transformer differential	The selection of the starpoint measurement channel for the restricted earth fault protection on the HV side. This setting is only visible if the option "Enabled" is selected for the "Enable I0d> (REF) HV side" setting.
Enable I0d> (REF) LV side	0: Disabled 1: Enabled	-	0: Disabled	- transformer status monitoring - transformer differential	The selection of whether the restricted earth fault stage on the LV side is enabled or disabled.
LV side starpint meas.	0: IO1 1: IO2	-	0: IO1	- transformer status monitoring - transformer differential	The selection of the starpoint measurement channel for the restricted earth fault protection on the LV side. This setting is only visible if the option "Enabled" is selected for the "Enable I0d> (REF) LV side" setting.

Table. 5.4.18. - 148. Settings for the operating characteristics.

Name	Range	Step	Default	Description
Differential calculation mode	0: Add 1: Subtract	-	1: Subtract	The calculation mode of the differential current. The mode selection depends on the CTs' installation direction and the desired current directions. If the current flow on both sides is in the same direction, the differential current is subtracted. If the current flows are in the opposite directions, the differential current is added.
Bias calculation mode	0: Average 1: Maximum	-	0: Average	The calculation mode of the biasing current. With the average mode the operation may be set to be more sensitive. With the maximum mode the bias is always higher and thus provides a more stable operation.
Idb> Pick-up	0.01…100.00 %	0.01 %	10.00 %	The base sensitivity for the differential characteristics.
Turnpoint 1	0.01…50.00 × I_n	0.01 × I_n	1.00 × I_n	Turnpoint 1 for the differential characteristics.
Slope 1	0.01…250.00 %	0.01 %	10.00 %	Slope 1 for the differential characteristics.
Turnpoint 2	0.01…50.00 × I_n	0.01 × I_n	3.00 × I_n	Turnpoint 2 for the differential characteristics.
Slope 2	0.01…250.00 %	0.01 %	200.00 %	Slope 2 of the differential characteristics-
Enable harmonic blocking	0: No harmonic blocking 1: 2nd harmonic blocking 2: 5th harmonic blocking 3: 2nd and 5th harmonic blocking	-	1: 2nd harmonic blocking	The selection of the internal blockings to be used for the detection of transformer normal operations that cause differential currents.

2nd harmonic blocking pick-up	0.01…50.00 %	0.01 %	15.00 %	The pick-up detection for the 2nd harmonic blocking stage. This setting is only visible if the "Enable harmonic blocking" setting is set to "1" or "3".
5th harmonic blocking pick-up	0.01…50.00 %	0.01 %	35.00 %	The pick-up detection for the 5th harmonic blocking stage. This setting is only visible if the "Enable harmonic blocking" setting is set to "2" or "3".
Enable Idi> stage	0: Disabled 1: Enabled	-	1: Enabled	The selection of whether the non-biased and the non-blocked differential stage is enabled or disabled.
Idi> Non-biased pick-up	200.00…1500.00 %	0.01 %	600.00 %	The pick-up setting for the non-biased and non-blocked differential stage. This setting is only visible if the "Enable Idi> stage" is disabled.
HV I0d> Pick-up	0.01…100.00 %	0.01 %	10.00 %	The base sensitivity for the HV side restricted earth fault differential characteristics. This setting is only visible if the "Enable I0d> (REF) HV side" setting is enabled.
HV I0d> Turnpoint 1	0.01…50.00 × I_n	0.01 × I_n	1.00 × I_n	Turnpoint 1 for the HV side restricted earth fault differential characteristics. This setting is only visible if the "Enable I0d> (REF) HV side" setting is enabled.
HV I0d> Slope 1	0.01…250.00 %	0.01 %	10.00 %	Slope 1 of the HV side restricted earth fault differential characteristics. This setting is only visible if the "Enable I0d> (REF) HV side" setting is enabled.
HV I0d> Turnpoint 2	0.01…50.00 × I_n	0.01 × I_n	3.00 × I_n	Turnpoint 2 for the HV side restricted earth fault differential characteristics. This setting is only visible if the "Enable I0d> (REF) HV side" setting is enabled.
HV I0d> Slope 2	0.01…250.00 %	0.01 %	200.00 %	Slope 2 of the HV side restricted earth fault differential characteristics. This setting is only visible if the "Enable I0d> (REF) HV side" setting is enabled.
LV I0d> Pick-up	0.01…100.00 %	0.01 %	10.00 %	The base sensitivity for the LV side restricted earth fault differential characteristics. This setting is only visible if the "Enable I0d> (REF) LV side" setting is enabled.
LV I0d> Turnpoint 1	0.01…50.00 × I_n	0.01 × I_n	1.00 × I_n	Turnpoint 1 for the LV side restricted earth fault differential characteristics. This setting is only visible if the "Enable I0d> (REF) LV side" setting is enabled.
LV I0d> Slope 1	0.01…250.00 %	0.01 %	10.00 %	Slope 1 of the LV side restricted earth fault differential characteristics. This setting is only visible if the "Enable I0d> (REF) LV side" setting is enabled.
LV I0d> Turnpoint2	0.01…50.00 × I_n	0.01 × I_n	3.00 × I_n	Turnpoint 2 for the LV side restricted earth fault differential characteristics. This setting is only visible if the "Enable I0d> (REF) LV side" setting is enabled.
LV I0d> Slope 2	0.01…250.00 %	0.01 %	200.00 %	Slope 2 of the LV side restricted earth fault differential characteristics. This setting is only visible if the "Enable I0d> (REF) LV side" setting is enabled.

Table. 5.4.18. - 149. Calculations of the transformer differential function.

Name	Description
L1Bias	The calculated phase L1 bias current
L2Bias	The calculated phase L2 bias current
L3Bias	The calculated phase L3 bias current
L1Diff	The calculated phase L1 differential current
L2Diff	The calculated phase L2 differential current
L3Diff	The calculated phase L3 differential current
L1Char	The calculated phase L1 maximum differential current allowed with current bias level
L2Char	The calculated phase L1 maximum differential current allowed with current bias level
L3Char	The calculated phase L1 maximum differential current allowed with current bias level

HV I0d> Bias current	The calculated HV side restricted earth fault bias current
HV I0d> Diff current	The calculated HV side restricted earth fault differential current
HV I0d> Char current	The calculated HV side restricted earth fault differential current allowed with current bias level
LV I0d> Bias current	The calculated LV side restricted earth fault bias current
LV I0d> Diff current	The calculated LV side restricted earth fault differential current
LV I0d> Char current	The calculated LV side restricted earth fault differential current allowed with current bias level

Table. 5.4.18. - 150. Output signals of the transformer differential function.

Name	Description
Idb> Bias Trip	The TRIP output signal from the biased differential stage
Idi> Nobias Trip	The TRIP output signal from the non-biased and non-blocked differential stage
Idb> Bias Blocked	The BLOCKED output from the biased differential stage (external blocking)
Idi> Bias Blocked	The BLOCKED output from the non-biased and non-blocked differential stage (external blocking)
Idb> 2^{nd} harm block on	The output of the 2^{nd} harmonic activation signal
Idb> 5^{th} harm block on	The output of the 5^{th} harmonic activation signal
HV I0d> Trip	The TRIP output signal from the biased restricted earth fault differential stage on the HV side
HV I0d> Trip	The BLOCKED output signal from the biased restricted earth fault differential stage on the HV side
LV I0d> Trip	The TRIP output signal from the biased restricted earth fault differential stage on the LV side
LV I0d> Trip	The BLOCKED output signal from the biased restricted earth fault differential stage on the LV side

Events and registers

The transformer differential function (abbreviated "DIF" in event block names) generates events from internal status changes. The data register is available, based on the changes in the tripping events.

Table. 5.4.18. - 151. Event codes.

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} harmonic ON
4557	71	DIF1	13	L1 2^{nd} harmonic OFF

4558	71	DIF1	14	L2 2nd harmonic ON
4559	71	DIF1	15	L2 2nd harmonic OFF
4560	71	DIF1	16	L3 2nd harmonic ON
4561	71	DIF1	17	L3 2nd harmonic OFF
4562	71	DIF1	18	L1 5th harmonic ON
4563	71	DIF1	19	L1 5th harmonic OFF
4564	71	DIF1	20	L2 5th harmonic ON
4565	71	DIF1	21	L2 5th harmonic OFF
4566	71	DIF1	22	L3 5th harmonic ON
4567	71	DIF1	23	L3 5th harmonic 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

The function registers its operation into the last twelve (12) time-stamped registers. The table below presents the structure of the function's register content.

Table. 5.4.18. - 152. Register content.

Name	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event code	4544-4575 Descr.
L1 bias current	Registered L1 bias current
L1 diff. current	Registered L1 maximum differential current
L1 char. current	Registered L1 maximum differential current with bias
L2 bias current	Registered L2 bias current
L2 diff. current	Registered L2 maximum differential current
L2 char. current	Registered L2 maximum differential current with bias
L3 bias current	Registered L3 bias current
L3 diff. current	Registered L3 maximum differential current
L3 char. current	Registered L3 maximum differential current with bias
HV I0d> bias current	Registered HV side REF bias current
HV I0d> differential current	Registered HV side REF differential current
HV I0d> characteristics current	Registered HV side REF maximum differential current with bias
LV I0d> bias current	Registered LV side REF bias current
LV I0d> differential current	Registered LV side REF differential current
LV I0d> characteristics current	Registered LV side REF maximum differential current with bias

Used SG	Setting group in use
Ftype	Detected fault type (faulty phases)

5.4.19. Voltage memory function

Certain protection functions (such as impedance or directional overcurrent) use the relay's measured current and voltage to determine whether the electrical network fault appears to be inside the protected area. The determination is made by comparing the angle between the operating quantity (zone/trip area) to the actual measured quantity. The function produces an output when the required terms are met.

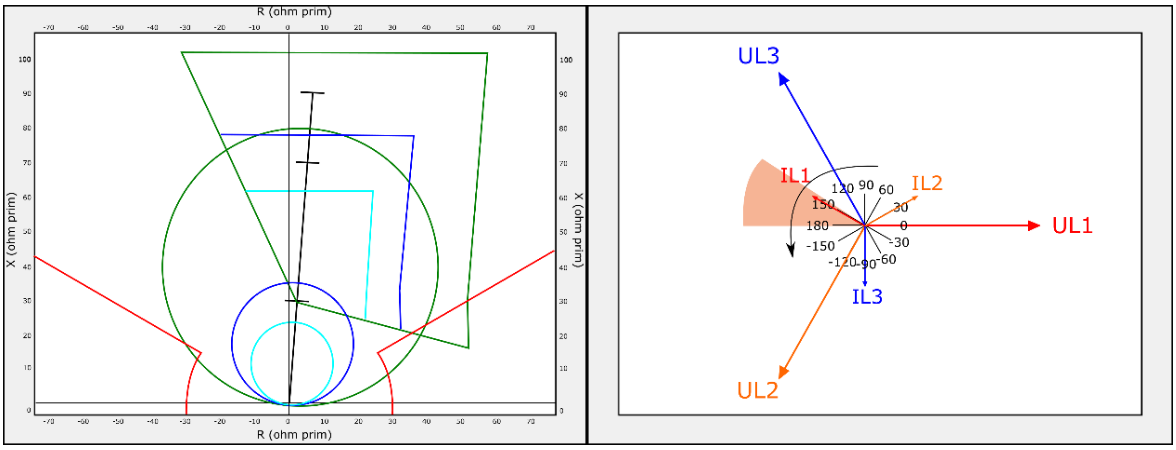
In close-in faults the system voltage on the secondary side may fall down to a few volts or close to nothing. In such cases, when the measured voltage is absent, the fault direction cannot be solved. As backup, non-directional protection can be used for tripping, but in such cases the selectivity of the network will reduce. However, an angle memory for voltage can be used to prevent this from happening. An adjustable voltage level with pre-fault voltage angles can be used as a reference for fault direction and/or distance. The reference can be set manually for duration. Thanks to the configurable voltage memory even time-delayed backup tripping can be initiated.

The user can activate voltage memory (and find all related settings) by following this path in relay settings: *Measurement → Transformers → VT Module (3U/4U) 1 → Voltage memory* ("Activated"/"Disabled").

The activation of voltage memory depends of following criteria:

1. All used line-to-line or line-to-neutral voltages need to be below the set value for the "VMEM activation voltage" parameter.
2. At least one phase current must be above the set value for the "Measured current condition 3I>" parameter. This setting limit is <u>optional</u>.

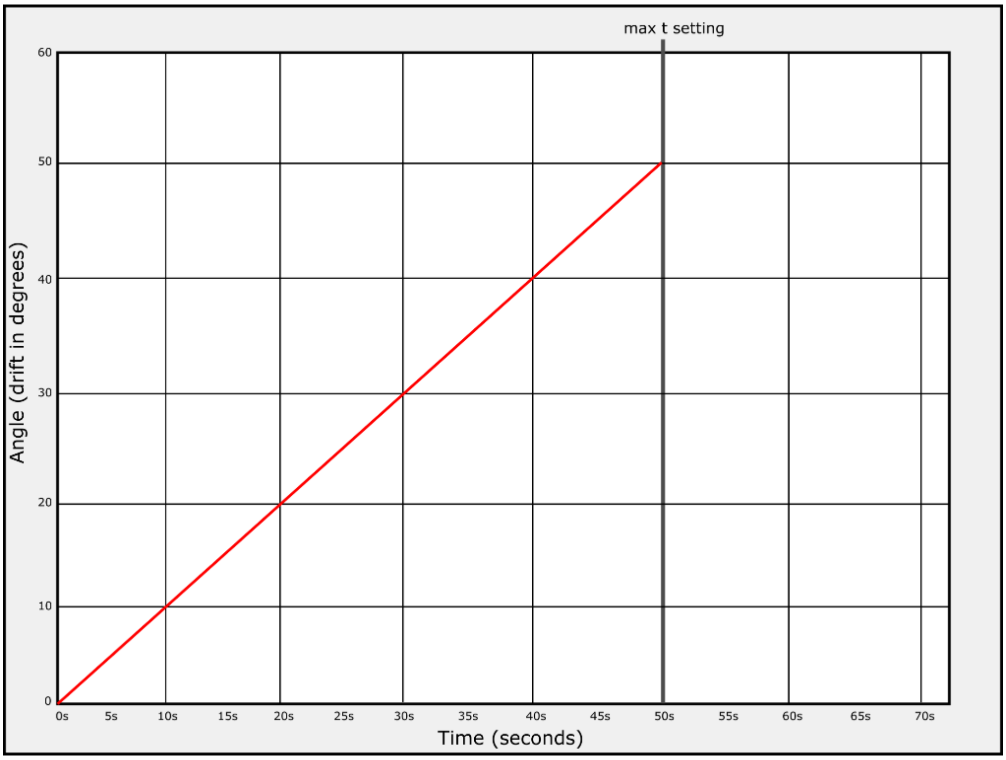
Figure. 5.4.19. - 108. Distance protection characteristics and directional overcurrent.



Voltage memory activates when the above-mentioned criteria are met. Voltage memory uses the "VMEM activation voltage" parameter as voltage amplitude even when the actual measured voltage has decreased below it or close to zero. The angle used by this function is the one captured the moment before the fault occurred and voltage memory was activated. When voltage memory is activate, the output "Voltage memory on" signal is activated. This signal can be found in the device's I/O matrix.

While voltage memory is active, voltages are absent and therefore angle measurement is not possible. Healthy state angles (before a fault) are used during a fault. This is why a drift between the assumed voltage angle and the actual measured phase current angle takes place. While voltage memory is used, the angle of phase currents drifts approximately one degree for each passing second (see the graph below).

Figure. 5.4.19. - 109. Voltage angle drift.



The blocking signal for voltage memory can be found among other stage-related settings in the tab *VT Module (3U/4U) 1*. The blocking signal is checked in the beginning of each program cycle.

Measured input

The function block uses analog voltage and current measurements' fundamental frequency RMS values.

Table. 5.4.19. - 153. Measurement inputs of the voltage 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 modes 3LN and 3LL use three voltage inputs: channels U_A, U_B and U_C. When the voltage mode is set to 2LL, only two channels (U_A and U_B) are in use, and the memory is based on the line-to-line voltages U_{12} and U_{32}. When the mode 2LL+U0 is used, the memory is based on calculated phase-to-neutral voltages.

Pick-up

VMEM activation voltage and **Measured current condition 3I>**

When the voltage memory function is enabled, it activates when all line voltages drop below the "VMEM activation voltage" threshold limit. This limit can be set to be anything between 2...50 V AC. When "Measured current condition 3I>" is used, activation cannot be based on just the voltage. Therefore, at least one of the three-phase currents must also rise above the set current pick-up setting.

VMEM max active time

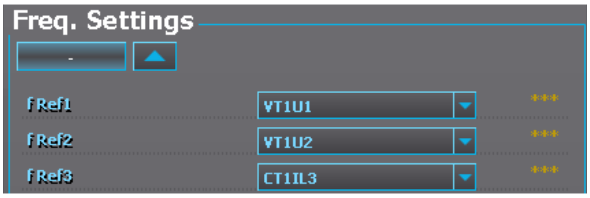
Voltage memory can be active for a specific period of time, set in "VMAX active time". It can be anything between 0.02...50.00 seconds. The function supports the definite time (DT) delay type. It depends on the application for how long the memory should be used. During massive bolted faults, the fault should be cleared and the breaker opened as soon as possible; therefore, a short operating time for voltage memory is usually applied. A typical delay for voltage memory is between 0.5...1.0 s. When the operating time passes and voltage memory is no longer used, directional overcurrent and/or distance protection goes to the unidirectional mode to secure a safe tripping. The memory uses longer operating times when a backup protection is applied (e.g. in distance-protection zones are farther away).

Forced CT f tracking on VMEM

While fixed frequency tracking is used, all protection stage-based sampling (apart from frequency protection) is based on a set fixed frequency such as 50 Hz or 60 Hz. When the frequency drops massively during a fault while angle memory is in use, it is also possible that the frequency of the system starts to fluctuate. In such cases, if current sampling of used protection stages is based on 50/60 Hz, there could be an error in current magnitude and in angle measurement. To minimize these errors, it is recommended that the frequency is measured and protection-based sampling from the current is performed while voltages are gone.

When the "Forced CT f tracking" parameter is activated and voltages are gone, the frequency from the selected current-based reference channel 3 (the current from IL3) is used for current sampling. This eliminates any possible measurement errors in the fixed frequency mode.

Figure. 5.4.19. - 110. Frequency reference channels.



For example, let us say a 500 A current is measured on the primary side while the fixed frequency is set to 50 Hz. This results in the frequency dropping to 46 Hz, while the actual current measurement would be 460 A. Therefore, the system would have an error of 40 A.

Events

The voltage memory function (abbreviated "M1VT" in event block names) generates events from the status changes in various activities. The user can select the status ON or OFF for messages in the main event buffer.

Table. 5.4.19. - 154. Event codes.

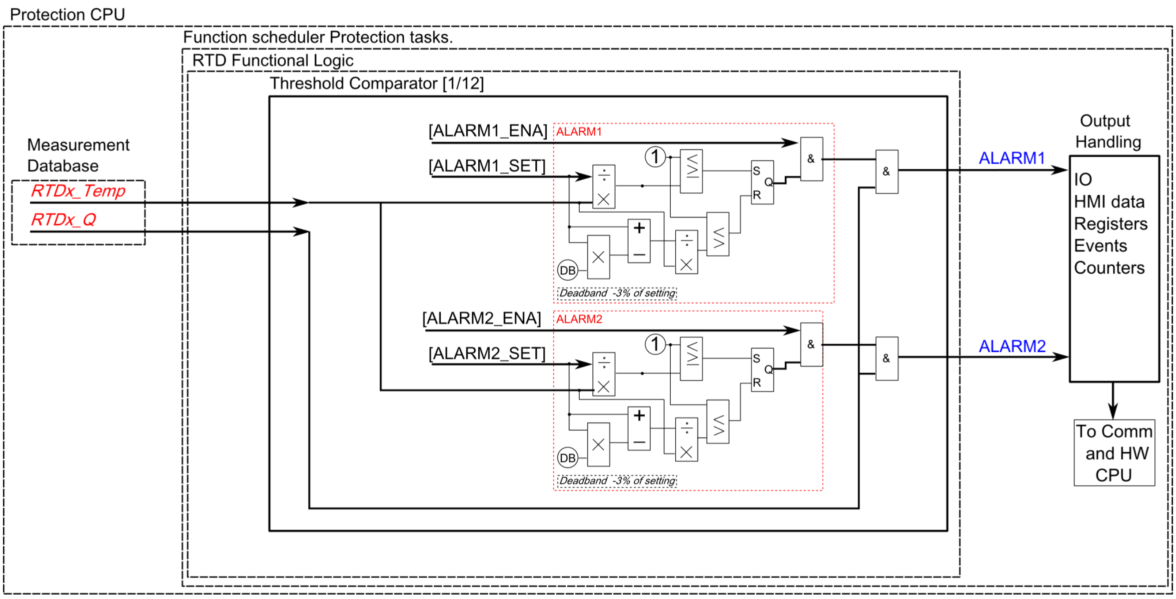
Event number	Event channel	Event block name	Event code	Description
12160	190	M1VT1	0	Voltage memory enabled
12161	190	M1VT1	1	Voltage memory disabled
12162	190	M1VT1	2	Voltage low detected ON
12163	190	M1VT1	3	Voltage low detected OFF

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

5.4.20. Resistance temperature detectors (Modbus IO) (49T)

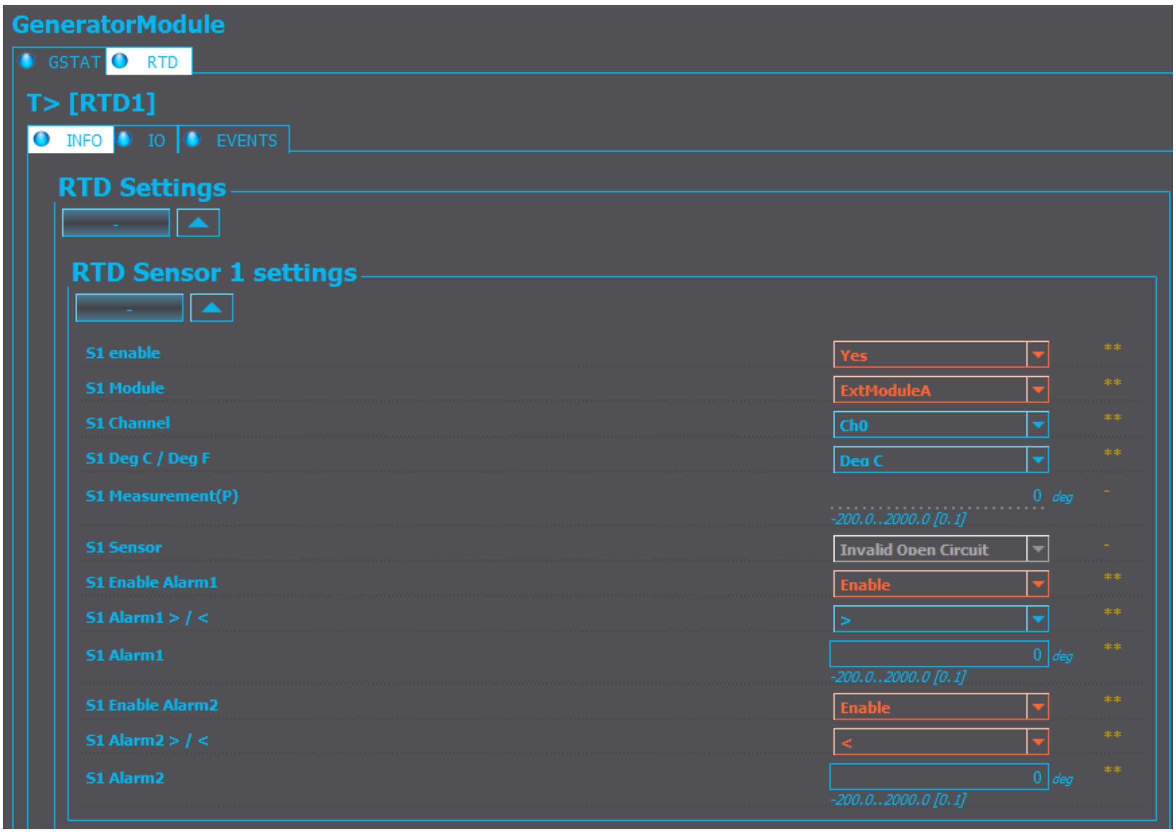
Resistance temperature detectors (or RTDs) can be used to measure both motor temperatures and ambient temperatures. Typically an RTD is a thermocouple or of type PT100. Up to three (3) separate RTD modules based on an external Modbus are supported; each can hold up to eight (8) measurement elements. Twelve (12) individual element monitors can be set for this alarm function, and each of those can be set to alarm two (2) separate alarms from one selected input. The user can set alarms and measurements to be either in degrees Celsius or Fahrenheit.

The following figure shows the principal structure of the resistance temperature detection function.



Setting up an RTD measurement, the user first needs to set the measurement module to scan the wanted RTD elements. A multitude of Modbus-based modules are supported. Communication requires bitrate, datbits, parity, stopbits and Modbus I/O protocol to be set; this is done at *Communication → Connections*. Once communicaion is set, the wanted channels are selected at *Communication → Protocols → ModbusIO*. Then the user selects the measurement module from the three (3) available modules (A, B and C), as well as the poll address. Additionally, both the module type and the polled channels need to be set. When using a thermocouple module, the thermo element type also needs to be set for each of the measurement channels. Once these settings are done the RTDs are ready for other functions.

Figure. 5.4.20. - 111. RTD alarm setup.



When in the motor module, the function can be set to monitor the measurement data from previously set RTD channels. A single channel can be set to have several alarms if the user sets the channel to multiple sensor inputs. In each sensor setting the user can select the monitored module and channel, as well as the monitoring and alarm setting units (°C or °F). The alarms can be enabled, given a setting value (in degrees), and be set to trigger either above or below the setting value. There are twelve (12) available sensor inputs in the function. An active alarm requires a valid channel measurement. It can be invalid if communication is not working or if a sensor is broken.

Settings

Table. 5.4.20. - 155. Function settings for Channel x (Sx).

Name	Range	Step	Default	Description
Sx enable	0: No 1: Yes	-	0: No	Enables/disables the selection of sensor measurements and alarms.
Sx module	0: Module A 1: Module B 2: Module C	-	0: Module A	Selects the measurement module.

Sx channel	0: Channel 0 1: Channel 1 3: Channel 2 4: Channel 3 5: Channel 4 6: Channel 5 7: Channel 6 8: Channel 7	-	0: Channel 0	Selects the measurement channel in the selected module.
Sx Deg C/Dec F	0: Deg C 1: Deg F	-	0: Deg C	Selects the measurement temperature scale (Celsius or Fahrenheit).
Sx Measurement	-	-	-	Displays the measurement value in the selected temperature scale.
Sx sensor	0: Ok 1: Invalid	-	-	Displays the measured sensor's 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	Enables/disables the selection of Alarm 1 for the measurement channel x.
Sx Alarm1 >/<	0: > 1: <	-	0: >	Selects whether the measurement is above or below the setting value.
Sx Alarm1	-101.0…2000.0 deg	0.1 deg	0.0 deg	Sets the value for Alarm 1. The alarm is activated if the measurement goes above or below this setting mode (depends on the selected mode in "Sx Alarm1 >/<").
Sx sensor	0: Ok 1: Invalid	-	-	Displays the measured sensor's 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	Enables/disables the selection of Alarm 2 for the measurement channel x.
Sx Alarm2 >/<	0: > 1: <	-	0: >	Selects whether the measurement is above or below the setting value.
Sx Alarm2	-101.0…2000.0 deg	0.1 deg	0.0 deg	Sets the value for Alarm 2. The alarm is activated if the measurement goes above or below this setting mode (depends on the selected mode in "Sx Alarm2 >/<").

When the RTDs have been set, the values can be read to SCADA (or some other control system). The alarms can also be used for direct output control as well as in logics.

Events

The resistance temperature detector function (abbreviated "RTD" in event block names) generates events and registers from the status changes in ALARM and MEAS INVALID. The user can select the status ON or OFF for messages in the main event buffer. The function offers sixteen (16) independent stages; the events are segregated for each stage operation.

The triggering event of the function (ALARM, MEAS INVALID) is recorded with a time stamp and with process data values. The function registers its operation into the last twelve (12) time-stamped registers.

Table. 5.4.20. - 156. Event codes.

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

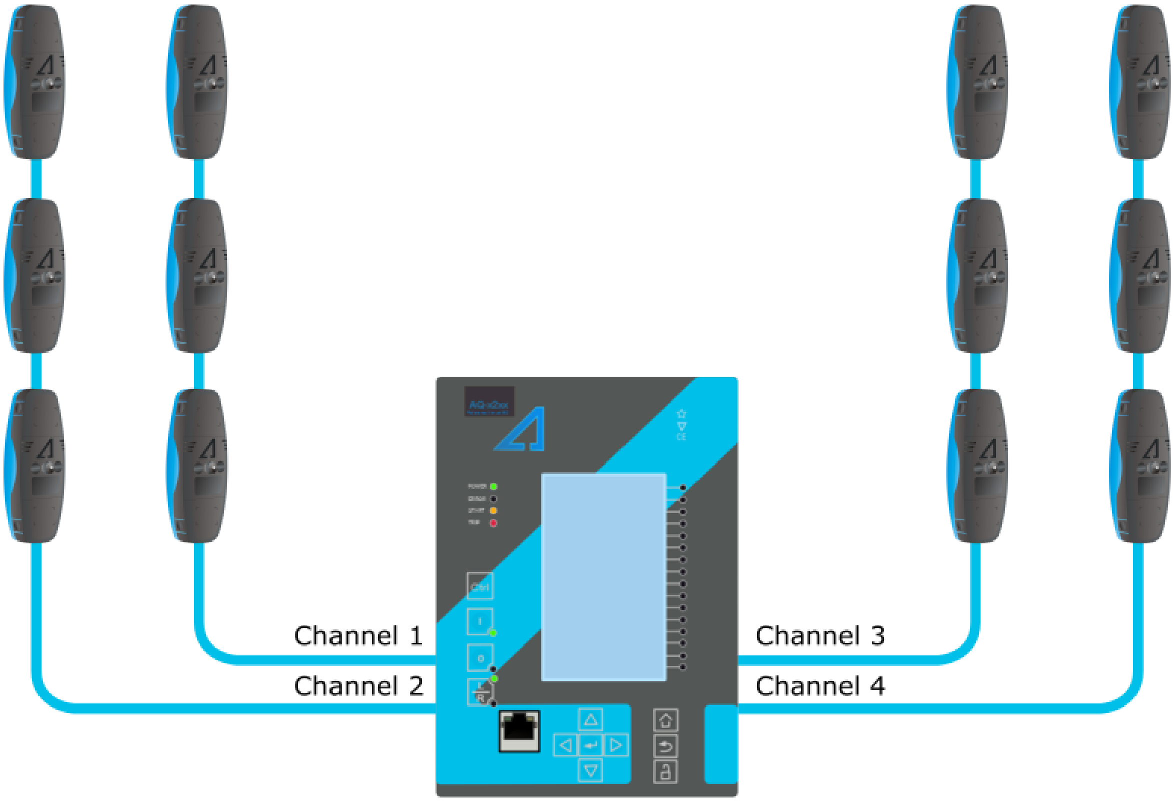
4454	69	RTD1	38	S10 Alarm2 ON
4455	69	RTD1	39	S10 Alarm2 OFF
4456	69	RTD1	40	S11 Alarm1 ON
4457	69	RTD1	41	S11 Alarm1 OFF
4458	69	RTD1	42	S11 Alarm2 ON
4459	69	RTD1	43	S11 Alarm2 OFF
4460	69	RTD1	44	S12 Alarm1 ON
4461	69	RTD1	45	S12 Alarm1 OFF
4462	69	RTD1	46	S12 Alarm2 ON
4463	69	RTD1	47	S12 Alarm2 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
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

5.4.21. Arc fault protection (IArc>/I0Arc>; 50Arc/50NArc)

Arc faults occur for a multitude of reasons: e.g. insulation failure, incorrect operation of the protected device, corrosion, overvoltage, dirt, moisture, incorrect wiring, or even because of aging caused by electric load. It is important to detect the arc as fast as possible in order to minimize its effects. Using arc sensors to detect arc faults is much faster than merely measuring currents and voltages. In busbar protection IEDs with normal protection can be too slow to disconnect arcs within a safe time frame. For example, it may be necessary to delay operation time for hundreds of milliseconds when setting up an overcurrent protection relay to control the feeder breakers to achieve selectivity. This delay can be avoided by using arc protection. The arc protection card has a high speed output to trip signals faster as well as to extend the speed of arc protection.

Figure. 5.4.21. - 112. IED equipped with arc protection.



The arc protection card has four (4) sensor channels, and up to three (3) arc point sensors can be connected to each channel. The sensor channels support Arcteq AQ-01 (light sensing) and AQ-02 (pressure and light sensing) units. Optionally, the protection function can also be applied with a phase current or a residual current condition: the function trips only if the light and overcurrent conditions are met.

The outputs of the function are the following:

- Light In
- Pressure In
- Arc binary input signal status
- Zone trip
- Zone blocked
- Sensor fault signals.

The arc protection function uses a total of eight (8) separate setting groups which can be selected from one common source.

Table. 5.4.21. - 157. Output signals of the IArc>/I0Arc> function.

Outputs	Activation condition
Channel 1 Light In Channel 2 Light In Channel 3 Light In Channel 4 Light In	The arc protection card's sensor channel detects light.
Channel 1 Pressure In Channel 2 Pressure In Channel 3 Pressure In Channel 4 Pressure In	The arc protection card's sensor channel detects light.
ARC Binary input signal	The arc protection card's binary input is energized.

I/I0 Arc> Ph. curr. START I/I0 Arc> Res. curr. START	The measured phase current or the residual current is over the set limit.
I/I0 Arc> Ph. curr. BLOCKED I/I0 Arc> Res. curr. BLOCKED	The phase current or the residual current measurement is blocked by an input.
I/I0 Arc> Zone 1 TRIP I/I0 Arc> Zone 2 TRIP I/I0 Arc> Zone 3 TRIP I/I0 Arc> Zone 4 TRIP	All required conditions for tripping the zone are met (light OR light and current).
I/I0 Arc> Zone 1 BLOCKED I/I0 Arc> Zone 2 BLOCKED I/I0 Arc> Zone 3 BLOCKED I/I0 Arc> Zone 4 BLOCKED	All required conditions for tripping the zone are met (light OR light and current) but the tripping is blocked by an input.
I/I0 Arc> S1 Sensor fault I/I0 Arc> S2 Sensor fault I/I0 Arc> S3 Sensor fault I/I0 Arc> S4 Sensor fault	The detected number of sensors in the channel does not match the settings.
I/I0 Arc> IO unit fault	The number of connected AQ-100 series units does not match the number of units set in the settings.

The operational logic consists of the following:

- input magnitude selection
- input magnitude processing
- threshold comparator
- two block signal checks
- output processing.

The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed current magnitudes.

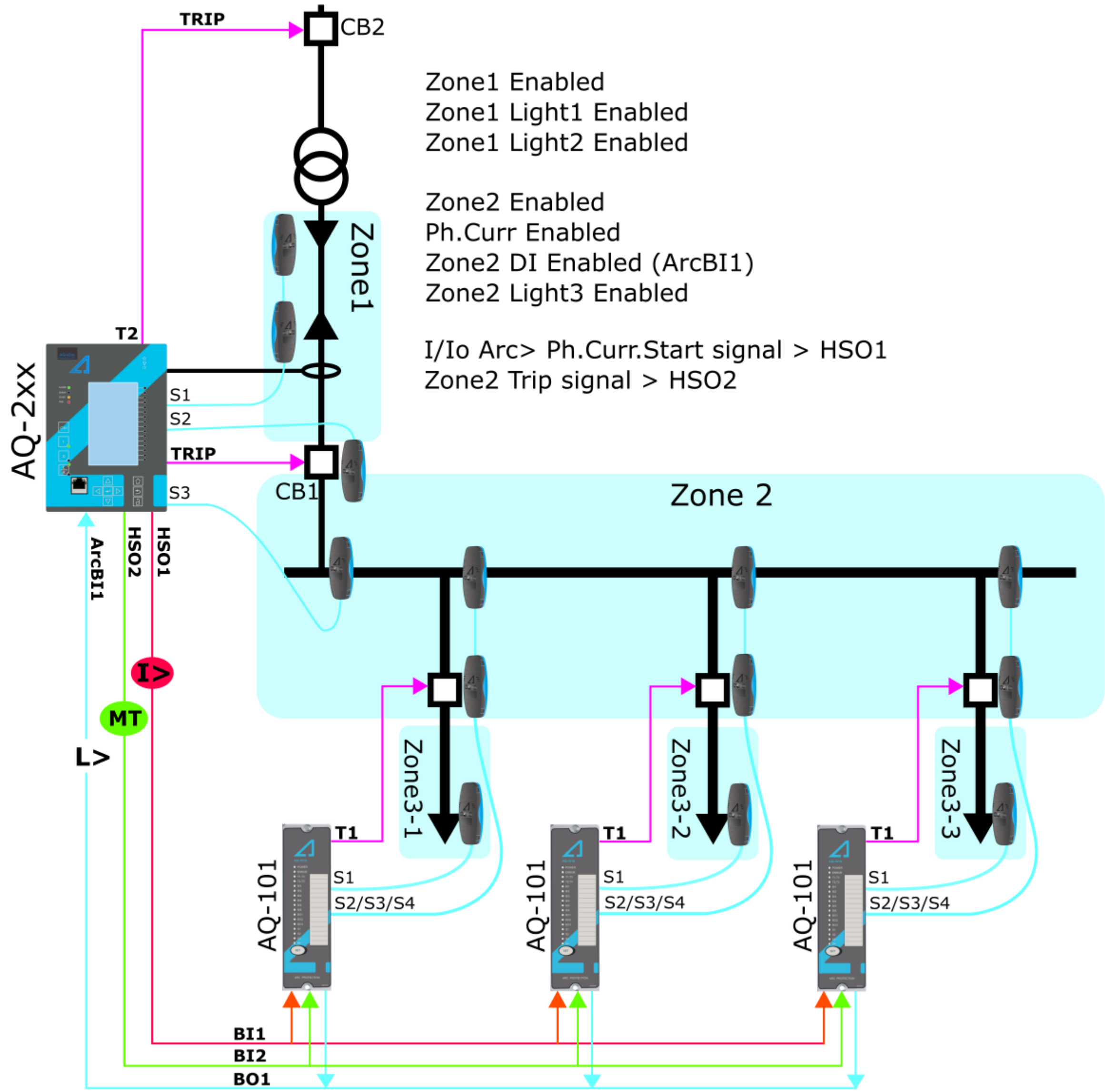
The function outputs the TRIP, BLOCKED, light sensing etc. signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signal. The time stamp resolution is 1 ms. The function also a resettable cumulative counter for the TRIP and BLOCKED events for each zone.

Example of scheme setting

The following examples helps the user better understand how the arc protection function is set. In the examples AQ-101 models are used to extend the protection of Zone 2 and to protect each outgoing feeder (Zone 3).

Scheme IA1 is a single-line diagram with AQ-2xx series relays and with AQ-101 arc protection relays. The settings are for an incomer AQ-200 relay.

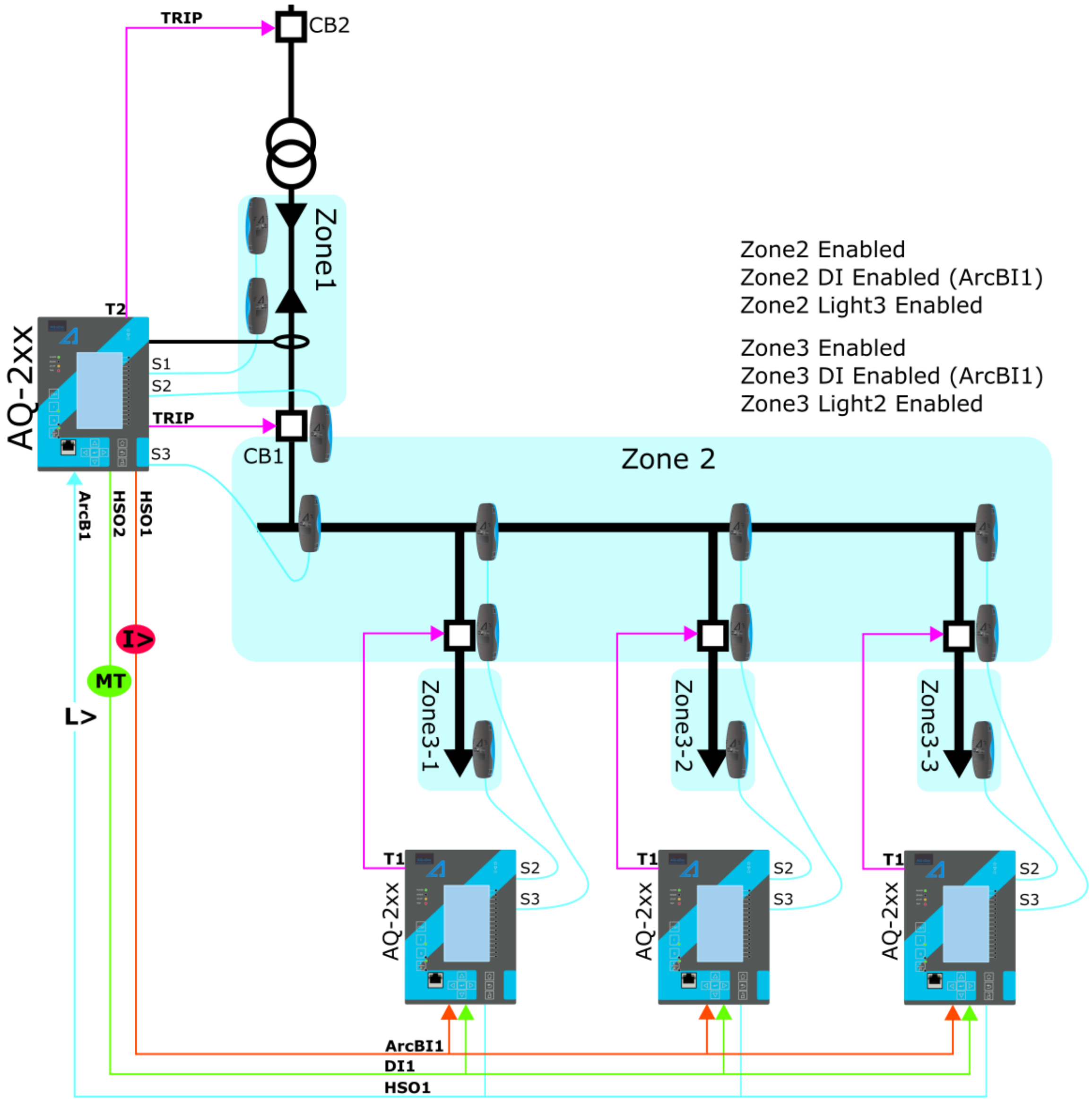
Figure. 5.4.21. - 113. Scheme IA1 (with AQ-101 arc protection relays).



To set the zones for the AQ-2xx models sensor channels start by enabling the protected zones (in this case, Zones 1 and 2). Then define which sensor channels are sensing which zones (in this case, sensor channels S1 and S2 are protecting Zone 1). Enable Light 1 of Zone 1 as well as Light 2 of Zone 2. The sensor channel S3 deals with Zone 2. Enable Light 3 of Zone 2. The high-speed output contacts HSO1 and HSO2 have been set to send overcurrent and master trip signals to the AQ-101 arc protection relays. The AQ-100 series units send out test pulses in specific intervals to check the health of the wiring between the AQ-100 series units. The parameter *I/I0 Arc> Self supervision test pulse* should be activated when connecting the AQ-100 series units to the AQ-200 series arc protection card to prevent the pulses from activating ArcBI1.

The next example is almost like the previous one: it is also a single-line diagram with AQ-2xx series relays. However, this time each outgoing feeder has an AQ-2xx protection relay instead of an AQ-101 arc protection relay.

Figure. 5.4.21. - 114. Scheme IA1 (with AQ-200 protection relays).



The settings for the relay supervising the incoming feeder are the same as in the first example. The relays supervising the busbar and the outgoing feeder, however, have a different setting. Both Zones 2 and 3 need to be enabled as there are sensors connected to both Zone 2 and 3 starts. Sensors connected to the channel S3 are in Zone 2. Then enable Light 3 of Zone 2. The sensor connected to the channel S2 is in Zone 3. Then enable Light 2 of Zone 3.

If any of the channels have a pressure sensing sensor, enable it the same way as the regular light sensors. If either phase overcurrent or residual overcurrent is needed for the tripping decision, they can be enabled in the same way as light sensors in the zone. When a current channel is enabled, the measured current needs to be above the set current limit in addition to light sensing.

Measured input

Arc protection uses samples based on current measurements. If the required number of samples is found to be above the setting limit, the current condition activates. The arc protection can alternatively use either phase currents or residual currents in the tripping decision.

Pick-up

The pick-up of each zone of the Iarc>/I0arc> function is controlled by one of the following: the phase current pick-up setting, the residual current pick-up setting, or the sensor channels. The pick-up setting depends on which of these are activated in the zone.

Table. 5.4.21. - 158. Enabled Zone pick-up settings.

Name	Description
Phase current pick-up	The phase current measurement's pick-up value (in p.u.).
I0 input selection	Selects the residual current channel (I01 or I02).
Res.current pick-up	The residual current measurement's pick-up value (in p.u.).
Zone Ph. curr. Enabled	The phase overcurrent allows the zone to trip when light is detected.
Zone Res. curr. Enabled	The residual overcurrent allows the zone to trip when light is detected.
Zone Light 1 Enabled	Light detected in sensor channel 1 trips the zone.
Zone Light 2 Enabled	Light detected in sensor channel 2 trips the zone.
Zone Light 3 Enabled	Light detected in sensor channel 3 trips the zone.
Zone Light 4 Enabled	Light detected in sensor channel 4 trips the zone.
Zone Pres. 1 Enabled	Pressure detected in sensor channel 1 trips the zone.
Zone Pres. 2 Enabled	Pressure detected in sensor channel 2 trips the zone.
Zone Pres. 3 Enabled	Pressure detected in sensor channel 3 trips the zone.
Zone Pres. 4 Enabled	Pressure detected in sensor channel 4 trips the zone.

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

Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's 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 the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup current values and its fault type to be issued.

The blocking signal can also be tested in the commissioning phase by a software switch signal when the relay's testing mode "Enable stage forcing" is activated (*General → Device*).

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

Events and registers

The arc fault protection function (abbreviated "ARC" in event block names) generates events and registers from the status changes in START, TRIP, and BLOCKED. The user can select the status ON or OFF for messages in the main event buffer.

The triggering event of the function (START, TRIP or BLOCKED) is recorded with a time stamp and with process data values.

Table. 5.4.21. - 159. Event codes.

Event number	Event channel	Event block name	Event code	Description
4736	74	ARC1	0	Zone 1 Trip ON
4737	74	ARC1	1	Zone 1 Trip OFF
4738	74	ARC1	2	Zone 1 Block ON
4739	74	ARC1	3	Zone 1 Block OFF
4740	74	ARC1	4	Zone 2 Trip ON
4741	74	ARC1	5	Zone 2 Trip OFF
4742	74	ARC1	6	Zone 2 Block ON
4743	74	ARC1	7	Zone 2 Block OFF
4744	74	ARC1	8	Zone 3 Trip ON
4745	74	ARC1	9	Zone 3 Trip OFF
4746	74	ARC1	10	Zone 3 Block ON
4747	74	ARC1	11	Zone 3 Block OFF
4748	74	ARC1	12	Zone 4 Trip ON
4749	74	ARC1	13	Zone 4 Trip OFF
4750	74	ARC1	14	Zone 4 Block ON
4751	74	ARC1	15	Zone 4 Block OFF
4752	74	ARC1	16	Phase current Blocked ON
4753	74	ARC1	17	Phase current Blocked OFF
4754	74	ARC1	18	Phase current Start ON
4755	74	ARC1	19	Phase current Start OFF
4756	74	ARC1	20	Residual current Blocked ON
4757	74	ARC1	21	Residual current Blocked OFF
4758	74	ARC1	22	Residual current Start ON
4759	74	ARC1	23	Residual current Start OFF
4760	74	ARC1	24	Channel 1 Light ON
4761	74	ARC1	25	Channel 1 Light OFF
4762	74	ARC1	26	Channel 1 Pressure ON
4763	74	ARC1	27	Channel 1 Pressure OFF
4764	74	ARC1	28	Channel 2 Light ON
4765	74	ARC1	29	Channel 2 Light OFF
4766	74	ARC1	30	Channel 2 Pressure ON
4767	74	ARC1	31	Channel 2 Pressure OFF

4768	74	ARC1	32	Channel 3 Light ON
4769	74	ARC1	33	Channel 3 Light OFF
4770	74	ARC1	34	Channel 3 Pressure ON
4771	74	ARC1	35	Channel 3 Pressure OFF
4772	74	ARC1	36	Channel 4 Light ON
4773	74	ARC1	37	Channel 4 Light OFF
4774	74	ARC1	38	Channel 4 Pressure ON
4775	74	ARC1	39	Channel 4 Pressure OFF
4776	74	ARC1	40	DI Signal ON
4777	74	ARC1	41	DI Signal OFF
4778	74	ARC1	42	I/I0 Arc> Sensor 1 Fault ON
4779	74	ARC1	43	I/I0 Arc> Sensor 1 Fault OFF
4780	74	ARC1	44	I/I0 Arc> Sensor 2 Fault ON
4781	74	ARC1	45	I/I0 Arc> Sensor 2 Fault OFF
4782	74	ARC1	46	I/I0 Arc> Sensor 3 Fault ON
4783	74	ARC1	47	I/I0 Arc> Sensor 3 Fault OFF
4784	74	ARC1	48	I/I0 Arc> Sensor 4 Fault ON
4785	74	ARC1	49	I/I0 Arc> Sensor 4 Fault OFF
4786	74	ARC1	50	I/I0 Arc> I/O-unit Fault ON
4787	74	ARC1	51	I/I0 Arc> I/O-unit Fault OFF

The function registers its operation into the last twelve (12) time-stamped registers. The table below presents the structure of the function's register content.

Table. 5.4.21. - 160. Register content.

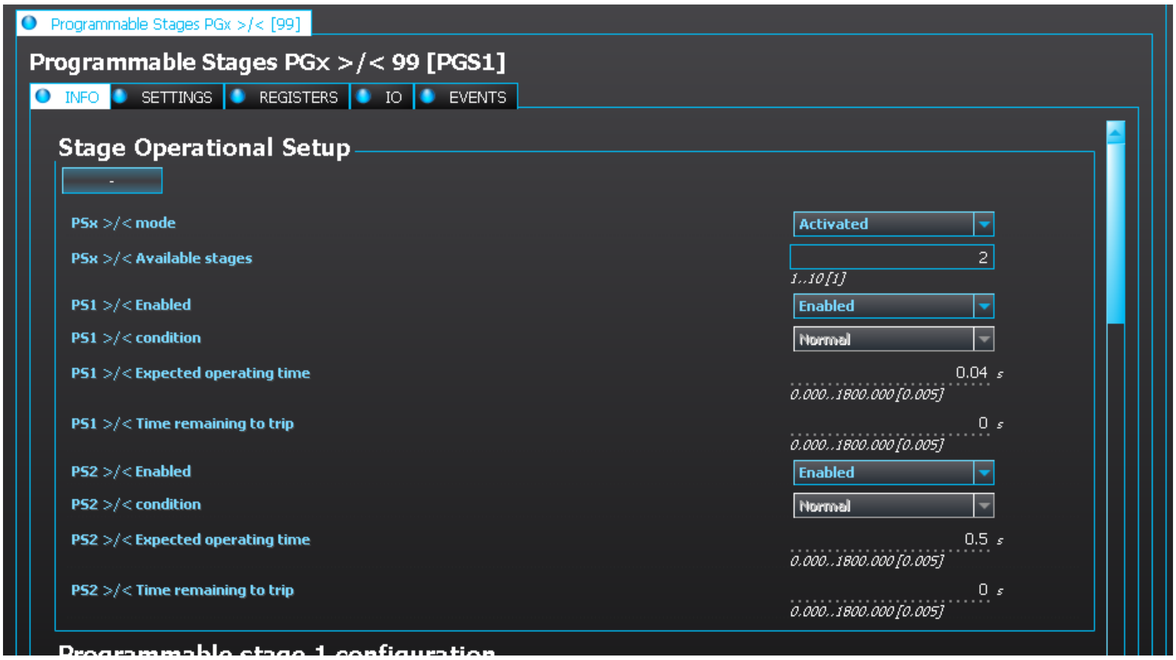
Date and time	Event code	Phase A current	Phase B current	Phase C current	Residual current	Active sensors	Used SG
dd.mm.yyyy hh:mm:ss.mss	4736-4787 Descr.	Trip -20 ms averages	Trip -20 ms averages	Trip -20 ms averages	Trip -20 ms averages	1...4	Setting group 1...8 active

5.4.22. Programmable stage (PGx >/<; 99)

The programmable stage is a stage that the user can program to create more advanced applications, either as an individual stage or together with programmable logic. The relay has ten programmable stages, and each can be set to follow one to three analog measurements. The programmable stages have three available options: overX, underX and rate-of-change of the selected signal. Each includes a definite time delay to trip after a pick-up has been triggered.

The programmable stage cycle time is 5 ms. The pick-up delay depends on which analog signal is used as well as its refresh rate (typically under a cycle in a 50 Hz system).

The number of programmable stages to be used is set in the *INFO* tab. When this function has been set as "Activated", the number of programmable stages can be set anywhere between one (1) and ten (10) depending on how many the application needs. In the image below, the number of programmable stages have been set to two which makes PS1 and PS2 to appear. Inactive stages are hidden until they are activated.



Please note that setting the number of available stages does not activate those stages, as they also need to be enabled individually with the *PSx >/< Enabled* parameter. When enabled an active stage shows its current state (condition), the expected operating time and the time remaining to trip under the activation parameters. If a stage is not active the *PSx>/< condition* parameter will merely display "Disabled".

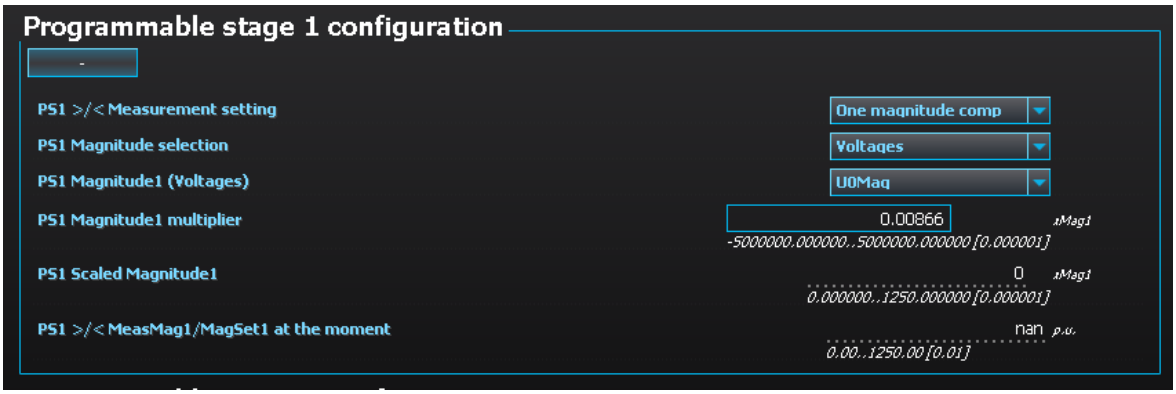
Setting up programmable stages

Programmable stages can be set to follow one, two or three analog measurements with the *PSx >/< Measurement setting* parameter. The user must choose a measurement signal value to be compared to the set value, and possibly also set a scaling for the signal. The image below is an example of scaling: a primary neutral voltage has been scaled to a percentage value for easier handling when setting up the comparator.

The scaling factor was calculated by taking the inverse value of a 20 kV system:

$$k = \frac{1}{20\,000\ \text{V}/\sqrt{3}} = 0.008\ 66$$

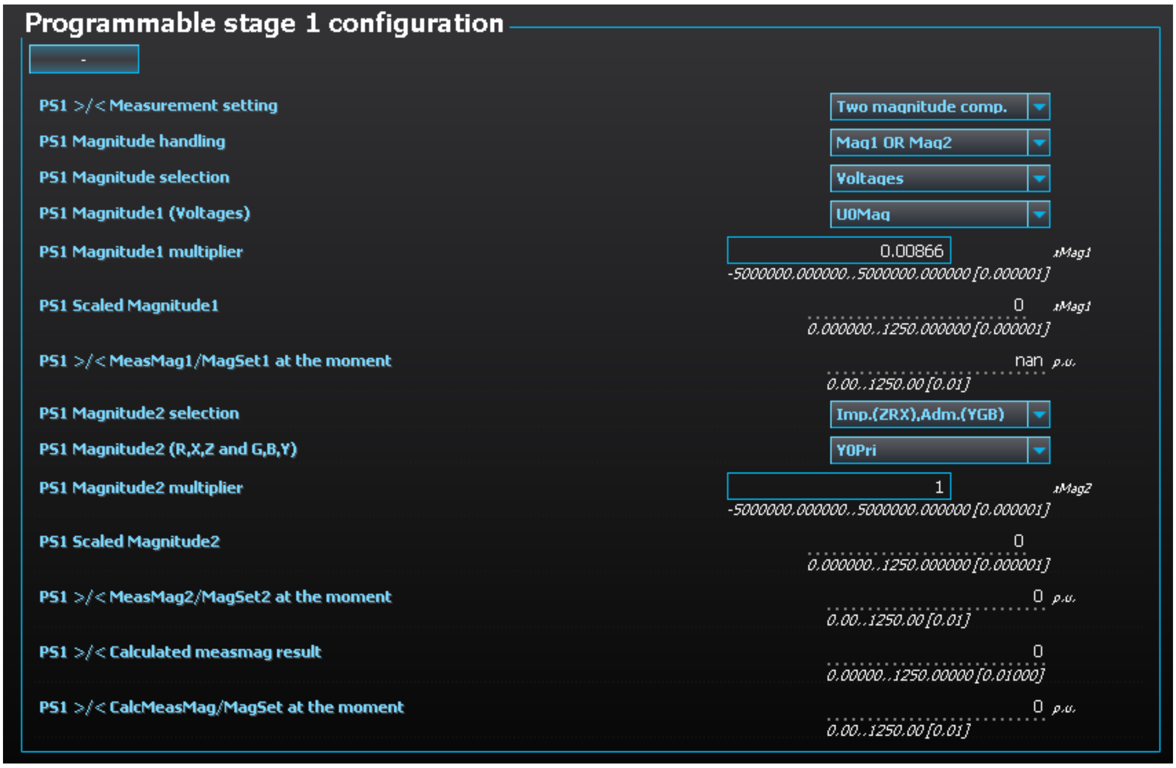
When this multiplier is in use, the full earth fault neutral voltage is 11 547 V primary which is then multiplied with the above-calculated scaling factor, inversing the final result to 100%. This way a pre-processed signal is easier to set, although it is also possible to just use the scaling factor of 1.0 and set the desired pick-up limit as the primary voltage. Similaryly, any chosen measurement value can be scaled to the desired form.



When two or three signals are chosen for comparison, an additional signal (*PSx Magnitude handling*) setting appears. From its drop-down menu the user chooses how the signals are pre-processed for comparison. The table below presents the available modes for a two-signal comparison.

Mode	Description
0: Mag1 x Mag2	Multiplies Signal 1 by Signal 2. The comparison uses the product of this calculation.
1: Mag1 / Mag2	Divides Signal 1 by Signal 2. The comparison uses the product of this calculation.
2: Max (Mag1, Mag2)	The bigger value of the chosen signals is used in the comparison.
3: Min (Mag1, Mag2)	The smaller value of the chosen signals is used in the comparison.
4: Mag1 OR Mag2	Either of the chosen signals has to fulfill the pick-up condition. Both signals have their own pick-up setting.
5: Mag1 AND Mag2	Both of the chosen signals have to fulfill the pick-up condition. Both signals have their own pick-up setting.
6: Mag1 – Mag2	Subtracts Signal 2 from Signal 1. The comparison uses the product of this calculation.

The image below is an example of setting an analog comparison with two signals. The stage will trip if either of the measured signals fulfills the comparison condition.

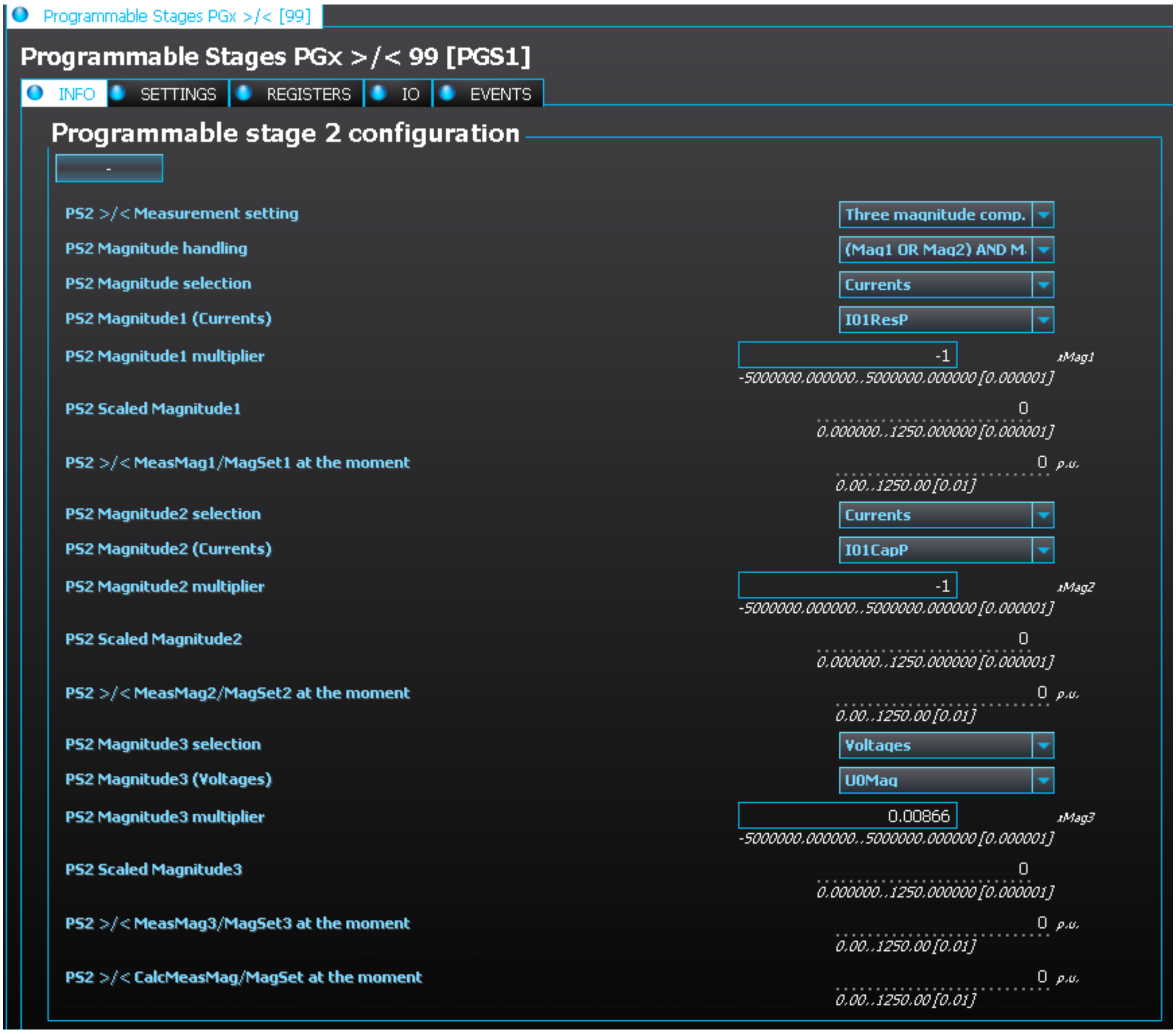


Similarly, the user can set up a comparison of three values. The table below presents the available modes for a three-signal comparison.

Mode	Description
0: Mag1 x Mag2 x Mag3	Multiplies Signals 1, 2 and 3. The comparison uses the product of this calculation.
1: Max (Mag1, Mag2, Mag3);	The biggest value of the chosen signals is used in the comparison.
2: Min (Mag1, Mag2, Mag3)	The smallest value of the chosen signals is used in the comparison.
3: Mag1 OR Mag2 OR Mag3	Any of the signals fulfills 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	Signals 1 OR 2 AND 3 need to fulfill the pick-up condition. Each signal has their own pick-up setting.

The image below is an example of setting an analog comparison with three signals. The stage will trip if Signal 1 or Signal 2 as well as Signal 3 fulfill the pick-up condition.



The settings for different comparisons are in the setting groups. This means that each signal parameter can be changed by changing the setting group.

When setting the comparators, the user must first choose a comparator mode. The following modes are available:

Mode	Description
0: Over >	**Greater than**. If the measured signal is greater than the set pick-up level, the comparison condition is fulfilled.
1: Over (abs) >	**Greater than (absolute)**. If the absolute value of the measured signal is greater 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. The user can also set a blocking limit: the comparison is not active when the measured value is less than 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. The user can also set a blocking limit: the comparison is not active when the measured value is less than 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 20 ms, 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 20 ms in 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 20 ms, 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 20 ms in either direction, the comparison condition is fulfilled. The condition is not dependent on direction.

The pick-up level is set individually for each comparison. When setting up the pick-up level, the user needs to take into account the modes in use as well as the desired action. The pick-up limit can be set either as positive or as negative. Each pick-up level has a separate hysteresis setting which is 3 % by default.

The user can set the operating and releasing time delays for each stage.

Analog signals

The numerous analog signals have been divided into categories to help the user find the desired value.

Currents

IL1	Description
IL1 ff (p.u.)	IL1 Fundamental frequency value (in p.u.)
IL1 2nd h.	IL1 2nd harmonic value (in p.u.)
IL1 3rd h.	IL1 3rd harmonic value (in p.u.)
IL1 4th h.	IL1 4th harmonic value (in p.u.)
IL1 5th h.	IL1 5th harmonic value (in p.u.)
IL1 7th h.	IL1 7th harmonic value (in p.u.)
IL1 9th h.	IL1 9th harmonic value (in p.u.)
IL1 11th h.	IL1 11th harmonic value (in p.u.)
IL1 13th h.	IL1 13th harmonic value (in p.u.)
IL1 15th h.	IL1 15th harmonic value (in p.u.)
IL1 17th h.	IL1 17th harmonic value (in p.u.)
IL1 19th h.	IL1 19th harmonic value (in p.u.)
IL2	Description
IL2 ff (p.u.)	IL2 Fundamental frequency value (in p.u.)
IL2 2nd h.	IL2 2nd harmonic value (in p.u.)
IL2 3rd h.	IL2 3rd harmonic value (in p.u.)
IL2 4th h.	IL2 4th harmonic value (in p.u.)
IL2 5th h.	IL2 5th harmonic value (in p.u.)
IL2 7th h.	IL2 7th harmonic value (in p.u.)
IL2 9th h.	IL2 9th harmonic value (in p.u.)

IL2 11th h.	IL2 11th harmonic value (in p.u.)
IL2 13th h.	IL2 13th harmonic value (in p.u.)
IL2 15th h.	IL2 15th harmonic value (in p.u.)
IL2 17th h.	IL2 17th harmonic value (in p.u.)
IL2 19th h.	IL2 19th harmonic value (in p.u.)
IL3	Description
IL3 ff (p.u.)	IL3 Fundamental frequency value (in p.u.)
IL3 2nd h.	IL3 2nd harmonic value (in p.u.)
IL3 3rd h.	IL3 3rd harmonic value (in p.u.)
IL3 4th h.	IL3 4th harmonic value (in p.u.)
IL3 5th h.	IL3 5th harmonic value (in p.u.)
IL3 7th h.	IL3 7th harmonic value (in p.u.)
IL3 9th h.	IL3 9th harmonic value (in p.u.)
IL3 11th h.	IL3 11th harmonic value (in p.u.)
IL3 13th h.	IL3 13th harmonic value (in p.u.)
IL3 15th h.	IL3 15th harmonic value (in p.u.)
IL3 17th h.	IL3 17th harmonic value (in p.u.)
IL3 19th h.	IL3 19th harmonic value (in p.u.)
I01	Description
I01 ff (p.u.)	I01 Fundamental frequency value (in p.u.)
I01 2nd h.	I01 2nd harmonic value (in p.u.)
I01 3rd h.	I01 3rd harmonic value (in p.u.)
I01 4th h.	I01 4th harmonic value (in p.u.)
I01 5th h.	I01 5th harmonic value (in p.u.)
I01 7th h.	I01 7th harmonic value (in p.u.)
I01 9th h.	I01 9th harmonic value (in p.u.)
I01 11th h.	I01 11th harmonic value (in p.u.)
I01 13th h.	I01 13th harmonic value (in p.u.)
I01 15th h.	I01 15th harmonic value (in p.u.)
I01 17th h.	I01 17th harmonic value (in p.u.)
I01 19th h.	I01 19th harmonic value (in p.u.)
IL02	Description
I02 ff (p.u.)	I02 Fundamental frequency value (in p.u.)
I02 2nd h.	I02 2nd harmonic value (in p.u.)
I02 3rd h.	I02 3rd harmonic value (in p.u.)
I02 4th h.	I02 4th harmonic value (in p.u.)
I02 5th h.	I02 5th harmonic value (in p.u.)

I02 7th h.	I02 7th harmonic value (in p.u.)
I02 9th h.	I02 9th harmonic value (in p.u.)
I02 11th h.	I02 11th harmonic value (in p.u.)
I02 13th h.	I02 13th harmonic value (in p.u.)
I02 15th h.	I02 15th harmonic value (in p.u.)
I02 17th h.	I02 17th harmonic value (in p.u.)
I02 19th h.	I02 19th harmonic value (in p.u.)
TRMS	Description
IL1 TRMS	IL1 True RMS value (in p.u.)
IL2 TRMS	IL2 True RMS value (in p.u.)
IL3 TRMS	IL3 True RMS value (in p.u.)
I01 TRMS	I01 True RMS value (in p.u.)
I02 TRMS	I02 True RMS value (in p.u.)
Calculated	Description
I0Z Mag	Zero sequence current value (in p.u.)
I0CALC Mag	Calculated I0 value (in p.u.)
I1 Mag	Positive sequence current value (in p.u.)
I2 Mag	Negative sequence current value (in p.u.)
IL1 Ang	IL1 angle of current fundamental frequency
IL2 Ang	IL2 angle of current fundamental frequency
IL3 Ang	IL3 angle of current fundamental frequency
I01 Ang	I01 angle of current fundamental frequency
I02 Ang	I02 angle of current fundamental frequency
I0CALC Ang	Angle of calculated residual current
I1 Ang	Angle of positive sequence current
I2 Ang	Angle of negative sequence current
I01ResP	I01 primary current of a current-resistive component
I01CapP	I01 primary current of a current-capacitive component
I01ResS	I01 secondary current of a current-resistive component
I01CapS	I01 secondary current of a current-capacitive component
I02ResP	I02 primary current of a current-resistive component
I02CapP	I02 primary current of a current-capacitive component

Voltages

Phase-to-phase voltages	Description
UL12Mag	UL12 Primary voltage V
UL23Mag	UL23 Primary voltage V
UL31Mag	UL31 Primary voltage V
Phase-to-neutral voltages	Description
UL1Mag	UL1 Primary voltage V

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
U1 pos.seq.V Mag	Positive sequence voltage
U2 neg.seq.V Mag	Negative sequence voltage
U0CalcAng	Calculated residual voltage angle
U1 pos.seq.V Ang	Positive sequence voltage angle
U2 neg.seq.V Ang	Negative sequence voltage angle

Powers

Name	Description
S3PH	Three-phase apparent power S (kVA)
P3PH	Three-phase active power P (kW)
Q3PH	Three-phase reactive power Q (kvar)
tanfi3PH	Three-phase active power direction
cosfi3PH	Three-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)
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

Impedance and admittance (ZRX & YGB)

Name	Description
RL12Pri	Resistance R L12 primary (Ω)
XL12Pri	Reactance X L12 primary (Ω)
RL23Pri	Resistance R L23 primary (Ω)
XL23Pri	Reactance X L23 primary (Ω)
RL31Pri	Resistance R L31 primary (Ω)
XL31Pri	Reactance X L31 primary (Ω)
RL12Sec	Resistance R L12 secondary (Ω)
XL12Sec	Reactance X L12 secondary (Ω)
RL23Sec	Resistance R L23 secondary (Ω)
XL23Sec	Reactance X L23 secondary (Ω)
RL31Sec	Resistance R L31 secondary (Ω)
XL31Sec	Reactance X L31 secondary (Ω)
Z12Pri	Impedance Z L12 primary (Ω)
Z23Pri	Impedance Z L23 primary (Ω)
Z31Pri	Impedance Z L31 primary (Ω)
Z12Sec	Impedance Z L12 secondary (Ω)
Z23Sec	Impedance Z L23 secondary (Ω)
Z31Sec	Impedance Z L31 secondary (Ω)
Z12Angle	Impedance Z L12 angle
Z23Angle	Impedance Z L23 angle
Z31Angle	Impedance Z L31 angle
RL1Pri	Resistance R L1 primary (Ω)
XL1Pri	Reactance X L1 primary (Ω)
RL2Pri	Resistance R L2 primary (Ω)
XL2Pri	Reactance X L2 primary (Ω)
RL3Pri	Resistance R L3 primary (Ω)
XL3Pri	Reactance X L3 primary (Ω)
RL1Sec	Resistance R L1 secondary (Ω)
XL1Sec	Reactance X L1 secondary (Ω)
RL2Sec	Resistance R L2 secondary (Ω)
XL2Sec	Reactance X L2 secondary (Ω)
RL3Sec	Resistance R L3 secondary (Ω)
XL3Sec	Reactance X L3 secondary (Ω)
Z1Pri	Impedance Z L1 primary (Ω)
Z2Pri	Impedance Z L2 primary (Ω)
Z3Pri	Impedance Z L3 primary (Ω)
Z1Sec	Impedance Z L1 secondary (Ω)
Z2Sec	Impedance Z L2 secondary (Ω)

Z3Sec	Impedance Z L3 secondary (Ω)
Z1Angle	Impedance Z L1 angle
Z2Angle	Impedance Z L2 angle
Z3Angle	Impedance Z L3 angle
RSeqPri	Positive Resistance R primary (Ω)
XSeqPri	Positive Reactance X primary (Ω)
RSeqSec	Positive Resistance R secondary (Ω)
XSeqSec	Positive Reactance X secondary (Ω)
ZSeqPri	Positive Impedance Z primary (Ω)
ZSeqSec	Positive Impedance Z secondary (Ω)
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)
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
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

Others

Name	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
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

The outputs of the function are the START, TRIP and BLOCKED signals. The overvoltage function uses a total of eight (8) separate setting groups which can be selected from one common source.

The function can operate on instant or time-delayed mode. Definite time (DT) delay can be selected in the In time-delayed mode.

The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed magnitudes.

The function outputs the START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signal. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

Pick-up

The *Pick-up setting Mag* setting parameter controls the pick-up of the PGx >/< function. This defines the maximum or minimum allowed measured magnitude before action from the function. The function constantly calculates the ratio between the set and the measured magnitudes. The user can set the reset hysteresis in the function (by default 3 %). It is always relative to the *Pick-up setting Mag* value.

Table. 5.4.22. - 161. Pick-up settings.

Name	Description	Range	Step	Default
PS# Pick-up setting Mag#/calc >/<	Pick-up magnitude	-5 000 000.0000…5 000 000.0000	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…1800.000 s	0.005 s	0.04 s
Release time delays	Pick-up release delay	0.000…1800.000 s	0.005 s	0.06 s

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

The user can reset characteristics through the application. The default setting is a 60 ms delay; the time calculation is held during the release time.

In the release delay option the operating time counter calculates the operating time during the release. When using this option the function does not trip if the input signal is not re-activated while the release time count is on-going.

Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's 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 the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup values of the selected signal and its fault type to be issued.

The blocking signal can also be tested in the commissioning phase by a software switch signal when the relay's testing mode "Enable stage forcing" is activated (*General → Device*).

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

Events and registers

The programmable stage function (abbreviated "PGS" in event block names) generates events and registers from the status changes in START, TRIP, and BLOCKED. The user can select the status ON or OFF for messages in the main event buffer.

The triggering event of the function (START, TRIP or BLOCKED) is recorded with a time stamp and with process data values.

Table. 5.4.22. - 162. Event codes.

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
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

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.

Table. 5.4.22. - 163. Register content.

Date and time	Event code	>/< Mag#	Mag#/Set#	Trip time remaining	Used SG
dd.mm.yyyy hh:mm:ss.mss	8576-8637 Descr.	The numerical value of the magnitude	Ratio between the measured magnitude and the pick-up setting	0 ms...1800 s	Setting group 1...8 active

5.5. Control functions

5.5.1. Automatic voltage regulator (90)

The automatic voltage regulator (abbreviated AVR in this document) is used for secondary voltage control in transformers that have an on-load tap changer (OLTC). A voltage regulator raises or lowers the secondary voltage based on the bus voltage measurements. Actual controlling takes place in the tap changer: increasing (or decreasing) the secondary winding causes an increase (or a decrease) in the transformer output voltage.

The transformer secondary voltage and bus voltage may vary based on changes and variations in the load, the load power factor, the transmission system, and the resistance and reactance of the load. These all contribute to changes in the tap changer. The aim of using an automatic voltage regulator is to maintain a stable secondary voltage and thus make sure that the distribution voltage does not rise dangerously high or fall unusably low.

Utilities have to follow the regional, national and international regulations that specify the acceptable voltage range. For example, in Finland regulations (SFS-EN 50160) require that the distribution voltage is 230 V (phase-to-earth). Voltage quality measurement is done on a 10-minute average: 95 % of the measured voltages must be ±10 % of the nominal voltage and all measured voltages must be +10…-15 % of the nominal voltage. This measurement is usually taken from 20/0.4 kV distribution transformers on MV overhead lines (rural areas) and cable networks (urban areas) so the 20kV medium voltage is the side where the voltage has to be controlled for all distribution transformers behind the feeding transformer by controlling the load tap changer. This control model is commonly called bus regulation.

Other uses for voltage control are, for example, reactive power control and optimization of the transmission lines.

Features and configuration

The automatic voltage regulator features separate windows: definite and inverse operating time voltages raise and lower windows and the instant overvoltage lowers them, whereas undervoltage the in-built overcurrent function blocks all commands to raise or lower the windows. The target voltage as well as the operating settings for the voltage windows can be changed by editing the setting groups. The tap changer's location is monitored with mA, RTD, or digital input channel voltage measurement. The position of the tap changer can be controlled automatically and manually. The AVR monitors the phase-to-phase voltage of the bus. External commands can block the operation of the AVR either by completely blocking the control algorithm, or by only blocking the control outputs.

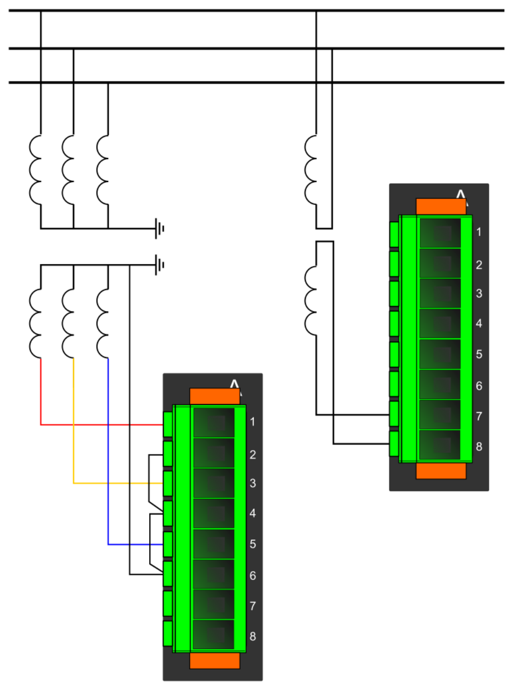
The following examples present how to configure the automatic voltage regulator.

General settings

General settings include the selection of the measurement reference voltage. Additionally, the measured phase-to-phase voltage and the measurement input (if U4 is used for voltage measurements) must be selected as well.

The image below two connection options for voltage measurement.

Figure. 5.5.1. - 115. Two connection options for voltage measurement.



The connection on the left shows the relay that has a full voltage connection with complete phase-to-phase or phase-to-earth voltages (3LN+U4; also on modes 3LL + U4 and 2LL+U3+U4); the AVR measurement voltage can be selected to be either U12, U23, or U31. If only one voltage is available for the AVR (the connection on the right), the regulator must be connected to the U4 input, and set to measure both from the U4 channel and from the connected voltage (U12, U23 or U31).

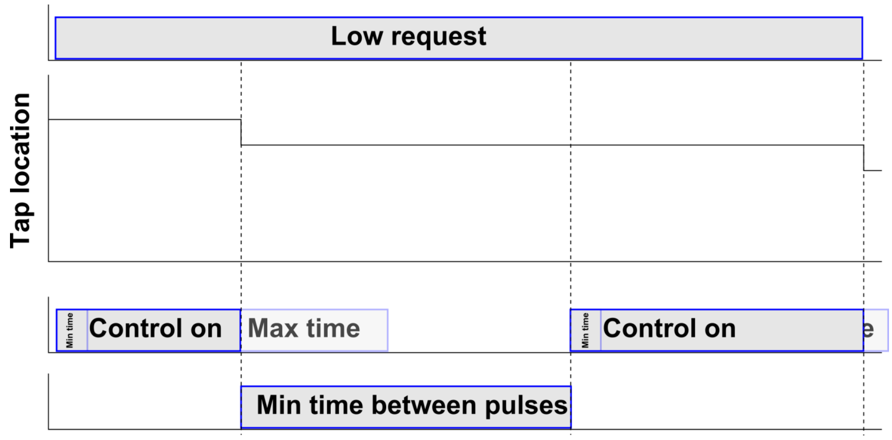
The general settings also include various online measurements and calculations from the AVR function as well as the location of the tap changer. Information about the settings and AVR status can be found later in this document.

Control settings

The control settings include the operating mode selection ("Auto" or "Manual") as well as the settings for the maximum and minimum control pulse lengths for the used output contacts. Additionally, the settings include the setting for the minimum instant operation wait time between pulses.

Below is an example of the settings that control pulse timings.

Figure. 5.5.1. - 116. Control pulse timing settings.



First, the user sets the minimum and maximum times for control pulses. If the tap changes during the control pulse, thus also changing the voltage and the controlled direction, the command is terminated. If the set maximum control time is exceeded, the control signal is terminated. After the termination, the set minimum time between pulses is used to prevent new control pulse outputs (esp. instant low requests) from taking place during this time.

Tap settings

The properties of the used tap changer are set in the tap settings. They allow for the configuration of the number of tap changer positions, the middle position, and the position indication message.

For example, let us say a transformer has a tap changer with 18 positions, with position 9 presenting the middle position. The tap changer location is indicated by the mA signal (4…20 mA). Each tap position has a 1.67 % effect on the transformer's output voltage. The highest mA value is expected when the tap is in the highest position.

According to these data, the tap changer properties are set to the AVR as follows:

Setting	Value
Tap position indication	mA input
Tap steps totally	18 steps
Tap center position	9 step
Tap step effect	1.67 %
mA input low range	4 mA
mA input high range	20 mA
Tap position indication	Max.mA.max.Pos

Based on these given values, the AVR function calculates the following:

Calculation	Value
Tap step voltage effect	334 V_{pri}
Tap maximum decrease	-15.03 %

Tap maximum increase	15.03 %
Tap control band	30.06 %
Tap step in mA	0.889 mA
mA input now	measured mA input value

These basic settings define the control area where the AVR must operate.

Either Channel 1 or 2 can be used to connect a mA input to an option card (see the image below).

Figure. 5.5.1. - 117. Connecting mA input to option card.

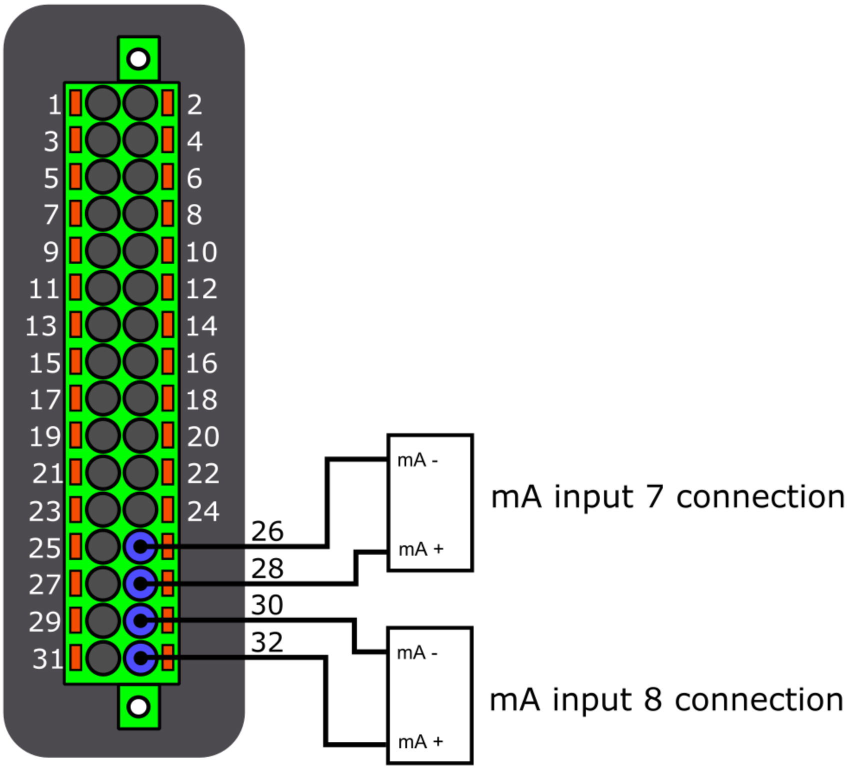
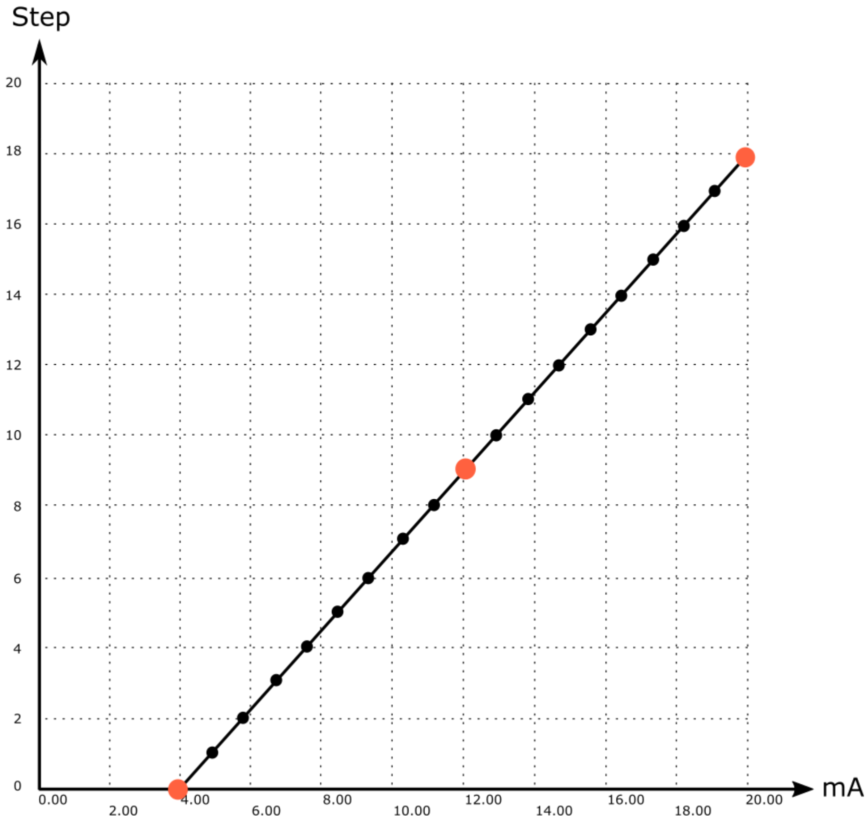
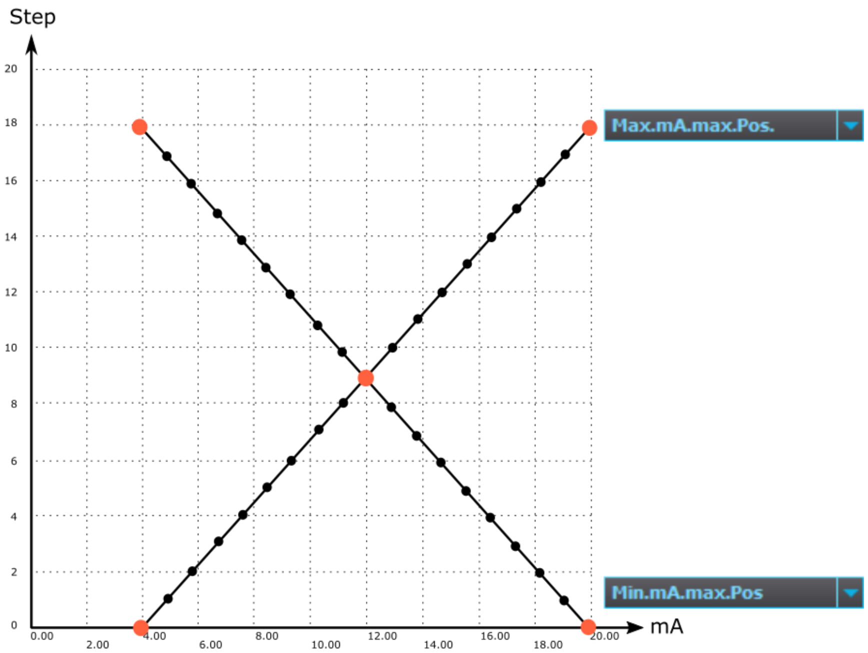


Figure. 5.5.1. - 118. Tap position indication (according to the example settings).



Some tap changers might work "inversely", meaning that the maximum mA measurement indicates that the tap changer is in the lowest position. If this is the case, this can be switched with the "Tap position indication" parameter, as shown in the image below.

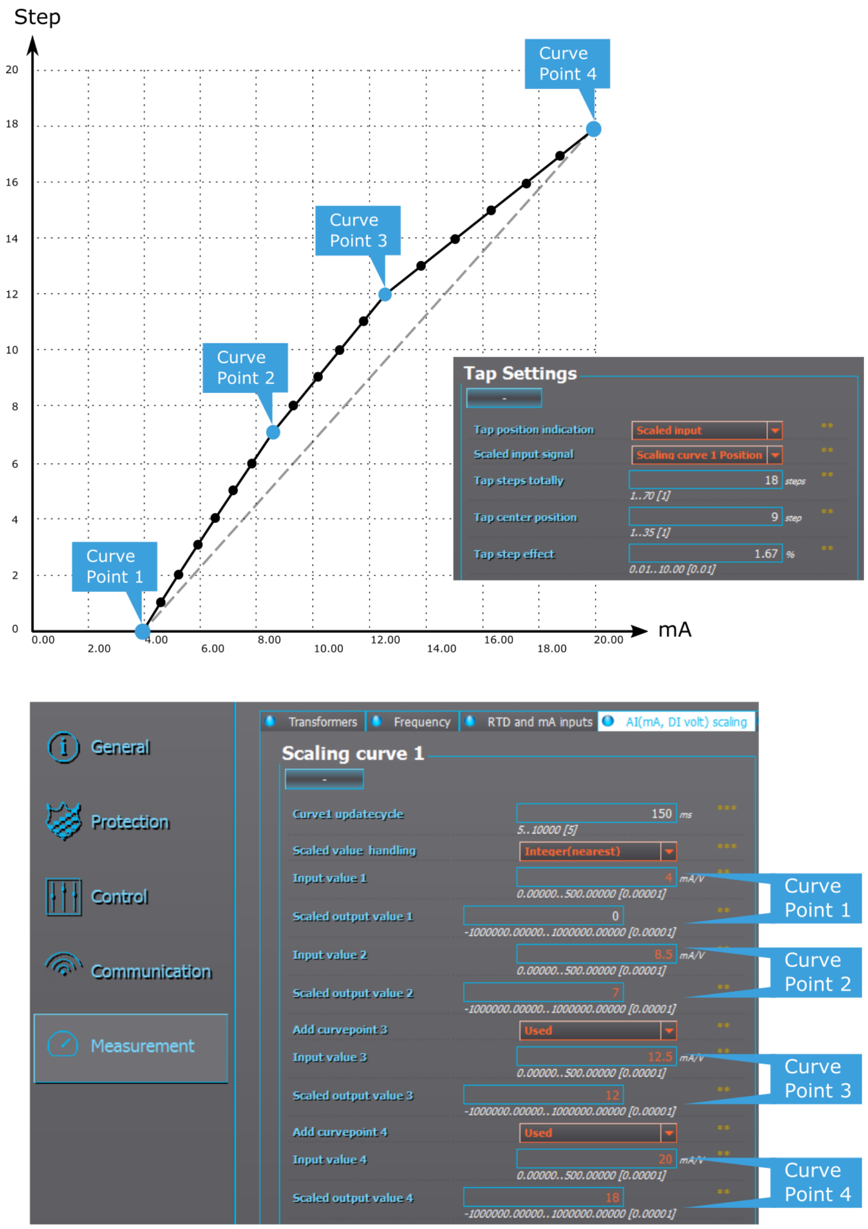
Figure. 5.5.1. - 119. Switching the tap position indication.



__Correcting non-linear mA tap position indication with current scaling__

When setting up the tap changer settings, it would be ideal to have the mA difference between each step be identical. However, this is not how it goes most of the time, and sometimes this non-linear increase can cause the AVR function to assume that the tap position has changed two or zero steps when in actuality the tap changer has been controlled for one step. This problem can be corrected by using the "Scaled input" mode, and then scaling the output value of the tap position that comes from the mA inputs. Below is an example where the tap changer has 18 positions and the mA/position curve has been corrected at two points between the minimum and maximum positions.

Figure. 5.5.1. - 120. Example of Scaled input setting.



External mA input

There is an alternative to using an RTD & mA card: one can also use an external mA unit (ADAM-4016) which connects to the RS-485 port.

BCD-coded digital inputs

Sometimes tap position indication is done by using multiple digital inputs. With binary-coded decimal (BCD) inputs any one decimal numeral can be represented by a five-bit pattern. You can use BCD inputs by setting the "Tap position indication" to "BCD-coded inputs" at the Tap settings. The digital inputs are then defined in the regulator's menu at *IO → Input signal control*. Up to five digital inputs can be set for BCD coding, and up to 31 positions can be indicated with BCD coding (see the image below).

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 mA measurement, RTD resistance is also an applicable option. To use RTD measurement the position indication needs to be scaled in *Measurement → AI (mA, DI volt) scaling* (see the image below).

Figure. 5.5.1. - 121. Example scaling for tap position indication with RTD measurement.

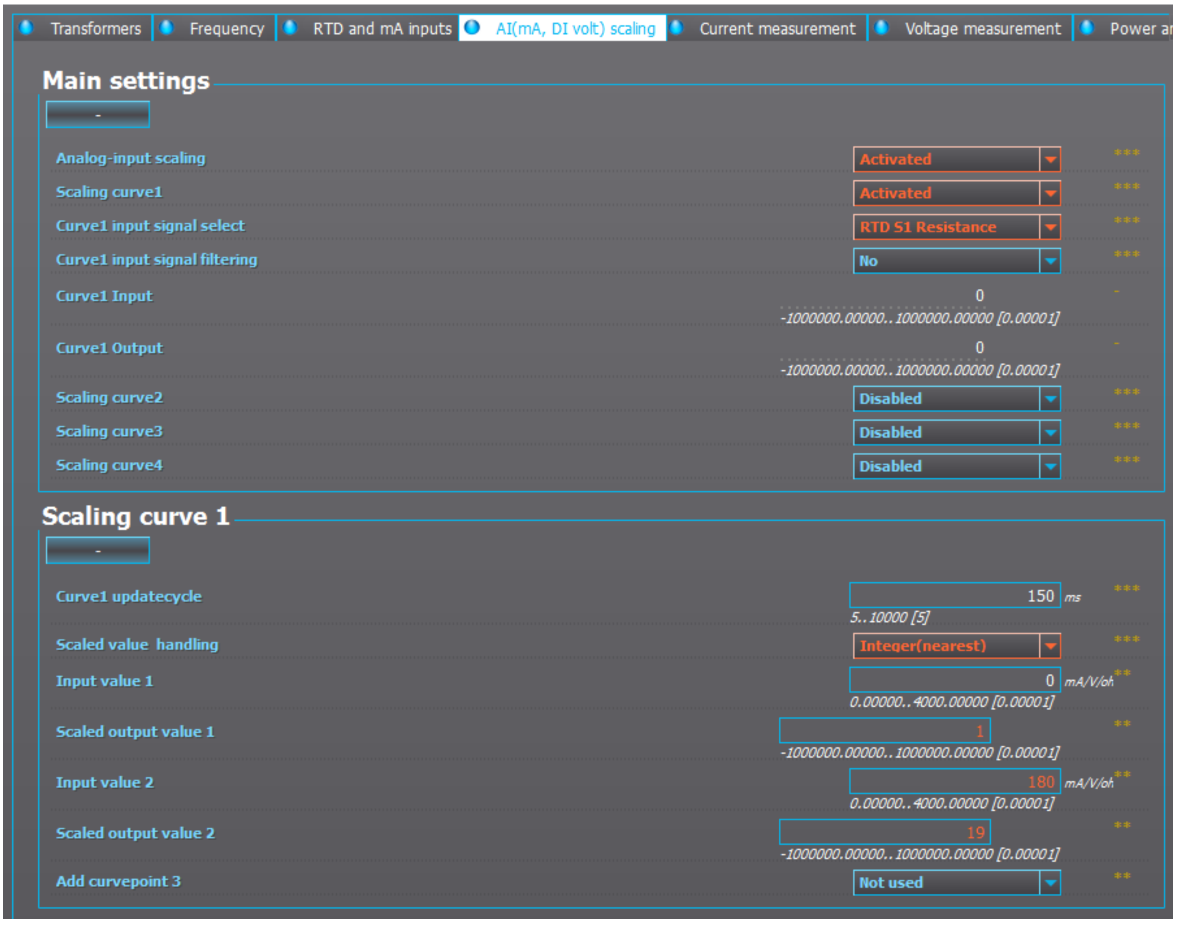
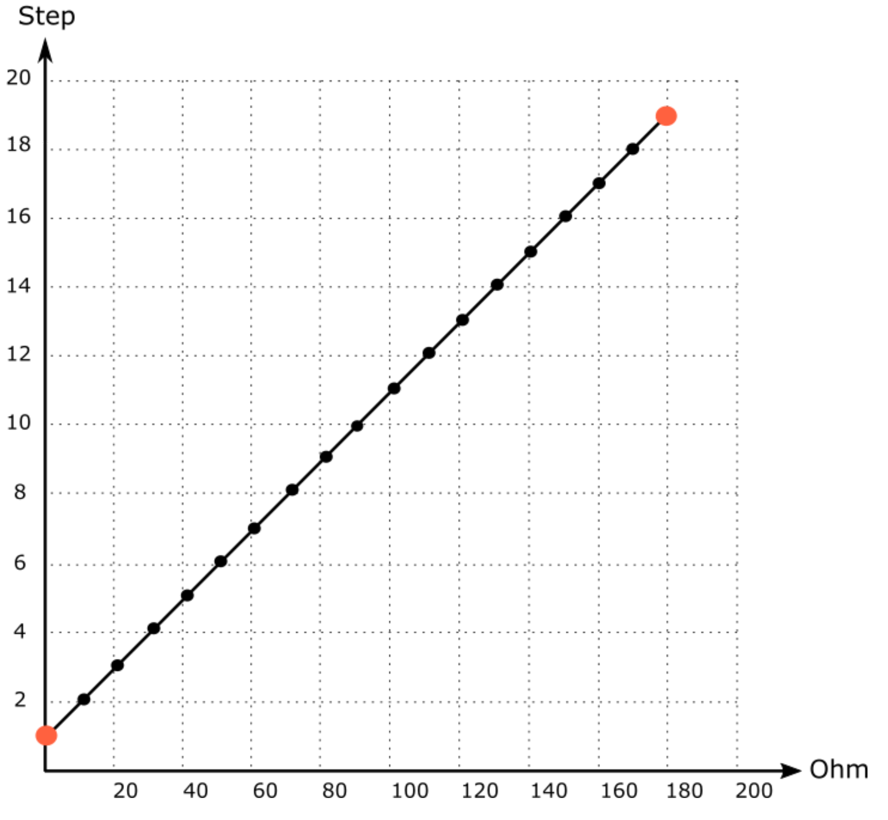


Figure. 5.5.1. - 122. Result of the above-mentioned example.



In the example figure above, the RTD card's Sensor 1 is used for tap position indication. With these settings the measured resistance (0...180 Ω) is transferred to the tap position 1...19. To use this scaling settting, please select the option "Scaled input" for the "Tap position status" parameter.

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 then use this to indicate the tap changer position. The setup procedure is nearly identical to the RTD measurement option setup (as described above), except the desired digital input is selected as the tap position source.

Voltage regulation settings ("Active settings")

The settings presented in this subsection can be changed online by changing the setting group.

The target voltage and the control window where the voltage should be kept need to be set for the regulator in percentage of the nominal value. When setting up the parameters for the voltage window one should consider the regulating sensitivity and the minimizing of control operations. An unnecessarily tight voltage window may cause excessive control operations which in turn cause the network voltage to fluctuate. The target should be a calm network that only causes necessary control operations. A correctly set voltage window is kind to the physical tap changer and keeps the network voltage stable during normal network events.

There are a few basic rules that apply to the setting of the parameters for the first voltage window. First, the window should never be set below the value of the tap step effect setting, and the window should never exceed the allowed variation loads.

Therefore, the minimum voltage window size can be calculated as follows:

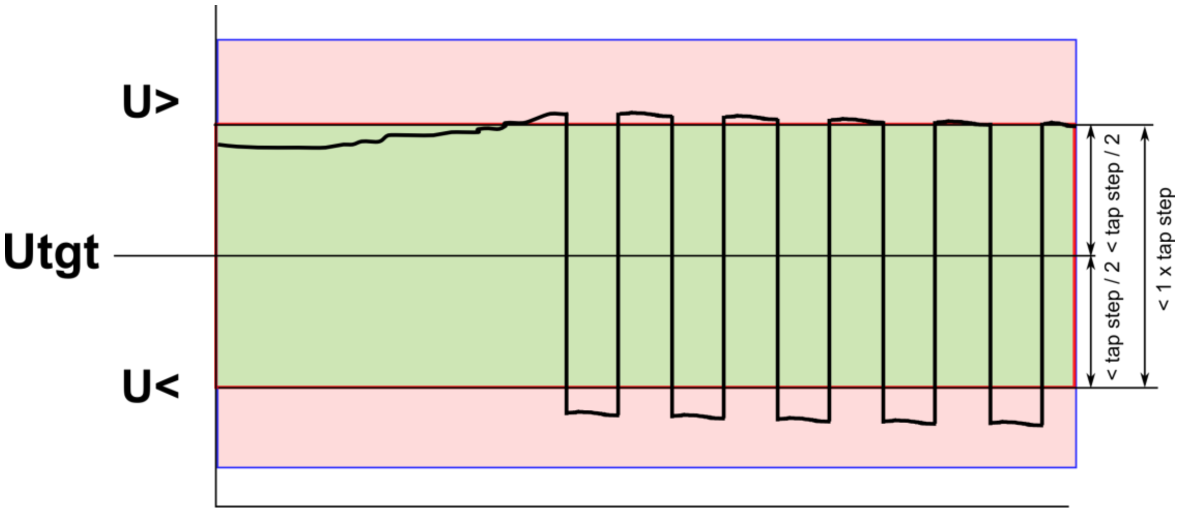
$$U >/<_{window} = 1.2 \times tap\ step\ effect\ \%$$

This gives 20 % more total band for regulating, and this setting ensures that the voltage remains within the voltage window after a tap change operation. You can increase the egulating sensitivity by setting a smaller window; however, this is not advised.

Next, the window must be set into the voltage regulator: divide the calculated $U>/<_{window}$ by two, and then set the result as the value for the parameters *U> setting (+U_{TGT})* and *U< setting (-U_{TGT})*. If the values for both window settings are equal, the regulator has same sensitivity for both overvoltage and undervoltage situations. The voltage windows as well as all other setting parameters are in relation to the set target voltage U_{TGT}. If the target voltage is changed, the voltage window setting parameters change as well to follow the new target voltage.

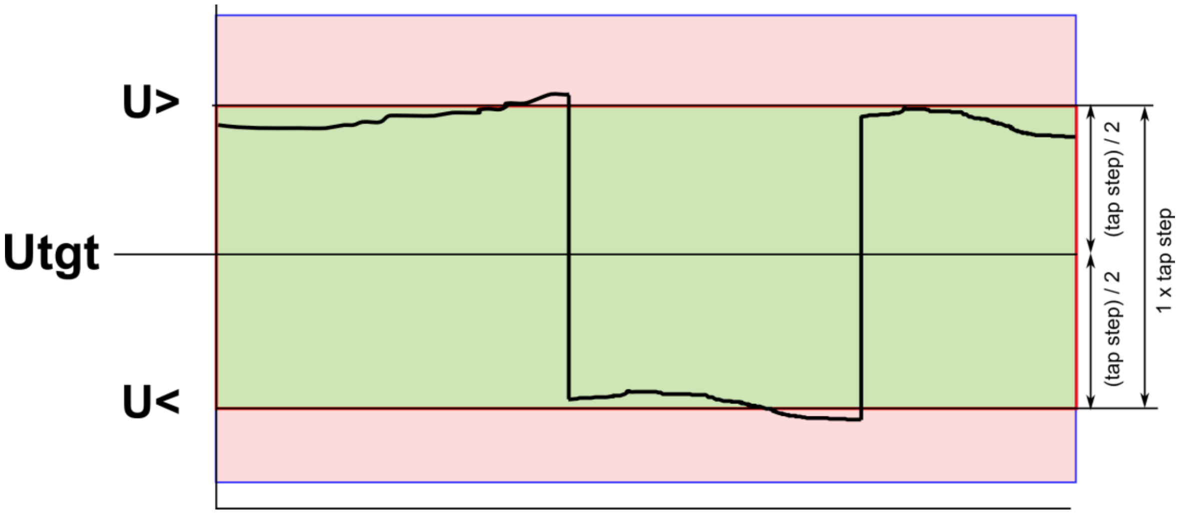
The following three images present various situations with the setting of the voltage window.

Figure. 5.5.1. - 123. Tight voltage window (window not reached).



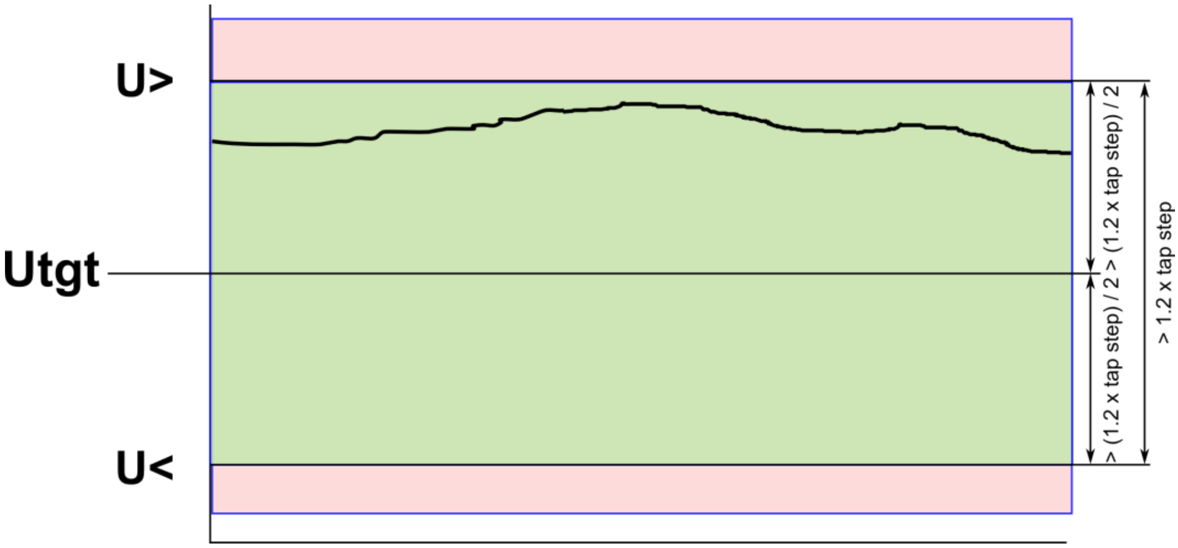
In this example situation the set voltage window is too tight compared to the tap effect. The AVR cannot reach the target window and thus lowers the voltage. Eventually a stable voltage may be found but the next tap change request will cause similar fluctuation and the cycle begins again.

Figure. 5.5.1. - 124. Tight voltage window (window reached but voltage near the limit).



In this example situation the set voltage window is still too tight compared to the tap effect. This time the AVR reaches the target window with one tap change, but afterwards the voltage is very close to the limit. If the voltage goes back to the original value, another tap change is needed. This may cause an excessive number of tap operations, and the quality of the network voltage is not significantly improved.

Figure. 5.5.1. - 125. Voltage window according to the recommendation.

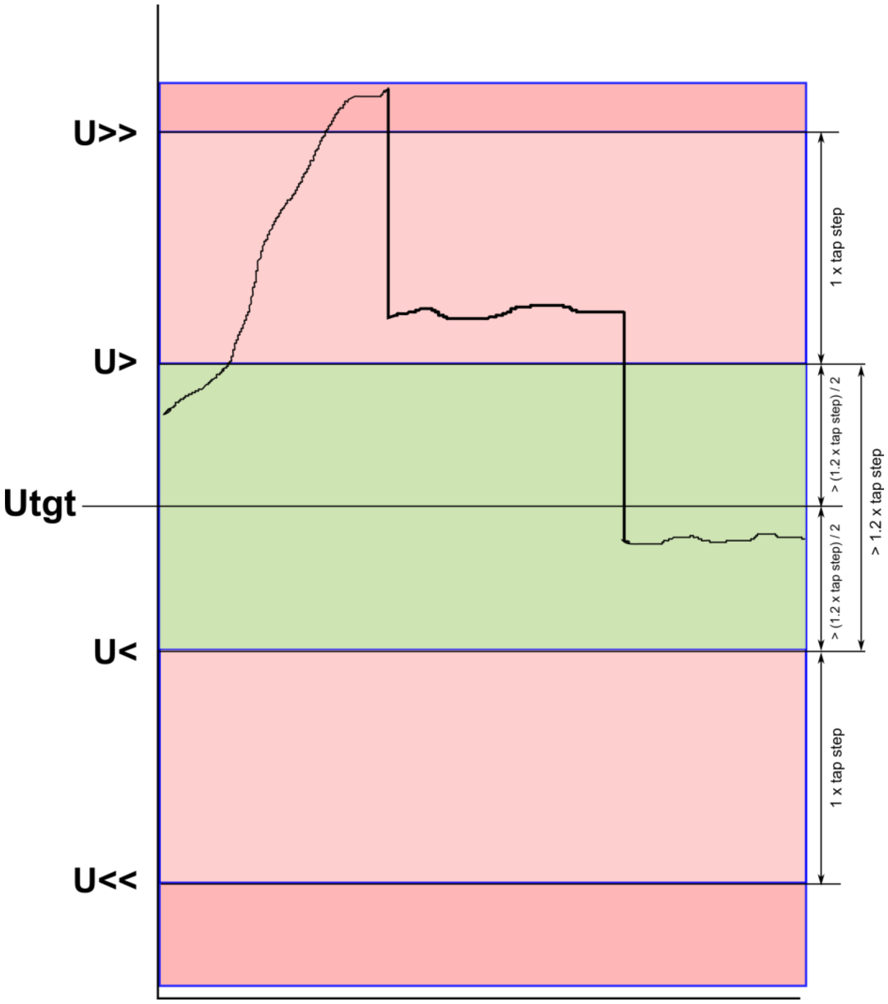


In this example the voltage window limits are set according to the recommendation: the set window is 20 % bigger than the tap step effect. This ensures that after tap changing the voltage is not too near the opposite voltage window limit. If the user wants more sensitivity, the voltage window can be set lower; however, it is not recommended that the set window is less than 5 % bigger than the tap step effect.

In automatic voltage regulator applications the first window ($U>/<_{window}$) is usually used for slower operation with a definite set operating time and small deviations. Typically this operating time is 30…120 seconds. The function starts counting the operating time when the measured voltage exceeds either of the set window limits. If the voltage remains beyond the limits until the set operating time has passed, a tap change operation is applied. If the measured voltage returns to within the target voltage window, the operating time counter is reset. A 3 % hysteresis is applied for the U> and U< pick-up resets in the voltage window.

When defining the setting limits for the second (fast operation) voltage window, it must be ensured that one tap change cannot bring the voltage within the first voltage window. See the image below, where the first window is 20 % bigger than the tap step effect and the second window is increased by two tap steps from the first window. When the voltage exceeds the higher limit of the second voltage window, one tap change operation is applied and it brings the voltage down. However, the voltage stays within the second window limits. Only when a second tap change is applied does the voltage drop within the limits of the first voltage window.

Figure. 5.5.1. - 126. Second voltage window two tap steps from the first voltage window.

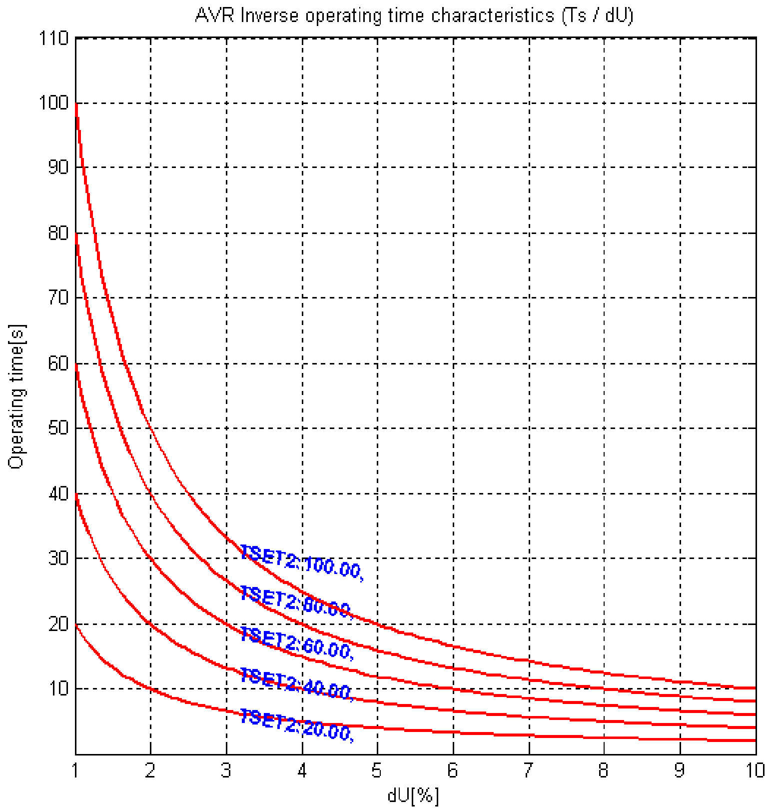


It is recommended that the operating time for the second (fast) window is in inverse mode, although it can also be set to the definite operating mode. Therefore, the more the measured voltage exceeds the threshold, the faster the operating time will be.

The AVR inverse operating time is calculated with the following equation:

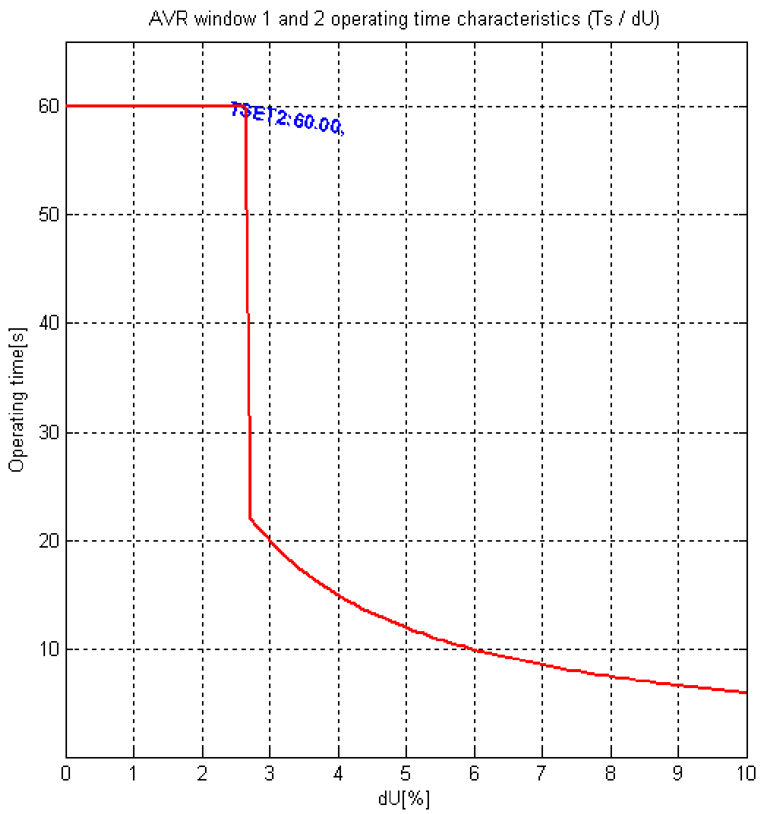
$$\text{Operating time} = \frac{U \gg / \ll \; time\ delay}{|\Delta U\%|}$$

Figure. 5.5.1. - 127. Inverse operating time characteristics for the second voltage window (U>>/<<$_{window}$).



The inverse operating time controls the voltage back to the set target window: the bigger the deviation (dU [%]) is, the smaller the operating time to get the voltage within the target window.

Figure. 5.5.1. - 128. Combined operating time characteristics of both voltage windows.



The figure above presents the combined operating time characteristics of both voltage windows as a function of the voltage deviation. As it shows, the faster inverse operation time characteristics are in effect until the voltage deviation hits the U>>/<< window threshold. After hitting the U>/< window threshold the graph follows the definite operating time characteristics.

Settings for this example are:

$$\text{U >/< pick-up} = \frac{(1.2\ \times tap\ step\ effect)}{2} = \frac{(1.2\ \times 1.67\ \%)}{2} \approx 1\ \%$$

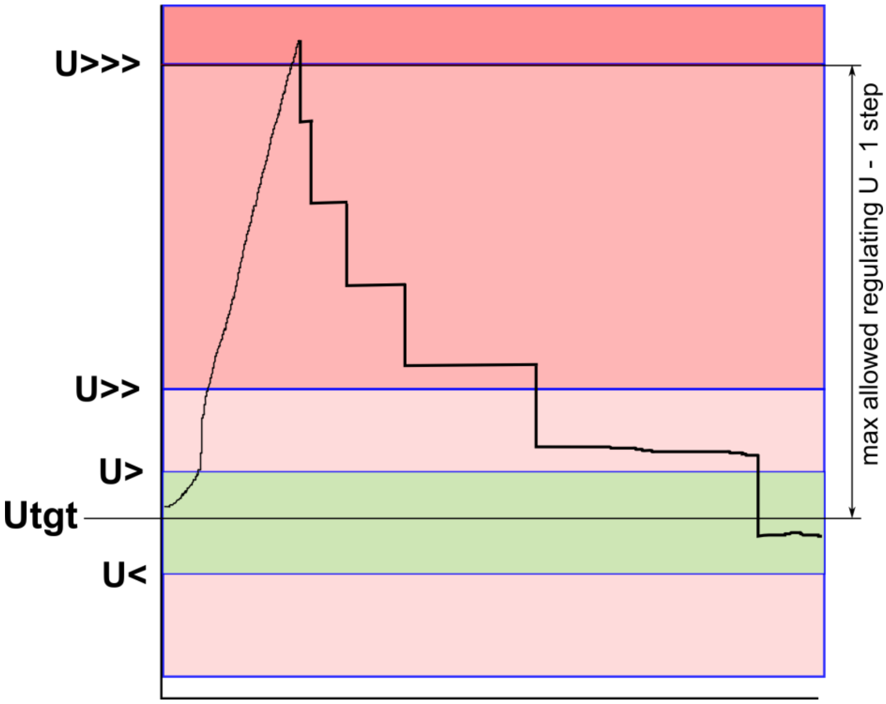
➔ operating time is 60 seconds

$$\text{U} \gg/\ll \text{pick-up} = U >< pick\text{-}up + tap\ step\ effect = 1\ \% + 1.67\ \% \approx 2.67\ \%$$

➔ operating time is 60 seconds

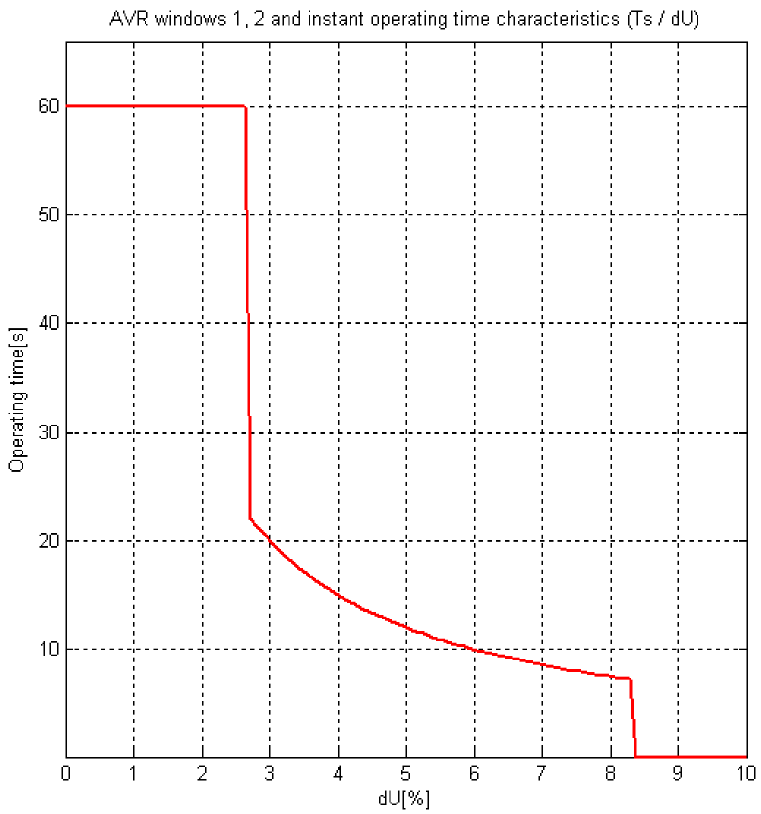
When a very high overvoltage occurs, the regulator instantly lowers the voltage without any other delays but the given minimum time between control pulses. This lowering function remains in use until the measured voltage is below the set instant low threshold level (U>>> Instant setting). After this level is reached, the time characteristics of the corresponding window calculate the consecutive time delays until the desired target window is reached.

Figure. 5.5.1. - 129. Instant low command with two time-delayed windows.



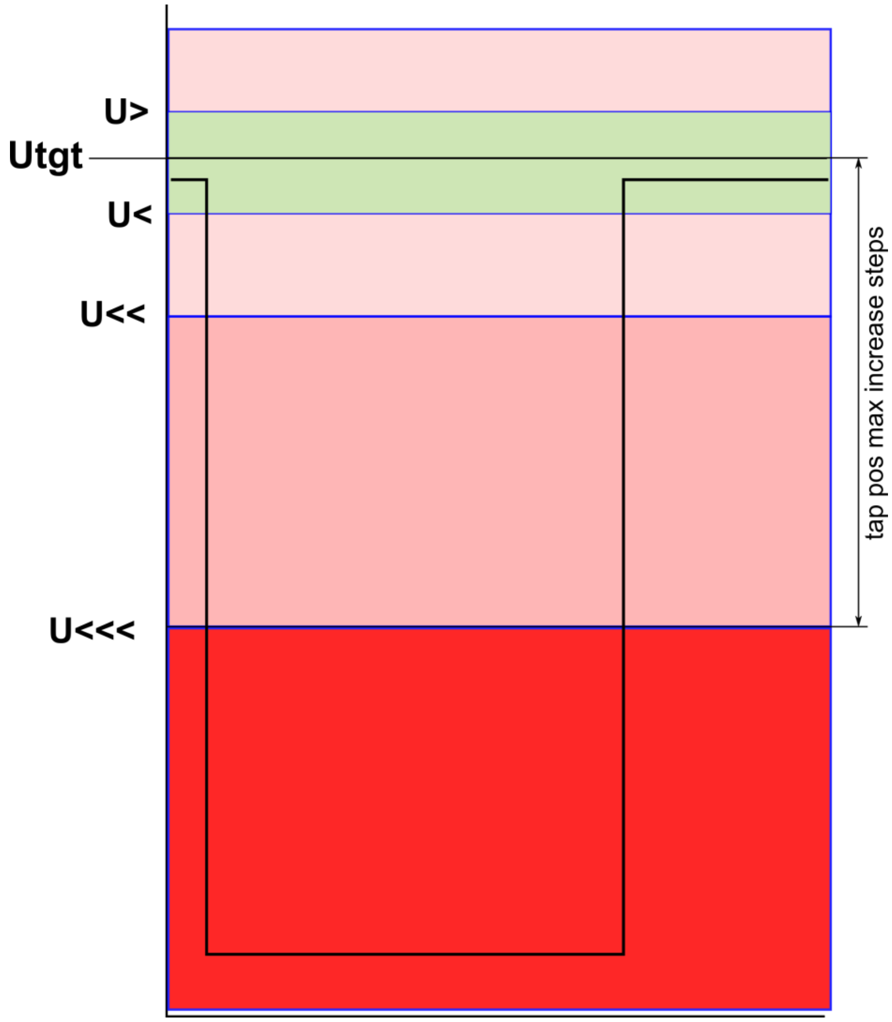
The pick-up setting recommendation for the instant low function is equal to the the maximum allowed overvoltage subtracted by the tap effect. This way there should not be situations where the voltage is allowed to stay above the maximum allowed voltage for a long time. For example, if the maximum allowed overvoltage is 10 % by local standards and the tap effect for the transformer is 1.67 %, the pick-up for the instant low function should be set to 8.33 % (10 % – 1.67 %).

Figure. 5.5.1. - 130. Effect of the Instant low setting on time characteristics.



The AVR's low voltage blocking prevents the tap changer's operations to avoid the control to the maximum position when the feeding voltage returns to the nominal level (see the image below). This can occur in various power-off situations, such as when there is a heavy short-circuit fault in the feeding network side, or when the tap drifts towads the maximum voltage.

Figure. 5.5.1. - 131. Low voltage blocking.



The recommended setting for low voltage blocking is the maximum tap increase positions effect. For example, if the tap changer has a ± 9 × 1.67 % control range, the undervoltage blocking should be set to 15 % (9 × 1.67 %).

The last part of the AVR configuration is to make sure that an overcurrent or a short-circuit fault on the load side does not cause a tap change operation due to the load-side voltage drop. If the regulator's operation is not blocked during the short-circuit fault when the transformer is under heavy overcurrent, the tap changer controls the voltage up to compensate for the voltage drop; this most probably ends up causing damage to the tap changer equipment. However, the blocking can also be achieved by internal overcurrent blocking (if the phase currents are measured with the AVR) or by a pick-up signal from the external overcurrent relay or transformer protection relay (GOOSE or a wired signal to the AVR's digital input).

Measured input

The AVR measures phase-to-phase voltages for voltage controlling. Optionally, the phase currents can be measured for overcurrent blocking.

Table. 5.5.1. - 164. Measurement inputs of the automatic voltage regulator 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

The general settings define the basic control settings for the voltage measurement configuration. The settings give general information about the AV regulator's condition and status. The general settings also include indications and measurements.

Table. 5.5.1. - 165. General setting parameters.

Name	Range	Step	Default	Description
Voltage measurement	0: U12 1: U23 2: U31 3: U4 input	-	0: U12	Selects the measured system voltage from the U1, U2 and U3 inputs.
U4 measures	0: U12 1: U23 2: U31	-	0: U12	Selects the measured system voltage from the U4 input. This setting is only visible if the "U4 input" option has been selected in the "Voltage measurement" parameter.
Vreg settings condition	1: U>> set too low 2: U< set too high 3: U> set higher than U>> 4: U< set lower than U<< 5: U>>> set too low 6: U<<< set too high 7: VT selection not ok	-	0	When opened displays the internal information about the settings. If the value differs from 0, the settings are not correct.
Vreg condition	1: Raise command on 2: Lower command on 3: Operation blocked 4: Output control blocked 5: U<<< block on 6: I> block on 7: Tap on highlimit 8: Tap on lowlimit 9: Operation blocked 10: U>/< pick-up on 11: U>>/<< pick-up on 12: Control wait time on 13: Manual control mode on	-	0	When opened displays the internal information about the automatic voltage regulator's current status. When the value is 0, nothing is happening.

Vreg timer active	0: - 1: Fine tune decrease 2: Fine tune increase 3: Low set decrease 4: High set decrease 5: Instant decrease 6: Low set increase 7: High set increase	-	0: -	Displays the timer, when the AVR is counting time.
Time left to operation	0.000…1800.000 s	0.005 s	-	Displays the time the counter has left before action.
Voltage now	0.00…140.00 $\%U_n$	0.01 $\%U_n$	-	Calculates the measured reference voltage.
Voltage difference to set target	0.00…140.00 $\%U_n$	0.01 $\%U_n$	-	Calculates the difference between the measured reference voltage and the set target voltage.
Voltage set now to	-50 000…50 000 V_{pri}	0.01 V_{pri}	-	Displays the primary voltage deviation. Based on the location of the tap changer.
U>>> (instant) setting	0.00…140.00 %	0.01 %	-	Displays the set instant stage (compared to the nominal 100 % level).
U>> setting	0.00…140.00 %	0.01 %	-	Displays the set upper limit of the second window (compared to the nominal 100 % level).
U> setting	0.00…140.00 %	0.01 %	-	Displays the set upper limit of the first window (compared to the nominal 100 % level).
U< setting	0.00…140.00 %	0.01 %	-	Displays the set lower limit of the first window (compared to the nominal 100 % level).
U<< setting	0.00…140.00 %	0.01 %	-	Displays the set lower limit of the second window (compared to the nominal 100 % level).
U<<< setting	0.00…140.00 %	0.01 %	-	Displays the set undervoltage blocking limit.
Voltage meas condition	0: U12 1: U23 2: U31 3: U4 input	-	0: U12	Selects the measured voltage. Please check that the selected voltage input is correct.
Tap location (– 0 +)	-30…30	1	0	The tap location in the tap changer, in relation to the middle point.
Absolute tap location	0…50	1	0	The tap location in the tap changer, in relation to the whole range (0…max) of tap steps.
Tap changer on high border	0: No 1: Yes	-	0: No	Indicates when the tap changer has reached the maximum voltage high position.
Tap changer on low border	0: No 1: Yes	-	0: No	Indicaters when the tap changer has reached the minimum voltage low position.

Control settings

The control settings define the control model as well as the manual increasing and decreasing commands from the HMI. The timing controls are here as well.

Table. 5.5.1. - 166. Control settings parameters.

Name	Description	Range	Step	Default	Description
Control mode		0: Auto 1: Manual	-	0: Auto	Selects the control mode: automatic or manual.

Manual tap increase		0: - 1: Increase	-	0: -	Increases the tap to a higher voltage by one step. This setting is only visible, when the manual control mode has been selected.
Manual tap decrease		0: - 1: Decrease	-	0: -	Decreases the tap to a lower voltage by one step. This setting is only visible, when the manual control mode has been selected.
Control pulselength max		0.000…1800.000 s	0.005 s	2.000 s	Sets the maximum time the tap control's output contact can be closed.
Control pulselength min		0.000…1800.000 s	0.005 s	2.000 s	Sets the minimum time the tap control's output contact must be closed.
Min time between pulses		0.000…1800.000 s	0.005 s	0.500 s	Sets the minimum time between the separate consecutive control commands.

Tap settings

The tap settings define the tap changer equipment properties and the connection for position indication to the regulator. The tap settings also include indicators and measurements.

Table. 5.5.1. - 167. Tap settings parameters.

Name	Range	Step	Default	Description
Tap position status ("Tap position indication")	0: Select 1: mA internal input 7 2: mA internal input 8 3: mA external input 4: Scaled input 5: BCD coded inputs 6: mAIn1 (card 1) 7: mAIn2 (card 2)	-	0: Select	Selects the tap changer's input mode. The "mA internal input x" options are the mA inputs found in the RTD and mA input cards. The "mA external input" option is an external mA input device connected to the RS-458 port. The "Scaled input" option in an input that has been scaled at *Measurements → AI(mA, DI volt) scaling*. The "BCD coded inputs" option refers to the digital inputs. The "mAIn x" options are the mA inputs included in the mA input card.
Tap position indication setting	0: Not selected 1: Set Ok 2: Wrong setting 3: Meas.Quality Fault.	-	0: Not selected	Displays the health of tap position status setting. Informs if the chosen measurement is not available or the quality of the measurement is not good.
External mA input channel	0: CH0 1: CH1 2: CH2 3: CH3 4: CH4 5: CH5 6: CH6 7: CH7	-	0: CH0	Selects the external mA input channel. This setting is only visible when "mA external input" is the selected input mode.
Scaled input signal	0: Scaling curve 1 (mA) 1: Scaling curve 2 (mA) 2: Scaling curve 3 (mA) 3: Scaling curve 4 (mA) 4: Scaling curve 1 (position) 5: Scaling curve 2 (position) 6: Scaling curve 3 (position) 7: Scaling curve 4 (position)	-	0: Scaling curve 1 (mA)	Selects the scaled input signal. This setting is only visible when "Scaled input" is the selected input mode.

Tap position ind. setting	0: Not selected 1: Set Ok 2: Wrong setting 3: Meas.Quality Fault.	-	-	Indicates the status of tap position indication settings. A read-only parameter.
Tap steps totally	1…70	1	18	Displays the number of steps from minimum to maximum.
Tap center location	1…35	1	9	Displays the position of the nominal, non-regulated tap location.
Tap step effect	0.01…10.00 %	0.01 %	1.67 %	Displays the effect of a step (in percentage based on the nominal voltage).
Tap step voltage effect	0.00…5000.00 V_{pri}	0.01 V_{pri}	0 V_{pri}	Sets the effect of one tap step on the primary voltage.
Tap maximum decrease	-140.00…0.00 %	0.01 %	0 %	Sets the maximum voltage decrease from the nominal position.
Tap maximum increase	0.00…140.00 %	0.01 %	0 %	Sets the maximum voltage increase from the nominal position.
Tap control band	0.00…140.00 %	0.01 %	0 %	Sets the tap changer's control band (the second voltage may vary).
Tap position indication	1: Max.mA.max.Pos. 2: Min.mA.max.Pos	-	1: Max.mA.max.Pos	Selects the hightest tap position, the maximum or the minimum value. This setting is not visible when "BCD coded inputs" is the selected input mode.
mA input low range	0.000…20.000 mA	0.001 mA	4.000 mA	Sets the minimum tap position measurement value. This setting is visible, when any of the following is the selected input mode: "mA input 7", "mA input 8", "mA external input", or "Scaled input".
mA input high range	0.010…20.000 mA	0.001 mA	20.000 mA	Sets the maximum tap position measurement value. This setting is visible, when any of the following is the selected input mode: "mA input 7", "mA input 8", "mA external input", or "Scaled input".
Tap step in mA	0.000…20.000 mA	0.001 mA	0 mA	Sets the effect of one tap step on the mA measurement. This setting is visible, when any of the following is the selected input mode: "mA input 7", "mA input 8", "mA external input", or "Scaled input".
mA input now (from the measurement)	0.000…20.000 mA	0.001 mA	-	Displays the mA input measurement value at the moment. This setting is visible, when any of the mA inputs is selected.
mA input now (in the set range)	0.000…20.000 mA	0.001 mA	-	Displays the mA input measurement value at the moment in the location indication range. For example, if the indication range is 4...20 mA and 6 mA is measured by the chosen channel, this parameter displays "2 mA". This setting is visible, when any of the mA inputs is selected.

Statistics

These parameters display the counters of the AVR's common operations and statuses.

Table. 5.5.1. - 168. Counters of the automatic voltage regulator function.

Name	Range	Description
AVR raised voltage	One tap control operation increases cumulative sum by 1	Displays how many times the regulator has increased the bus voltage.

AVR reduced voltage	One tap control operation increases cumulative sum by 1	Displays how many times the regulator has decreased the bus voltage.
AVR control blocked	One blocking operation increases cumulative sum by 1	Displays how many times the AVR operation has been blocked by an external command.
AVR undervoltage blocked	One blocking operation increases cumulative sum by 1	Displays how many times the AVR operation has been blocked by a detected undervoltage condition.
AVR overcurrent blocked	One blocking operation increases cumulative sum by 1	Displays how many times the AVR operation has been blocked by a detected overcurrent condition.
Clear statistics	0: - 1: Clear	Clears the statistics and resets the counters to zero.

Active settings

These settings define the AVR's regulating behavior.

Table. 5.5.1. - 169. Active setting parameters.

Name	Range	Step	Default	Description
Target voltage (UTGT)	70.00…140.00 %U_n	0.01 %U_n	100.00 %U_n	Sets the optimal regulating target voltage.
U>/< window in use	0: Not in use 1: In use	-	0: Not in use	Selects whether or not the low-set definite time voltage window is in use.
U> setting (+UTGT)	0.10…30.00 %U_n	0.01 %U_n	0.88 %U_n	Sets the HV limit for the low-set voltage window. This setting is only visible, when the "U>/< window in use" parameter is activated.
U< setting (-UTGT)	0.10…30.00 %U_n	0.01 %U_n	0.88 %U_n	Sets the LV limit for the low-set voltage window. This setting is only visible, when the "U>/< window in use" parameter is activated.
U>/< time delay (DT)	0.000…1800.000 s	0.005 s	60.000 s	Sets the operating time delay before a regulating command is sent for the high-set voltage window's threshold deviation. This setting is only visible, when the "U>/< window in use" parameter is activated.
U>>/<< window in use	0: Not in use 1: In use	-	0: Not in use	Selects whether or not the high-set definite/inverse time voltage window is in use.
U>> setting (+UTGT)	0.10…30.00 %U_n	0.01 %U_n	2.67 %U_n	Sets the HV limit for the high-set voltage window. This setting is only visible, when the "U>>/<< window in use" parameter is activated.
U<< setting (-UTGT)	0.10…30.00 %U_n	0.01 %U_n	2.67 %U_n	Sets the LV limit for the high-set voltage window. This setting is only visible, when the "U>>/<< window in use" parameter is activated.
U>>/<< time delay mode	0: Definite 1: Integral	-	1: Integral	Selects the time delay mode for the high-set voltage window.
U>>/<< time delay (DT/Multiplier)	0.000…1800.000 s	0.005 s	60.000 s	Sets the operating time delay before a regulating command is sent for the high-set voltage window's threshold deviation. If the "Definite" time delay mode is selected, this value is equal to the set delay time. If the "Integral" time delay mode is selected, this setting is the inverse operating time multiplier. This setting is only visible, when the "U>>/<< window in use" parameter is activated.

U>>> instant in use	0: Not in use 1: In use	-	0: Not in use	Selects whether or not the instant low stage is in use.
U>>> setting (+UTGT)	0.10…30.00 %U_n	0.01 %U_n	8.33 %U_n	Sets the overvoltage threshold for the U>>> instant low stage. This setting is only visible, when the "U>>> instant in use" parameter is activated.
U<<< block setting (-UTGT)	0.00…80.00 %U_n	0.01 %U_n	15.00 %U_n	Sets the undervoltage blocking threshold.
Internal OC blocking	0: Not in use 1: In use	-	0: Not in use	Selects whether or not the internal overcurrent detection blocks the AVR operation.
Internal OC pick-up >	0.00…40.00 × I_n	0.01 × I_n	2.00 × I_n	Sets the pick-up threshold for the internal overcurrent blocking. This setting is only visible, when the "Internal OC blocking" is activated.

External blocking

The operation of the automatic voltage regulator can be blocked either by internal or external input commands. If the operation is done externally, the operation can be blocked by digital inputs or by GOOSE messages. The AVR function provides two separate inputs for blocking. The first blocking input blocks the control algorithm's operation and the output contacts, the second one only blocks the output contacts while the control algorithm is still operational.

Table. 5.5.1. - 170. Blocking inputs.

Name	Description
AVR Block op and outs	The application block for the AVR function. This block should be used for all external blockings of the AVR operation. Blocks the output contacts and prevents the algorithm from operating.
AVR block control outs	The commissioning block for the actual controlling of the output contacts. Blocks only the output contacts of the AVR function.

Output signals

The AVR function has the following available output signals.

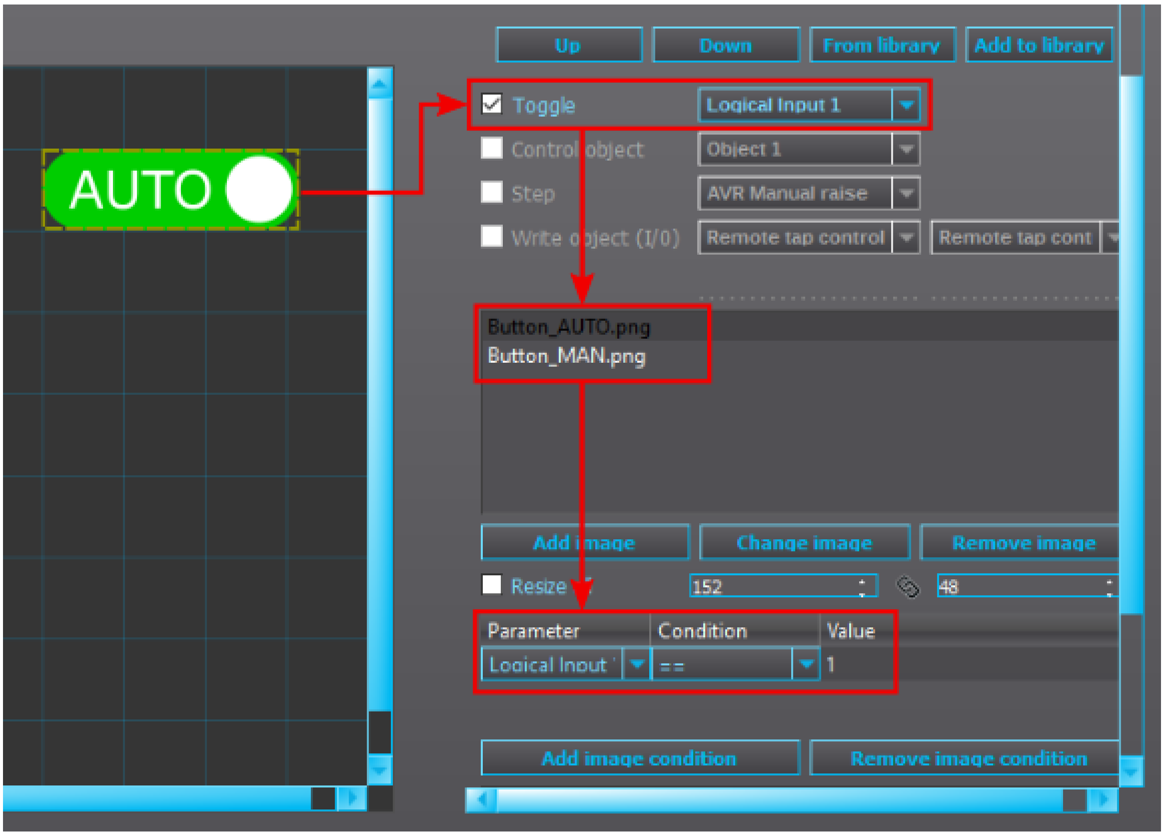
Table. 5.5.1. - 171. Output signals.

Name	Description
AVR raise tap CMD	The output command to raise the tap by one step.
AVR lower tap CMD	The output command to lower the tap by one step.
AVR in manual control	Indicates that the automatic voltage regulation mode is overridden by a manual control.
AVR U>/< started	Indicates that the threhold of the first voltage window has been exceeded, and that the AVR is counting time towards the tap change operation.
AVR U>>/<< started	Indicates that the threhold of the second voltage window has been exceeded, and that the AVR is counting time towards the tap change operation.
AVR outputs blocked	Indicates that the output contact control is blocked, and that 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 time delay of the AVR's consecutive controls is activated. Further output commands are suppressed until this signal is released.

AVR U< block active	Indicates that the internal undervoltage blocking of the tap change operation is active.
AVR I> block active	Indicates that the internal overcurrent blocking of the tap change operation is active.
AVR tap in highlimit	Indicates that no further voltage increase commands can be given because the tap changer is on the high limit.
AVR tap in lowlimit	Indicates that no further voltage decrease commands can be given because the tap changer is on the low limit.

Switching between automatic and manual control modes remotely and locally

If the user wants to switch between the manual and automatic control modes remotely and locally, the most practical way to do it is to use a logical input. Connect the logical input of your choice at *Control → Control functions → Voltage regulator → I/O → Input signal control →* "AVR to manual control". After the input has been set and the logic has been loaded to the relay, ithe user can switch between manual and automatic control modes through a SCADA connection. If the user requires local control for the mode switching, one needs to set a virtual button in the mimic to control the chosen logical input. In the mimic editor (*Tools → Mimic editor*) set an item in the mimic and click the button "From library", and then select one of the control button icons. Next, choose which logical input this button controls, and make sure that the two images in the item are following the status of the correct logical input (see the image below).



When the mimic is loaded to the relay, this virtual button can be controlled in through the relay HMI panel: choose it with the **Cntrl** button and then use the **I** and **0** buttons to activate the manual and automatic modes.

Controlling the tap changer in manual mode with User-buttons

The twelve function buttons next to display can be used to manually control the tap changer. To do this, simply set the desired push buttons at *Control → Control Functions → Voltage regulator → I/O → Input Signal Control →* "AVR Manual raise" or "AVR Manual lower". Please make sure that the chosen push buttons are in the Press release mode (*Control → User-button Settings → User-button Description Settings*). Please note that unit has to be in the manual mode for these button presses to take effect.

WARNING!

It is not recommended to connect push buttons directly to the tap changer's raising and lowering output contacts at *Control → Device IO → Device IO matrix*. If they are, the IED is not capable of prohobiting manual control when the voltage regulator function is in the automatic mode.

Controlling the voltage regulator remotely with IEC 61850

The automatic voltage regulator can also be controlled both locally and remotely with the IEC 61850 communication protocol. This requires that the voltage regulator is added to a dataset. Then the regulator can be controlled at *VRG AVCO/TapChg/Oper.* where "0" means "Stop", "1" means "Raise", and "2" means "Lower".

Events and registers

The automatic voltage regulator function (abbreviated "VRG" in event block names) generates events and registers from the status changes in internal pick-ups and other control events.

The function registers its operation into the last twelve (12) time-stamped registers. The triggering event of the function is recorded with a time stamp and with process data values.

Table. 5.5.1. - 172. Events codes.

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

The function registers its operation into the last twelve (12) time-stamped registers; this information is available for all provided instances separately. The register of the function records the ON event process data for Tap raise/lower, low voltage blocking, overcurrent blocking and other events. The table below presents the structure of the function's register content.

Table. 5.5.1. - 173. Register content.

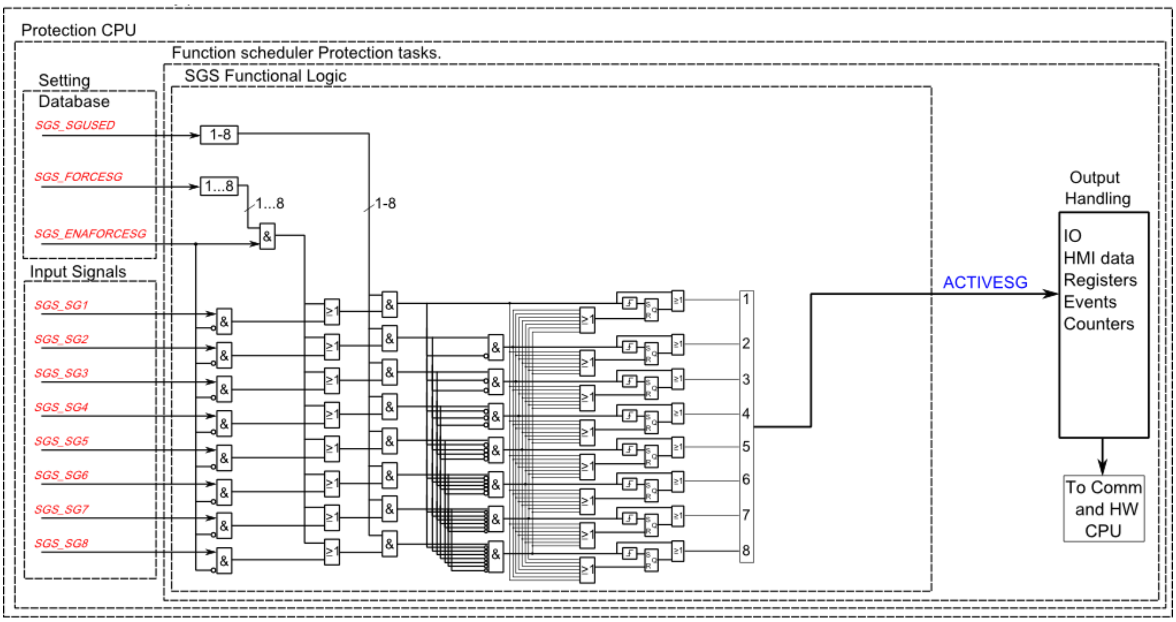
Date and time	Event	Voltage now	Tap now	Target volt	Control mode	Used SG
dd.mm.yyyy hh:mm:ss.mss	7360-7389 Descr.	Voltage at the moment of event	Tap location value	Target voltage	0: Auto 1: Manual	Setting group 1...8 active

5.5.2. Setting group selection

All relay types support up to eight (8) separate setting groups. The Setting group selection function block controls the availability and selection of the setting groups. By default, only Setting group 1 (SG1) is active and therefore the selection logic is idle. When more than one setting group is enabled, the setting group selector logic take control of the setting group activations based on the logic and conditions the user has programmed.

The following figure presents a simplified function block diagram of the setting group selection function.

Figure. 5.5.2. - 132. Simplified function block diagram of the setting group selection function.

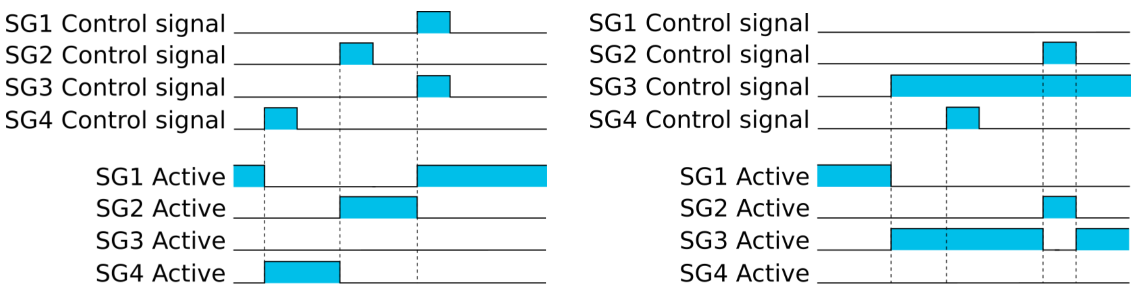


Setting group selection can be applied to each of the setting groups individually by activating one of the various internal logic inputs and connected digital inputs. The user can also force any of the setting groups on when the "Force SG change" setting is enabled by giving the wanted quantity of setting groups as a number in the communication bus or in the local HMI, or by selecting the wanted setting group from *Control → Setting groups*. When the forcing parameter is enabled, the automatic control of the local device is overridden and the full control of the setting groups is given to the user until the "Force SG change" is disabled again.

The switch and selection of application-controlled setting groups can be controlled either by pulses or by signal levels. The setting group controller block gives setting groups priority values for situations when more than one setting group is controlled at the same time: the request from a higher-priority setting group is taken into use.

If static signals are used for control, lower priority setting group requests are not applied. If pulse control is used, control of the setting group has to be applied to all setting groups. For example, if Setting group 2 is selected with a signal and then released, Setting group 1 is not automatically selected as the active setting group; instead, it needs to be specifically set as such.

Figure. 5.5.2. - 133. Example sequences of group changing (control with pulse only, or with both pulses and static signals).



Settings and signals

The settings of the setting group control function include the active setting group selection, the forced setting group selection, the enabling (or disabling) of the forced change, the selection of the number of active setting groups in the application, as well as the selection of the setting group changed remotely. If the setting group is forced to change, the corresponding setting group must be enabled and the force change must be enabled. Then, the setting group can be set from communications or from HMI to any available group. If the setting group control is applied with static signals right after the "Force SG" parameter is released, the application takes control of the setting group selection.

Table. 5.5.2. - 174. Settings of the setting group selection function.

Name	Range	Step	Default	Description
Active setting group			SG1	Displays which setting group is active.
Force SG	0: None 1: SG1 2: SG2 3: SG3 4: SG4 5: SG5 6: SG6 7: SG7 8: SG8	-	0: None	The selection of the overriding setting group. After "Force SG change" is enabled, any of the configured setting groups in the relay can be overriden. This control is always based on the pulse operating mode. It also requires that the selected setting group is specifically controlled to ON after "Force SG" is disabled. If there are no other controls, the last set setting group remains active.
Force SG change	0: Disabled 1: Enabled	-	0: Disabled	The selection of whether the setting group forcing is enabled or disabled. This setting has to be active before the setting group can be changed remotely or from a local HMI. This parameter overrides the local control of the setting groups and it remains on until the user disables it.
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	The selection of the activated setting groups in the application. If a setting group is enabled, it cannot be controlled to "Active". Newly-enabled setting groups copy their values from Setting group 1.
Remote SG change	0: None 1: SG1 2: SG2 3: SG3 4: SG4 5: SG5 6: SG6 7: SG7 8: SG8	-	0: None	This parameter can be controlled through SCADA to change the setting group remotely. Please note that if a higher priority setting group is being controlled by a signal, a lower priority setting group cannot be activated with this parameter.

Table. 5.5.2. - 175. Signals of the setting group selection function.

Name	Range	Step	Default	Description
Setting group 1	0: Not active 1: Active	-	0: Not active	The selection of Setting group 1 ("SG1"). Has the highest priority input in setting group control. Can be controlled with pulses or static signals. If static signal control is applied, no other SG requests will be processed.
Setting group 2	0: Not active 1: Active	-	0: Not active	The selection of Setting group 2 ("SG2"). Has the second highest priority input in setting group control. Can be controlled with pulses or static signals. If static signal control is applied, no requests with a lower priority than SG1 will be processed.

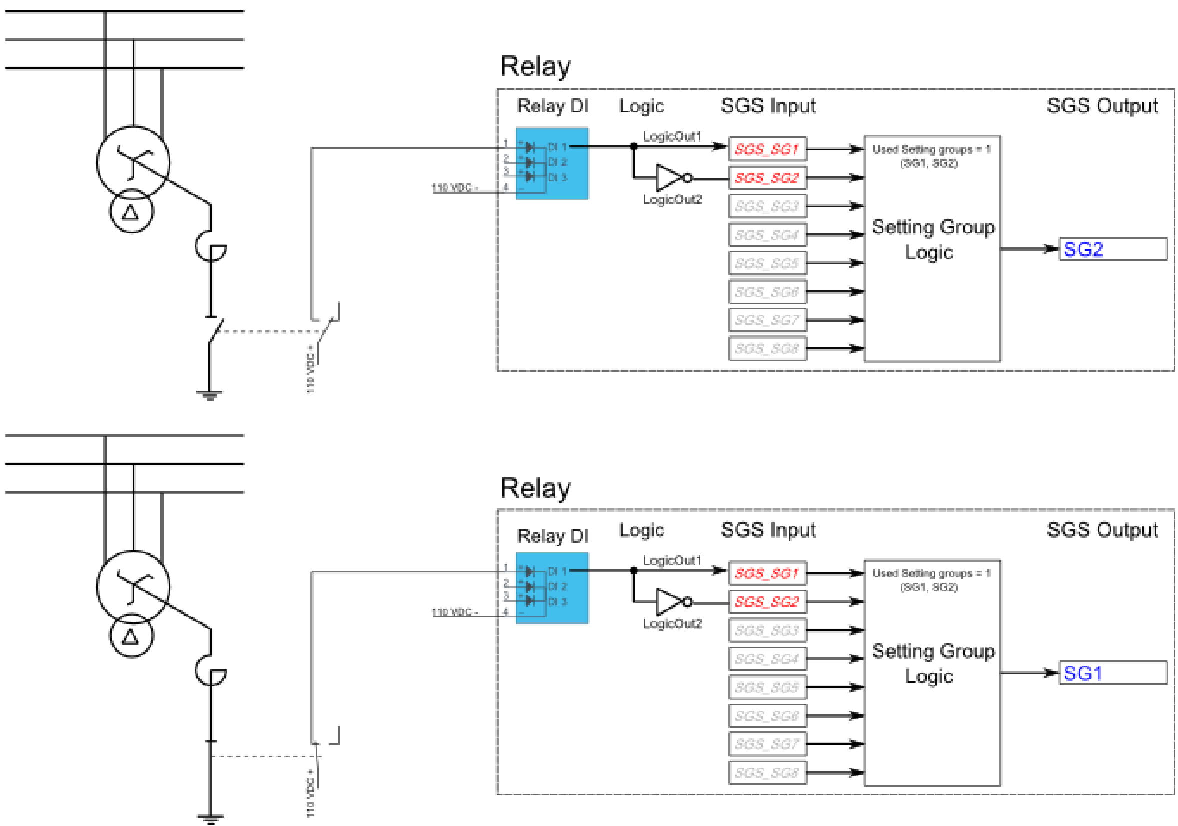
Setting group 3	0: Not active 1: Active	-	0: Not active	The selection of Setting group 3 ("SG3"). Has the third highest priority input in setting group control. Can be controlled with pulses or static signals. If static signal control is applied, no requests with a lower priority than SG1 and SG2 will be processed.
Setting group 4	0: Not active 1: Active	-	0: Not active	The selection of Setting group 4 ("SG4"). Has the fourth highest priority input in setting group control. Can be controlled with pulses or static signals. If static signal control is applied, no requests with a lower priority than SG1, SG2 and SG3 will be processed.
Setting group 5	0: Not active 1: Active	-	0: Not active	The selection of Setting group 5 ("SG5"). Has the fourth lowest priority input in setting group control. Can be controlled with pulses or static signals. If static signal control is applied, SG6, SG7 and SG8 requests will not be processed.
Setting group 6	0:Not active 1:Active	-	0:Not active	The selection of Setting group 6 ("SG6"). Has the third lowest priority input in setting group control. Can be controlled with pulses or static signals. If static signal control is applied, SG7 and SG8 requests will not be processed.
Setting group 7	0: Not active 1: Active	-	0: Not active	The selection of Setting group 7 ("SG7"). Has the second lowest priority input in setting group control. Can be controlled with pulses or static signals. If static signal control is applied, only SG8 requests will not be processed.
Setting group 8	0: Not active 1: Active	-	0: Not active	The selection of Setting group 8 ("SG8"). Has the lowest priority input in setting group control. Can be controlled with pulses or static signals. If static signal control is applied, all other SG requests will be processed regardless of the signal status of this setting group.

Example applications for setting group control

This chapter presents some of the most common applications for setting group changing requirements.

A Petersen coil compensated network usually uses directional sensitive earth fault protection. The user needs to control its characteristics between varmetric and wattmetric; the selection is based on whether the Petersen coil is connected when the network is compensated, or whether it is open when the network is unearthed.

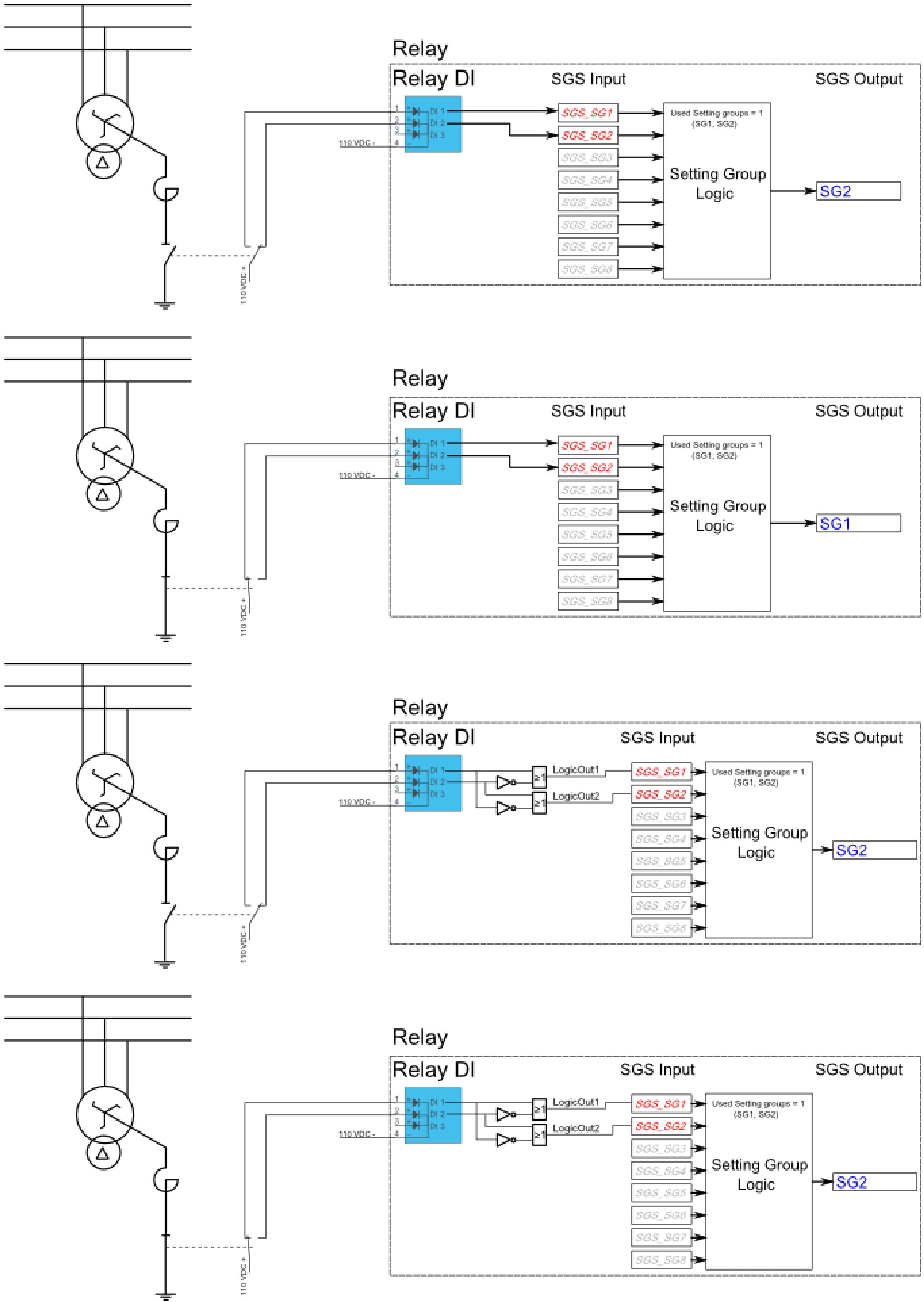
Figure. 5.5.2. - 134. Setting group control – one wire connection from Petersen coil status.



Depending on the application's requirements, the setting group control can be applied either with a one wire connection or with a two wire connection by monitoring the state of the Petersen coil connection.

When the connection is done with one wire, the setting group change logic can be applied as shown in the figure above. The status of the Petersen coil controls whether Setting group 1 is active. If the coil is disconnected, Setting group 2 is active. This way, if the wire is broken for some reason, the setting group is always controlled by SG2.

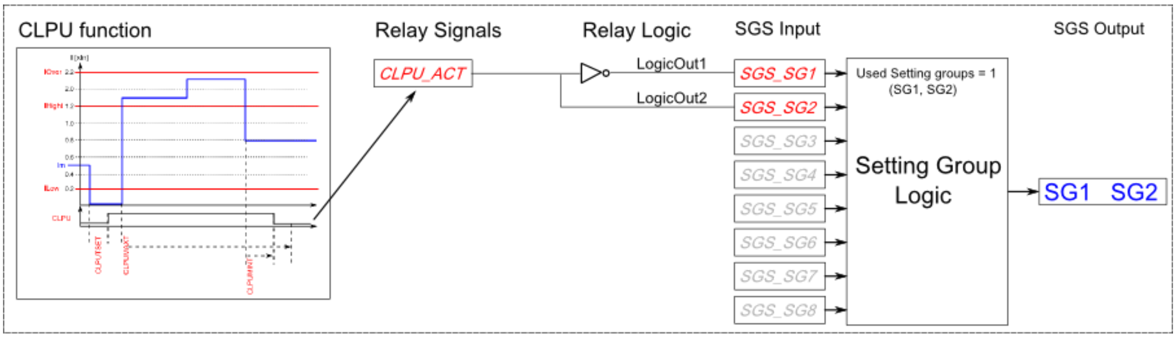
Figure. 5.5.2. - 135. Setting group control – two wire connection from Petersen coil status.



The images above depicts a two wire connection from the Petersen coil: the two images on the top depicts a direct connection, and the two image on the bottom includes additional logic. With a two wire connection the state of the Petersen coil can be monitored more securely. The additional logic ensures that a single wire loss will not affect the correct setting group selection.

The application-controlled setting group change can also be applied entirely from the relay's internal logics. For example, the setting group change can be based on the cold load pick-up function (see the image below).

Figure. 5.5.2. - 136. Entirely application-controlled setting group change with the cold load pick-up function.



In this example the cold load pick-up function's output is used for the automatic setting group change. Similarly to this application, any combination of the signals available in the relay's database can be programmed to be used in the setting group selection logic.

As all these examples show, setting group selection with application control has to be built fully before they can be used for setting group control. The setting group does not change back to SG1 unless it is controlled back to SG1 by this application; this explains the inverted signal NOT as well as the use of logics in setting group control. One could also have SG2 be the primary SG, while the ON signal would be controlled by the higher priority SG1; this way the setting group would automatically return to SG2 after the automatic control is over.

Events

The setting group selection function block (abbreviated "SGS" in event block names) generates events from its controlling status, its applied input signals, enabling and disabling of setting groups, as well as unsuccessful control changes. The function does not have a register.

Table. 5.5.2. - 176. Event codes.

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
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 Reqeuest ON
4191	65	SGS	31	Remote Change SG Request OFF
4192	65	SGS	32	Local Change SG Request ON
4193	65	SGS	33	Local Change SG Request OFF
4194	65	SGS	34	Force Change SG ON
4195	65	SGS	35	Force Change SG OFF
4196	65	SGS	36	SG Request Fail Not configured SG ON
4197	65	SGS	37	SG Request Fail Not configured SG OFF
4198	65	SGS	38	Force Request Fail Force ON
4199	65	SGS	39	Force Request Fail Force OFF
4200	65	SGS	40	SG Req. Fail Lower priority Request ON
4201	65	SGS	41	SG Req. Fail Lower priority Request 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
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

5.5.3. Object control and monitoring

The object control and monitoring function takes care of both for circuit breakers and disconnectors. The monitoring and controlling are based on the statuses of the relay's configured digital inputs and outputs. The number of controllable and monitored objects in each relay depends on the available inputs and outputs. One controllable object requires a minimum of two (2) output contacts. The status monitoring of one monitored object usually requires two (2) digital inputs. Alternatively, object status monitoring can be performed with a single digital input: the input's active state and its zero state (switched to 1 with a NOT gate in the Logic editor).

An object can be controlled by local control, by remote control, by an HMI mimic manually, or by a software function automatically. The function supports the modes "Direct control" and "Select before execute" while controlled remotely.

Object control consists of the following:

- control logic
- control monitor
- output handler.

In addition to these main parts, the user can add object-related circuit breaker failure protection (CBFP; 50BF) and object wear monitoring in the object control block. These additional functions are not included in the basic version of the object control block.

The outputs of the function are the OBJECT OPEN and OBJECT CLOSE control signals. Additionally, the function reports the monitored object's status and applied operations. The setting parameters are static inputs for the function, which can only be changed by the use in the function's setup phase.

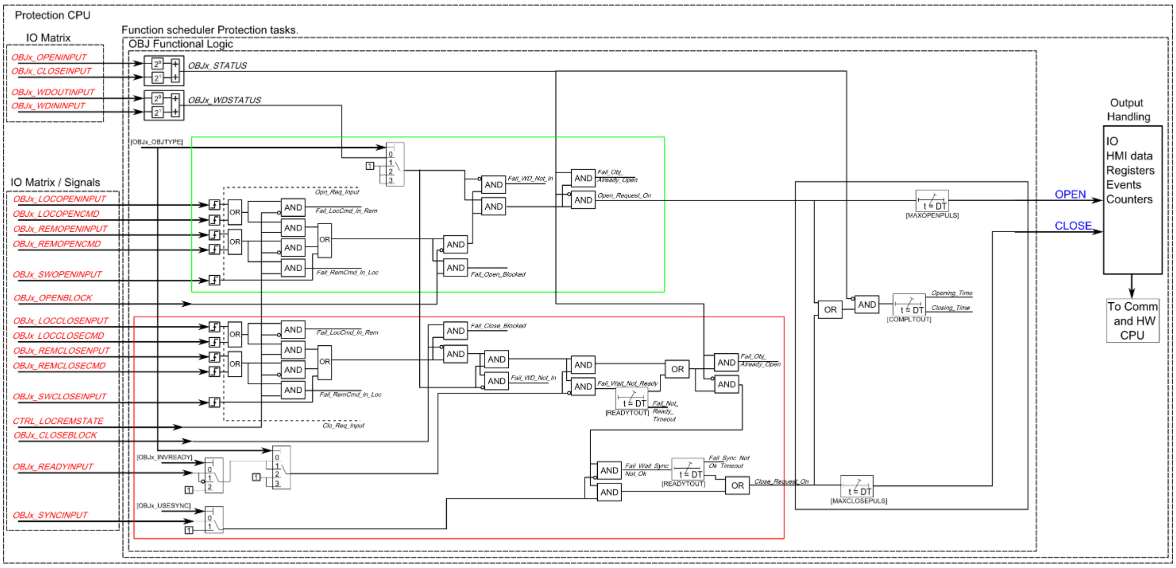
The inputs for the function are the following:

- digital input status indications (the OPEN and CLOSE status signals)
- blockings
- the OBJECT READY and SYNCHROCHECH monitor signals.
- Withdrawable cart IN and OUT status signals.

The function generates general time stamped ON/OFF events to the common event buffer from each of the two (2) output signals as well as several operational event signals. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for OPEN, CLOSE, OPEN FAIL, and CLOSE FAIL events.

The following figure presents a simplified function block diagram of the object control and monitoring function.

Figure. 5.5.3. - 137. Simplified function block diagram of the object control and monitoring function.



Settings

The following parameters help the user to define the object. The operation of the function varies based on these settings and the selected object type. The selected object type determines how much control is needed and which setting parameters are required to meet those needs.

Table. 5.5.3. - 177. Object set and status.

Name	Range	Step	Default	Description
Local/Remote status	0: Local 1: Remote	-	1: Remote	Defines the status of the relay's local or remote switch. Control of the object has to be applied in the correct control location. The remote controls cannot override the open or close commands while in "Local" status.
Object name	-	-	Objectx	The user-set name of the object, at maximum 32 characters long.
Object type	0: Withdrawable circuit breaker 1: Circuit breaker 2: Disconnector (MC) 3: Disconnector (GND)	-	1: Circuit breaker	The selection of the object type. This selection defines the number of required digital inputs for the monitored object. This affects the HMI and the monitoring of the circuit breaker. It also affects whether the withdrawable cart is in or out. See the next table ("Object types") for a more detailed look at which functionalities each of the object types have.
Objectx Breaker status	0: Intermediate 1: Open 2: Closed 3: Bad	-	-	Displays the status of breaker. Intermediate is displayed when neither of the status signals (open or close) are active. Bad status is displayed when both status signals (open and close) are active.
Objectx Withdraw status	0: WDIntermediate 1: WDCartOut 2: WDCart In 3: WDBad 4: Not in use	-	-	Displays the status of circuit breaker cart. WDIntermediate is displayed when neither of the status signals (in or out) are active. WDBad status is displayed when both status signals (in and out) are active. If the selected object type is not set to "Withdrawable circuit breaker", this setting displays the "No in use" option.

Additional status information	0: Open Blocked 1: Open Allowed 2: Close Blocked 3: Close Allowed 4: Object Ready 5: Object Not Ready 6: Sync Ok 7: Sync Not Ok	-	-	Displays additional information about the status of the object.
Use Synchrocheck	0: Not in use 1: Synchrocheck in use	-	0: Not in use	Selects whether the "Synchrocheck" condition is in use for the circuit breaker close command.
Use Object ready	0: Ready High 1: Ready Low 2: Not in use	-	2: Not in use	Selects whether the "Object ready" condition is in use for the circuit breaker close command.
Open requests	0…4 294 967 295	1	-	Displayes the number of successful "Open" requests.
Close requests	0…4 294 967 295	1	-	Displays the number of successful "Close" requests.
Open requests failed	0…4 294 967 295	1	-	Displays the number of failed "Open" requests.
Close requests failed	0…4 294 967 295	1	-	Displays the number of failed "Close" requests.
Clear statistics	0: - 1: Clear	-	0: -	Clears the request statistics, setting them back to zero (0). Automatically returns to "-" after the clearing is finished.

Table. 5.5.3. - 178. Object types.

Name	Functionalities	Description
Withdrawable circuit breaker	WD cart position Position Control Object ready Use synchrocheck Interlocks	The monitor and control configuration of the withdrawable circuit breaker.
Circuit breaker	Position indication Control Object ready Use synchrocheck Interlocks	The monitor and control configuration of the circuit breaker.
Disconnector (MC)	Position indication Control	The position monitoring and control of the disconnector.
Disconnector (GND)	Position indication	The position indication of the earth switch.

Table. 5.5.3. - 179. I/O.

Signal	Range	Description
Objectx Open input ("Objectx Open Status In")	Digital input or other logical signal selected by the user (SWx)	A link to a physical digital input. The monitored object's OPEN status. "1" refers to the active open state of the monitored object. Position indication of digital inputs and protection stage signals can be done by using IEC 61850 signals, GOOSE signals or logical signals.

Objectx Close input ("Objectx Close Status In")	Digital input or other logical signal selected by the user (SWx)	A link to a physical digital input. The monitored object's CLOSE status. "1" refers to the active close state of the monitored object. Position indication of digital inputs and protection stage signals can be done by using IEC 61850 signals, GOOSE signals or logical signals.
WD Object In ("Withdrw.CartIn.Status In")	Digital input or other logical signal selected by the user (SWx)	A link to a physical digital input. The monitored withdrawable object's position is IN. "1" means that the withdrawable object cart is in. Position indication of digital inputs and protection stage signals can be done by using IEC 61850 signals, GOOSE signals or logical signals.
WD Object Out ("Withdrw.CartOut.Status In")	Digital input or other logical signal selected by the user (SWx)	A link to a physical digital input. The monitored withdrawable object's position is OUT. "1" means that the withdrawable object cart is pulled out. Position indication of digital inputs and protection stage signals can be done by using IEC 61850 signals, GOOSE signals or logical signals.
Object Ready (Objectx Ready status In")	Digital input or other logical signal selected by the user (SWx)	A link to a physical digital input. Indicates that status of the monitored object. "1" means that the object is ready and the spring is charged for a close command. Position indication of digital inputs and protection stage signals can be done by using IEC 61850 signals, GOOSE signals or logical signals. The application can set the ready status to be either "1" or "0".
Syncrocheck permission ("Sync.Check status In")	Digital input or other logical signal selected by the user (SWx)	A link to a physical digital input or a synchrocheck function. "1" means that the synchrocheck conditions are met and the object can be closed. Position indication of digital inputs and protection stage signals can be done by using IEC 61850 signals, GOOSE signals or logical signals.
Objectx Open command ("Objectx Open Command")	OUT1…OUTx	The physical "Open" command pulse to the device's output relay.
Objectx Close command ("Objectx Close Command")	OUT1…OUTx	The physical "Close" command pulse to the device's output relay.

Table. 5.5.3. - 180. Operation settings.

Name	Range	Step	Default	Description
Breaker traverse time	0.02…500.00 s	0.02 s	0.2 s	Determines the maximum time between open and close statuses when the breaker switches. If this set time is exceeded and both open and closed status inputs are active, the status "Bad" is activated in the "Objectx Breaker status" setting. If neither of the status inputs are active after this delay, the status "Intermediate" is activated.
Maximum Close command pulse length	0.02…500.00 s	0.02 s	0.2 s	Determines the maximum length for a Close pulse from the output relay to the controlled object. If the object operates faster than this set time, the control pulse is reset and a status change is detected.
Maximum Open command pulse length	0.02…500.00 s	0.02 s	0.2 s	Determines the maximum length for a Open pulse from the output relay to the controlled object. If the object operates faster than this set time, the control pulse is reset and a status change is detected.

Control termination timeout	0.02…500.00 s	0.02 s	10 s	Determines the 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	0.00…500.00 s	0.02 s	0.2 s	Determines the length of the final trip pulse length. When the object has executed the final trip, this signal activates. If set to 0 s, the signal is continuous. This can be used in the matrix or in Logic editor.

Table. 5.5.3. - 181. Control settings (DI and Application).

Signal	Range	Description
Access level for MIMIC control	0: User 1: Operator 2: Configurator 3: Super user	Defines what level of access is required for MIMIC control. The default is the "Configurator" level.
Objectx LOCAL Close control input	Digital input or other logical signal selected by the user	The local Close command from a physical digital input (e.g. a push button).
Objectx LOCAL Open control input	Digital input or other logical signal selected by the user	The local Open command from a physical digital input (e.g. a push button).
Objectx REMOTE Close control input	Digital input or other logical signal selected by the user	The remote Close command from a physical digital input (e.g. RTU).
Objectx REMOTE Open control input	Digital input or other logical signal selected by the user	The remote Open command from a physical digital input (e.g. RTU).
Objectx Application Close	Digital input or other logical signal selected by the user	The Close command from the application. Can be any logical signal.
Objectx Application Open	Digital input or other logical signal selected by the user	The Close command from the application. Can be any logical signal.

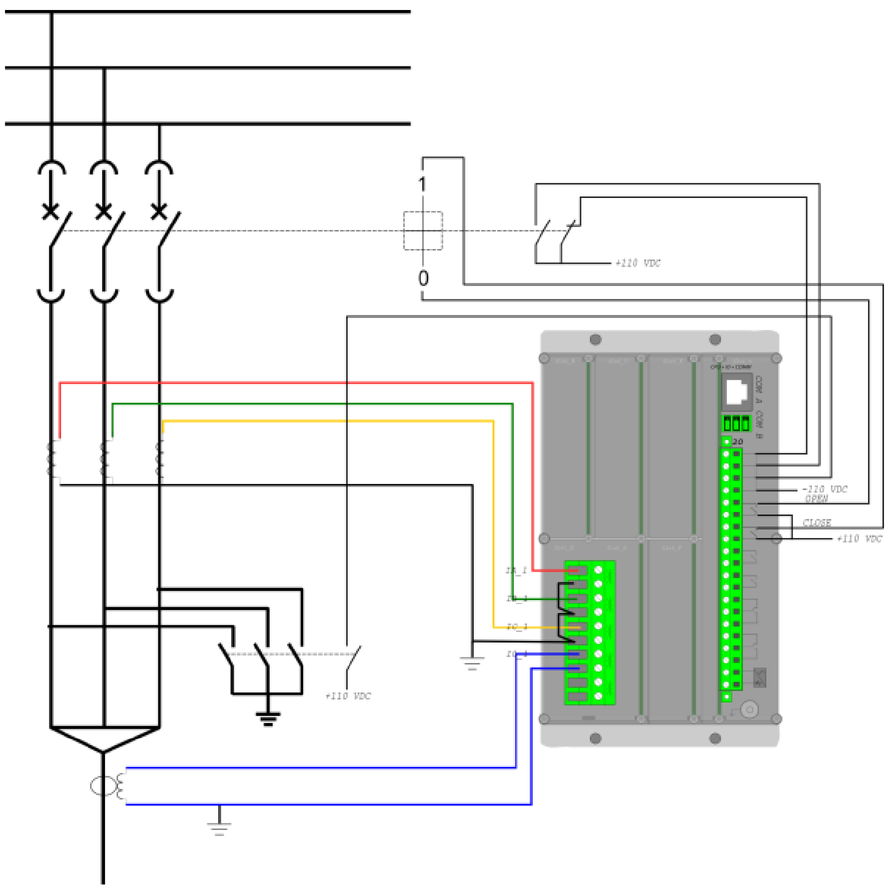
The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the blocking condition is not active.

Blocking and interlocking

The interlocking and blocking conditions can be set for each controllable object, with Open and Close set separately. Blocking and interlocking can be based on any of the following: other object statuses, a software function or a digital input.

The image below presents an example of an interlock application, where the closed earthing switch interlocks the circuit breaker close.

Figure. 5.5.3. - 138. Example of an interlock application.



In order for the blocking signal to be received on time, it has to reach the function 5 ms before the control command.

Events and registers

The object control and monitoring function (abbreviated "OBJ" in event block names) generates events and registers from the status changes in monitored signals as well as control command fails and operations. The user can select the status ON or OFF for messages in the main event buffer.

The function registers its operation into the last twelve (12) time-stamped registers. The triggering event of the function is recorded with a time stamp and with process data values.

Table. 5.5.3. - 182. Event codes of the OBJ function instances 1 – 10.

Event Number	Event channel	Event block name	Event Code	Description
2944	46	OBJ1	0	Object Intermediate
2945	46	OBJ1	1	Object Open
2946	46	OBJ1	2	Object Close
2947	46	OBJ1	3	Object Bad
2948	46	OBJ1	4	WD Intermediate
2949	46	OBJ1	5	WD Out
2950	46	OBJ1	6	WD In
2951	46	OBJ1	7	WD Bad
2952	46	OBJ1	8	Open Request ON

2953	46	OBJ1	9	Open Request OFF
2954	46	OBJ1	10	Open Command ON
2955	46	OBJ1	11	Open Command OFF
2956	46	OBJ1	12	Close Request ON
2957	46	OBJ1	13	Close Request OFF
2958	46	OBJ1	14	Close Command ON
2959	46	OBJ1	15	Close Command OFF
2960	46	OBJ1	16	Open Blocked ON
2961	46	OBJ1	17	Open Blocked OFF
2962	46	OBJ1	18	Close Blocked ON
2963	46	OBJ1	19	Close Blocked OFF
2964	46	OBJ1	20	Object Ready
2965	46	OBJ1	21	Object Not Ready
2966	46	OBJ1	22	Sync Ok
2967	46	OBJ1	23	Sync Not Ok
2968	46	OBJ1	24	Open Command Fail
2969	46	OBJ1	25	Close Command Fail
2970	46	OBJ1	26	Final trip ON
2971	46	OBJ1	27	Final trip OFF
3008	47	OBJ2	0	Object Intermediate
3009	47	OBJ2	1	Object Open
3010	47	OBJ2	2	Object Close
3011	47	OBJ2	3	Object Bad
3012	47	OBJ2	4	WD Intermediate
3013	47	OBJ2	5	WD Out
3014	47	OBJ2	6	WD In
3015	47	OBJ2	7	WD Bad
3016	47	OBJ2	8	Open Request ON
3017	47	OBJ2	9	Open Request OFF
3018	47	OBJ2	10	Open Command ON
3019	47	OBJ2	11	Open Command OFF
3020	47	OBJ2	12	Close Request ON
3021	47	OBJ2	13	Close Request OFF
3022	47	OBJ2	14	Close Command ON
3023	47	OBJ2	15	Close Command OFF
3024	47	OBJ2	16	Open Blocked ON
3025	47	OBJ2	17	Open Blocked OFF
3026	47	OBJ2	18	Close Blocked ON
3027	47	OBJ2	19	Close Blocked OFF
3028	47	OBJ2	20	Object Ready
3029	47	OBJ2	21	Object Not Ready

3030	47	OBJ2	22	Sync Ok
3031	47	OBJ2	23	Sync Not Ok
3032	47	OBJ2	24	Open Command Fail
3033	47	OBJ2	25	Close Command Fail
3034	47	OBJ2	26	Final trip ON
3035	47	OBJ2	27	Final trip OFF
3072	48	OBJ3	0	Object Intermediate
3073	48	OBJ3	1	Object Open
3074	48	OBJ3	2	Object Close
3075	48	OBJ3	3	Object Bad
3076	48	OBJ3	4	WD Intermediate
3077	48	OBJ3	5	WD Out
3078	48	OBJ3	6	WD In
3079	48	OBJ3	7	WD Bad
3080	48	OBJ3	8	Open Request ON
3081	48	OBJ3	9	Open Request OFF
3082	48	OBJ3	10	Open Command ON
3083	48	OBJ3	11	Open Command OFF
3084	48	OBJ3	12	Close Request ON
3085	48	OBJ3	13	Close Request OFF
3086	48	OBJ3	14	Close Command ON
3087	48	OBJ3	15	Close Command OFF
3088	48	OBJ3	16	Open Blocked ON
3089	48	OBJ3	17	Open Blocked OFF
3090	48	OBJ3	18	Close Blocked ON
3091	48	OBJ3	19	Close Blocked OFF
3092	48	OBJ3	20	Object Ready
3093	48	OBJ3	21	Object Not Ready
3094	48	OBJ3	22	Sync Ok
3095	48	OBJ3	23	Sync Not Ok
3096	48	OBJ3	24	Open Command Fail
3097	48	OBJ3	25	Close Command Fail
3098	48	OBJ3	26	Final trip ON
3099	48	OBJ3	27	Final trip OFF
3136	49	OBJ4	0	Object Intermediate
3137	49	OBJ4	1	Object Open
3138	49	OBJ4	2	Object Close
3139	49	OBJ4	3	Object Bad
3140	49	OBJ4	4	WD Intermediate
3141	49	OBJ4	5	WD Out
3142	49	OBJ4	6	WD In

3143	49	OBJ4	7	WD Bad
3144	49	OBJ4	8	Open Request ON
3145	49	OBJ4	9	Open Request OFF
3146	49	OBJ4	10	Open Command ON
3147	49	OBJ4	11	Open Command OFF
3148	49	OBJ4	12	Close Request ON
3149	49	OBJ4	13	Close Request OFF
3150	49	OBJ4	14	Close Command ON
3151	49	OBJ4	15	Close Command OFF
3152	49	OBJ4	16	Open Blocked ON
3153	49	OBJ4	17	Open Blocked OFF
3154	49	OBJ4	18	Close Blocked ON
3155	49	OBJ4	19	Close Blocked OFF
3156	49	OBJ4	20	Object Ready
3157	49	OBJ4	21	Object Not Ready
3158	49	OBJ4	22	Sync Ok
3159	49	OBJ4	23	Sync Not Ok
3160	49	OBJ4	24	Open Command Fail
3161	49	OBJ4	25	Close Command Fail
3162	49	OBJ4	26	Final trip ON
3163	49	OBJ4	27	Final trip OFF
3200	50	OBJ5	0	Object Intermediate
3201	50	OBJ5	1	Object Open
3202	50	OBJ5	2	Object Close
3203	50	OBJ5	3	Object Bad
3204	50	OBJ5	4	WD Intermediate
3205	50	OBJ5	5	WD Out
3206	50	OBJ5	6	WD In
3207	50	OBJ5	7	WD Bad
3208	50	OBJ5	8	Open Request ON
3209	50	OBJ5	9	Open Request OFF
3210	50	OBJ5	10	Open Command ON
3211	50	OBJ5	11	Open Command OFF
3212	50	OBJ5	12	Close Request ON
3213	50	OBJ5	13	Close Request OFF
3214	50	OBJ5	14	Close Command ON
3215	50	OBJ5	15	Close Command OFF
3216	50	OBJ5	16	Open Blocked ON
3217	50	OBJ5	17	Open Blocked OFF
3218	50	OBJ5	18	Close Blocked ON
3219	50	OBJ5	19	Close Blocked OFF

3220	50	OBJ5	20	Object Ready
3221	50	OBJ5	21	Object Not Ready
3222	50	OBJ5	22	Sync Ok
3223	50	OBJ5	23	Sync Not Ok
3224	50	OBJ5	24	Open Command Fail
3225	50	OBJ5	25	Close Command Fail
3226	50	OBJ5	26	Final trip ON
3227	50	OBJ5	27	Final trip OFF
9600	150	OBJ6	0	Object Intermediate
9601	150	OBJ6	1	Object Open
9602	150	OBJ6	2	Object Close
9603	150	OBJ6	3	Object Bad
9604	150	OBJ6	4	WD Intermediate
9605	150	OBJ6	5	WD Out
9606	150	OBJ6	6	WD In
9607	150	OBJ6	7	WD Bad
9608	150	OBJ6	8	Open Request ON
9609	150	OBJ6	9	Open Request OFF
9610	150	OBJ6	10	Open Command ON
9611	150	OBJ6	11	Open Command OFF
9612	150	OBJ6	12	Close Request ON
9613	150	OBJ6	13	Close Request OFF
9614	150	OBJ6	14	Close Command ON
9615	150	OBJ6	15	Close Command OFF
9616	150	OBJ6	16	Open Blocked ON
9617	150	OBJ6	17	Open Blocked OFF
9618	150	OBJ6	18	Close Blocked ON
9619	150	OBJ6	19	Close Blocked OFF
9620	150	OBJ6	20	Object Ready
9621	150	OBJ6	21	Object Not Ready
9622	150	OBJ6	22	Sync Ok
9623	150	OBJ6	23	Sync Not Ok
9624	150	OBJ6	24	Open Command Fail
9625	150	OBJ6	25	Close Command Fail
9626	150	OBJ6	26	Final trip ON
9627	150	OBJ6	27	Final trip OFF
9664	151	OBJ7	0	Object Intermediate
9665	151	OBJ7	1	Object Open
9666	151	OBJ7	2	Object Close
9667	151	OBJ7	3	Object Bad
9668	151	OBJ7	4	WD Intermediate

9669	151	OBJ7	5	WD Out
9670	151	OBJ7	6	WD In
9671	151	OBJ7	7	WD Bad
9672	151	OBJ7	8	Open Request ON
9673	151	OBJ7	9	Open Request OFF
9674	151	OBJ7	10	Open Command ON
9675	151	OBJ7	11	Open Command OFF
9676	151	OBJ7	12	Close Request ON
9677	151	OBJ7	13	Close Request OFF
9678	151	OBJ7	14	Close Command ON
9679	151	OBJ7	15	Close Command OFF
9680	151	OBJ7	16	Open Blocked ON
9681	151	OBJ7	17	Open Blocked OFF
9682	151	OBJ7	18	Close Blocked ON
9683	151	OBJ7	19	Close Blocked OFF
9684	151	OBJ7	20	Object Ready
9685	151	OBJ7	21	Object Not Ready
9686	151	OBJ7	22	Sync Ok
9687	151	OBJ7	23	Sync Not Ok
9688	151	OBJ7	24	Open Command Fail
9689	151	OBJ7	25	Close Command Fail
9690	151	OBJ7	26	Final trip ON
9691	151	OBJ7	27	Final trip OFF
9728	152	OBJ8	0	Object Intermediate
9729	152	OBJ8	1	Object Open
9730	152	OBJ8	2	Object Close
9731	152	OBJ8	3	Object Bad
9732	152	OBJ8	4	WD Intermediate
9733	152	OBJ8	5	WD Out
9734	152	OBJ8	6	WD In
9735	152	OBJ8	7	WD Bad
9736	152	OBJ8	8	Open Request ON
9737	152	OBJ8	9	Open Request OFF
9738	152	OBJ8	10	Open Command ON
9739	152	OBJ8	11	Open Command OFF
9740	152	OBJ8	12	Close Request ON
9741	152	OBJ8	13	Close Request OFF
9742	152	OBJ8	14	Close Command ON
9743	152	OBJ8	15	Close Command OFF
9744	152	OBJ8	16	Open Blocked ON
9745	152	OBJ8	17	Open Blocked OFF

9746	152	OBJ8	18	Close Blocked ON
9747	152	OBJ8	19	Close Blocked OFF
9748	152	OBJ8	20	Object Ready
9749	152	OBJ8	21	Object Not Ready
9750	152	OBJ8	22	Sync Ok
9751	152	OBJ8	23	Sync Not Ok
9752	152	OBJ8	24	Open Command Fail
9753	152	OBJ8	25	Close Command Fail
9754	152	OBJ8	26	Final trip ON
9755	152	OBJ8	27	Final trip OFF
9792	153	OBJ9	0	Object Intermediate
9793	153	OBJ9	1	Object Open
9794	153	OBJ9	2	Object Close
9795	153	OBJ9	3	Object Bad
9796	153	OBJ9	4	WD Intermediate
9797	153	OBJ9	5	WD Out
9798	153	OBJ9	6	WD In
9799	153	OBJ9	7	WD Bad
9800	153	OBJ9	8	Open Request ON
9801	153	OBJ9	9	Open Request OFF
9802	153	OBJ9	10	Open Command ON
9803	153	OBJ9	11	Open Command OFF
9804	153	OBJ9	12	Close Request ON
9805	153	OBJ9	13	Close Request OFF
9806	153	OBJ9	14	Close Command ON
9807	153	OBJ9	15	Close Command OFF
9808	153	OBJ9	16	Open Blocked ON
9809	153	OBJ9	17	Open Blocked OFF
9810	153	OBJ9	18	Close Blocked ON
9811	153	OBJ9	19	Close Blocked OFF
9812	153	OBJ9	20	Object Ready
9813	153	OBJ9	21	Object Not Ready
9814	153	OBJ9	22	Sync Ok
9815	153	OBJ9	23	Sync Not Ok
9816	153	OBJ9	24	Open Command Fail
9817	153	OBJ9	25	Close Command Fail
9818	153	OBJ9	26	Final trip ON
9819	153	OBJ9	27	Final trip OFF
9856	154	OBJ10	0	Object Intermediate
9857	154	OBJ10	1	Object Open
9858	154	OBJ10	2	Object Close

9859	154	OBJ10	3	Object Bad
9860	154	OBJ10	4	WD Intermediate
9861	154	OBJ10	5	WD Out
9862	154	OBJ10	6	WD In
9863	154	OBJ10	7	WD Bad
9864	154	OBJ10	8	Open Request ON
9865	154	OBJ10	9	Open Request OFF
9866	154	OBJ10	10	Open Command ON
9867	154	OBJ10	11	Open Command OFF
9868	154	OBJ10	12	Close Request ON
9869	154	OBJ10	13	Close Request OFF
9870	154	OBJ10	14	Close Command ON
9871	154	OBJ10	15	Close Command OFF
9872	154	OBJ10	16	Open Blocked ON
9873	154	OBJ10	17	Open Blocked OFF
9874	154	OBJ10	18	Close Blocked ON
9875	154	OBJ10	19	Close Blocked OFF
9876	154	OBJ10	20	Object Ready
9877	154	OBJ10	21	Object Not Ready
9878	154	OBJ10	22	Sync Ok
9879	154	OBJ10	23	Sync Not Ok
9880	154	OBJ10	24	Open Command Fail
9881	154	OBJ10	25	Close Command Fail
9882	154	OBJ10	26	Final trip ON
9883	154	OBJ10	27	Final trip OFF

Table. 5.5.3. - 183. Register content.

Name	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event code	2944-9883 Descr.
Recorded Object opening time	Time difference between the object receiving an "Open" command and the object receiving the "Open" status.
Recorded Object closing time	Time difference between the object receiving a "Close" command and object receiving the "Closed" status.
Object status	The status of the object.
WD status	The status of the withdrawable circuit breaker.
Open fail	The cause of an "Open" command's failure.
Close fail	The cause of a "Close" command's failure.
Open command	The source of an "Open" command.
Close command	The source of an "Open" command.
General status	The general status of the function.

5.5.4. Indicator object monitoring

The indicator object monitoring function takes care of the status monitoring of circuit breakers and disconnectors. The function's sole purpose is indication and does not therefore have any control functionality. To control circuit breakers and/or disconnectors, please use the Object control and monitoring function. The monitoring is based on the statuses of the configured relay's digital inputs. The number of monitored indicators in a relay depends on the available inputs and outputs. The status monitoring of one monitored object usually requires two (2) digital inputs. Alternatively, object status monitoring can be performed with a single digital input: the input's active state and its zero state (switched to 1 with a NOT gate in the Logic editor). The selection of the object type is done in Mimic editor.

The outputs of the function are the monitored indicator statuses (Open and Close). The setting parameters are static inputs for the function, which can only be changed by the use in the function's setup phase.

The inputs of the function are the binary status indications. The function generates general time stamped ON/OFF events to the common event buffer from each of the following signals: OPEN, CLOSE, BAD and INTERMEDIATE event signals. The time stamp resolution is 1 ms.

Settings

Function uses available hardware and software digital signal statuses. These input signals are also setting parameters for the function.

Table. 5.5.4. - 184. Indicator status.

Name	Range	Default	Description
Indicator name ("Ind. Name")	-	IndX	The user-set name of the object, at maximum 32 characters long.
IndicatorX Object status ("Ind.X Object Status")	0: Intermediate 1: Open 2: Closed 3: Bad	-	Displays the status of the indicator object. Intermediate status is displayed when neither of the status conditions (open or close) are active. Bad status is displayed when both of the status conditions (open and close) are active.

Table. 5.5.4. - 185. Indicator I/O.

Signal	Range	Description
IndicatorX Open input ("Ind.X Open Status In")	Digital input or other logical signal selected by the user (SWx)	A link to a physical digital input. The monitored indicator's OPEN status. "1" refers to the active "Open" state of the monitored indicator. Position indication of digital inputs and protection stage signals can be done by using IEC 61850 signals, GOOSE signals or logical signals.
IndicatorX Close input ("Ind.X Close Status In")	Digital input or other logical signal selected by the user (SWx)	A link to a physical digital input. The monitored indicator's CLOSE status. "1" refers to the active "Close" state of the monitored indicator. Position indication of digital inputs and protection stage signals can be done by using IEC 61850 signals, GOOSE signals or logical signals.

Events

The indicator object monitoring function (abbreviated "CIN" in event block names) generates events from the status changes in the monitored signals, including the continuous status indications. The user can select the status ON or OFF for messages in the main event buffer.

Table. 5.5.4. - 186. Event codes (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

11010	172	CIN10	2	Close
11011	172	CIN10	3	Bad

5.5.5. Synchrocheck (ΔV/Δa/Δf; 25)

Checking the synchronization is important to ensure the safe closing of the circuit breaker between two systems. When the circuit breaker is closed when the systems are not synchronized can cause several problems such as current surges which damage the interconnecting elements. The synchrocheck function has the following three stages:

- SYN1 – supervises the synchronization condition between the U4 channel and the selected input voltage
- SYN2 – supervises the synchronization condition between the U3 channel and the selected input voltage
- SYN3 – supervises the synchronization condition between the channels U3 and U4.

The seven images below present three different example connections and four example applications of the synchrocheck function.

Figure. 5.5.5. - 139. Example connection of the synchrocheck function (3LN+U4 mode, SYN1 in use, UL1 as reference voltage).

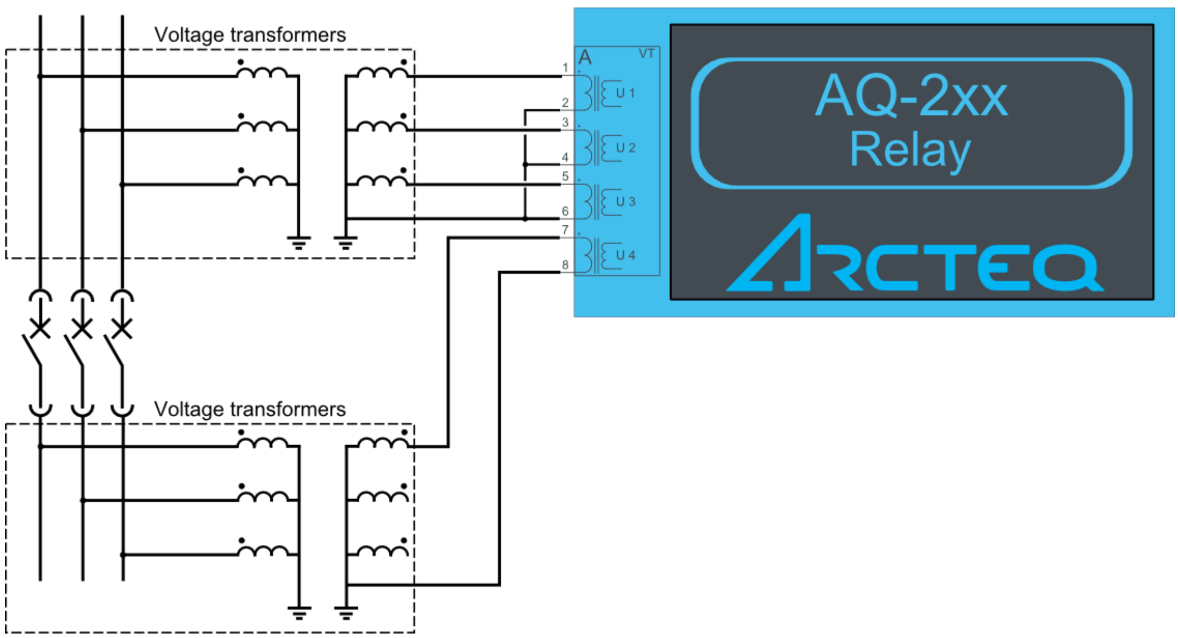


Figure. 5.5.5. - 140. Example connection of the synchrocheck function (2LL+U3+U0 mode, SYN2 in use, UL12 as reference voltage).

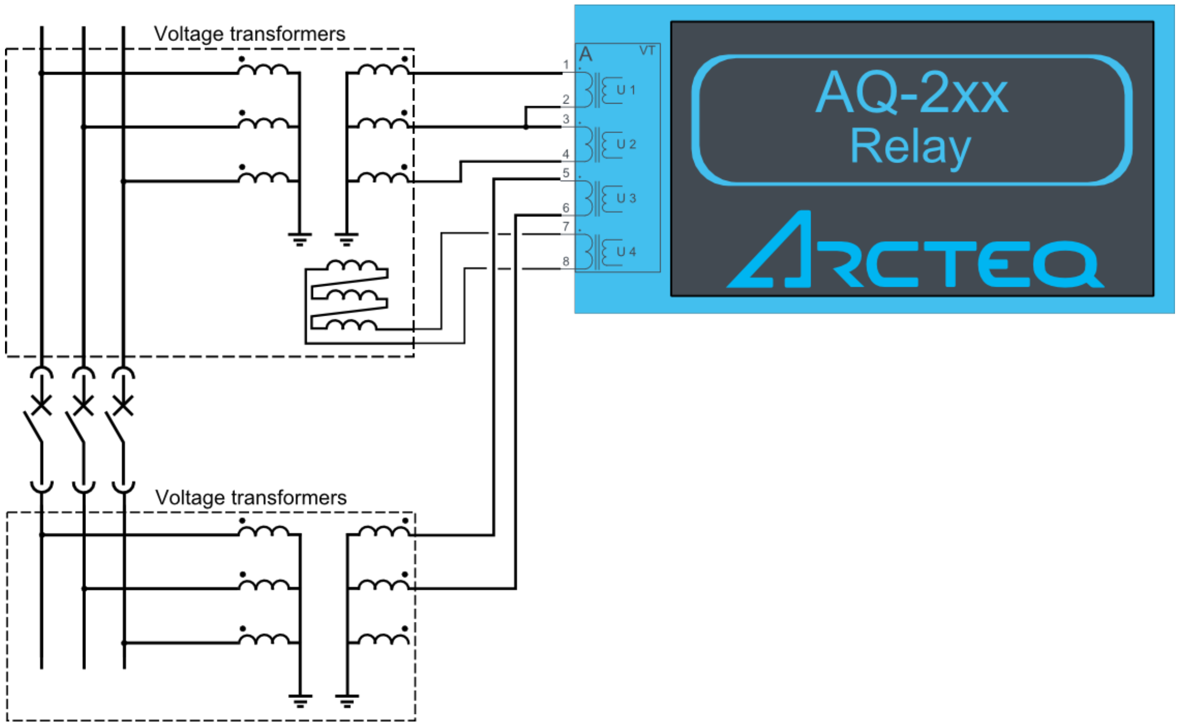


Figure. 5.5.5. - 141. Example connection of the synchrocheck function (2LL+U3+U4 mode, SYN3 in use, UL12 as reference voltage).

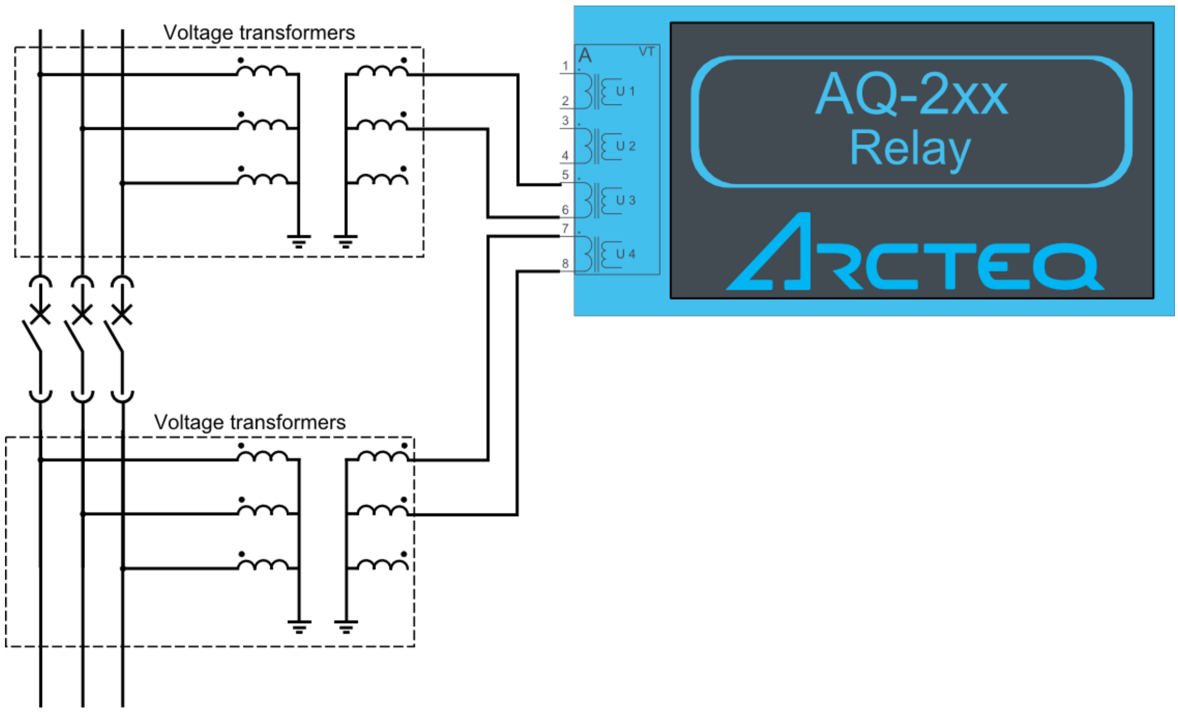


Figure. 5.5.5. - 142. Example application (synchrocheck over one breaker, with 3LL and 3LN VT connections).

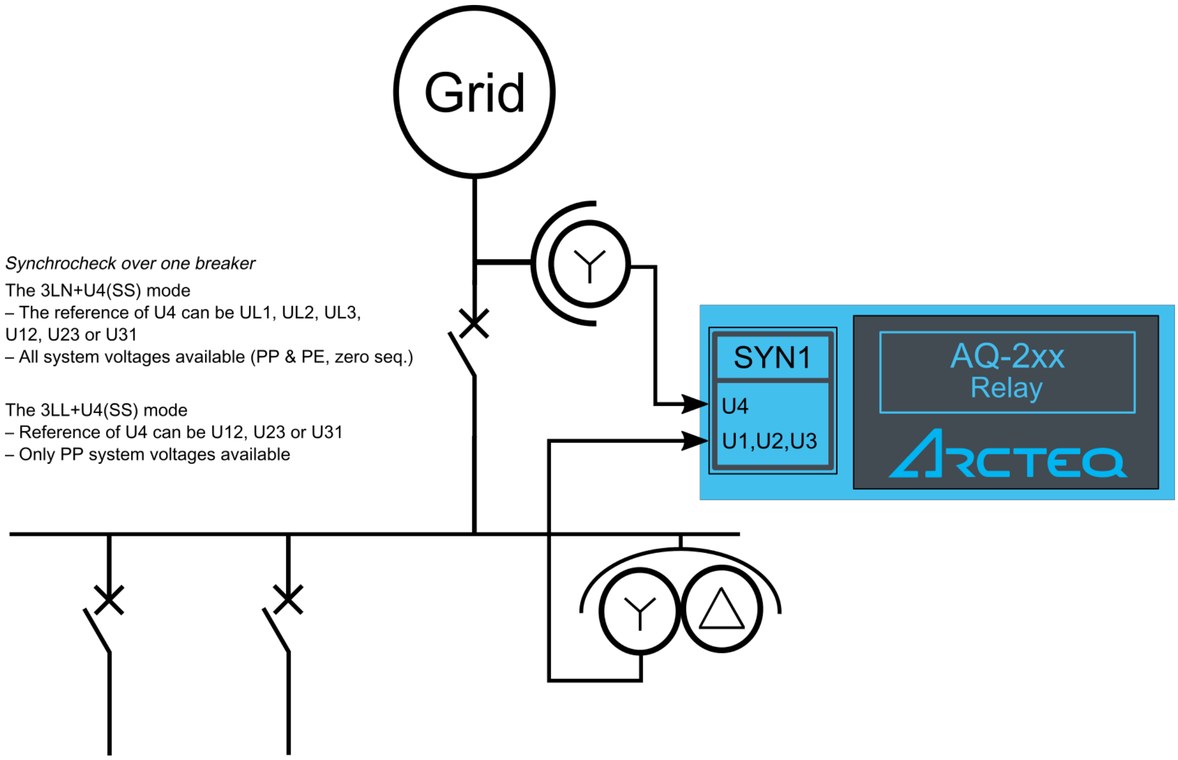


Figure. 5.5.5. - 143. Example application (synchrocheck over one breaker, with 2LL VT connection).

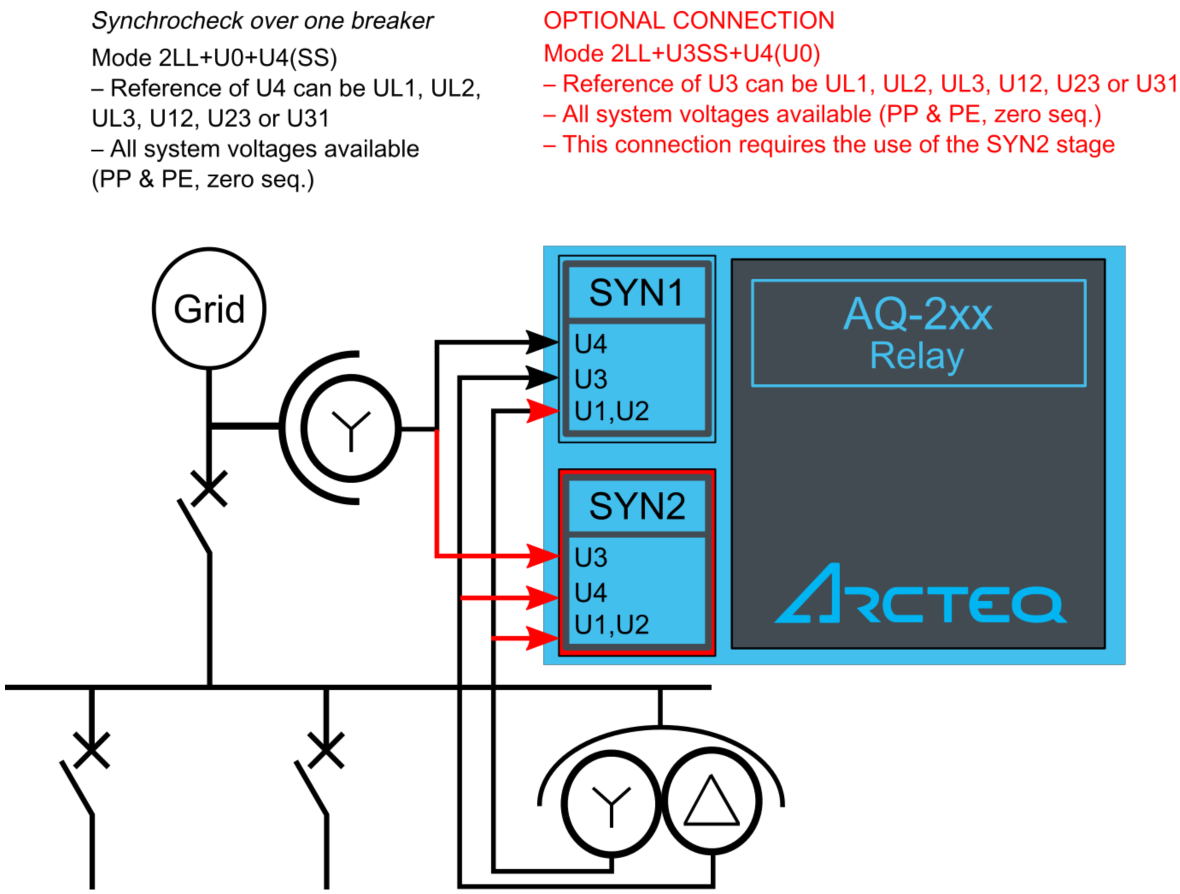


Figure. 5.5.5. - 144. Example application (synchrocheck over two breakers, with 2LL VT connection).

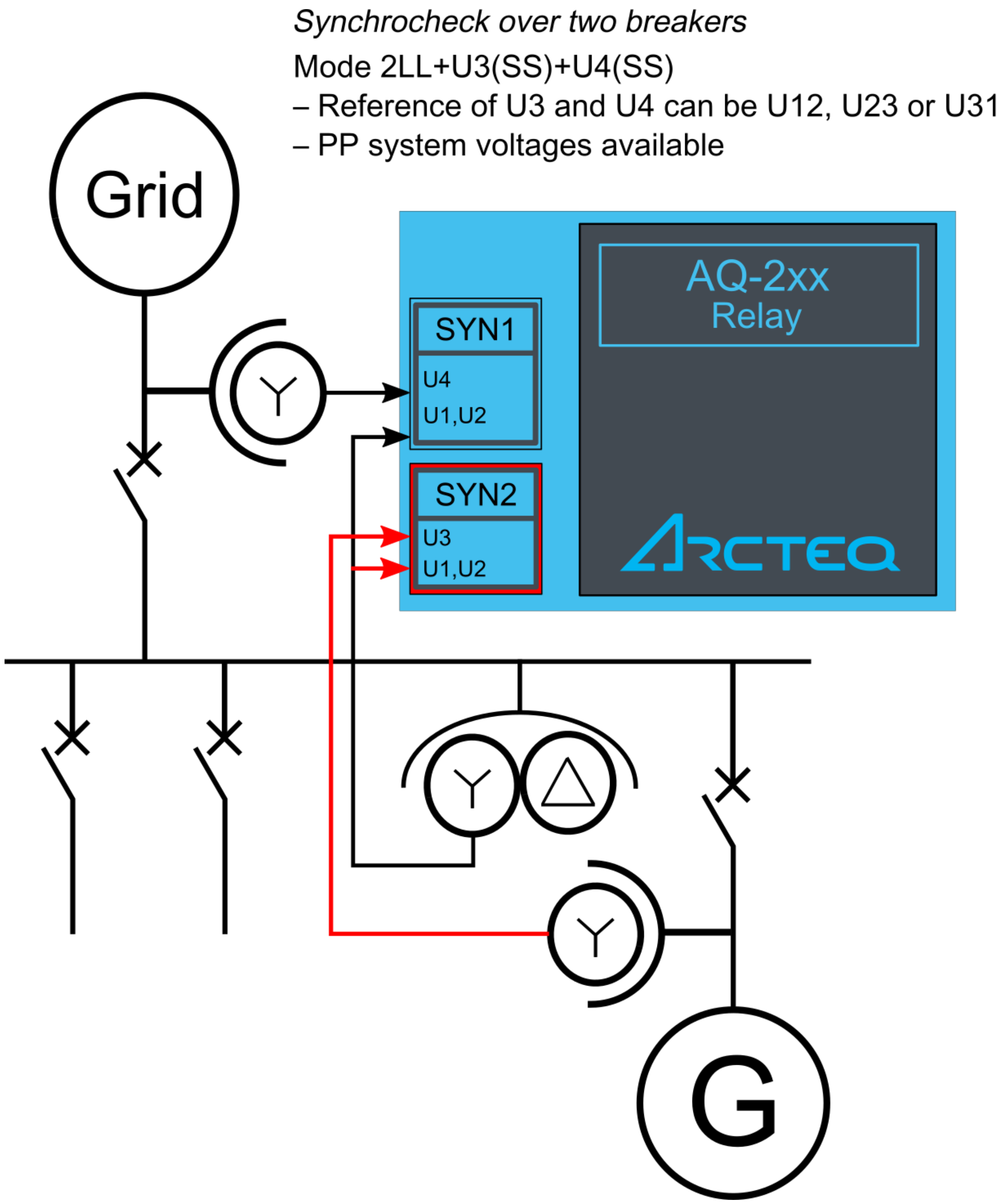
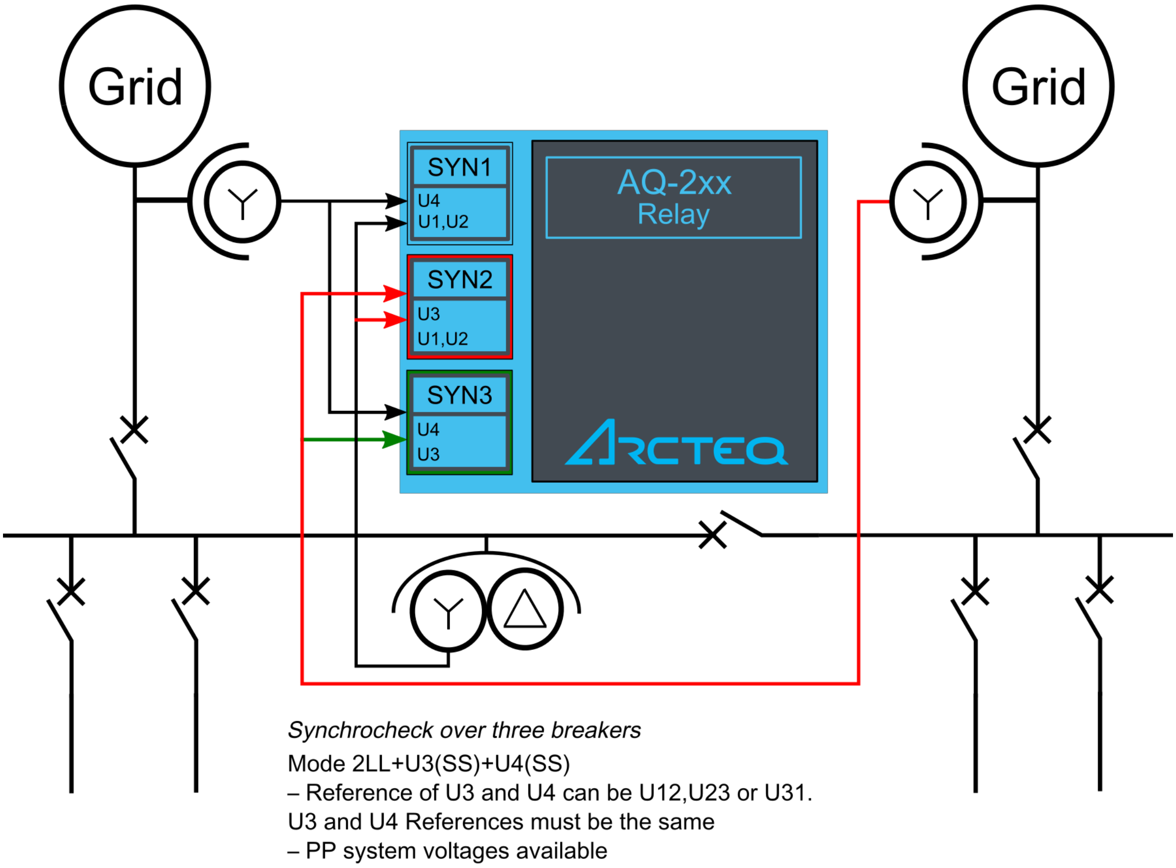


Figure. 5.5.5. - 145. Example application (synchrocheck over three breakers, with 2LL+U3+U4 connection).



The following aspects of the compared voltages are used in synchorization:

- voltage magnitudes
- voltage frequencies
- voltage phase angles

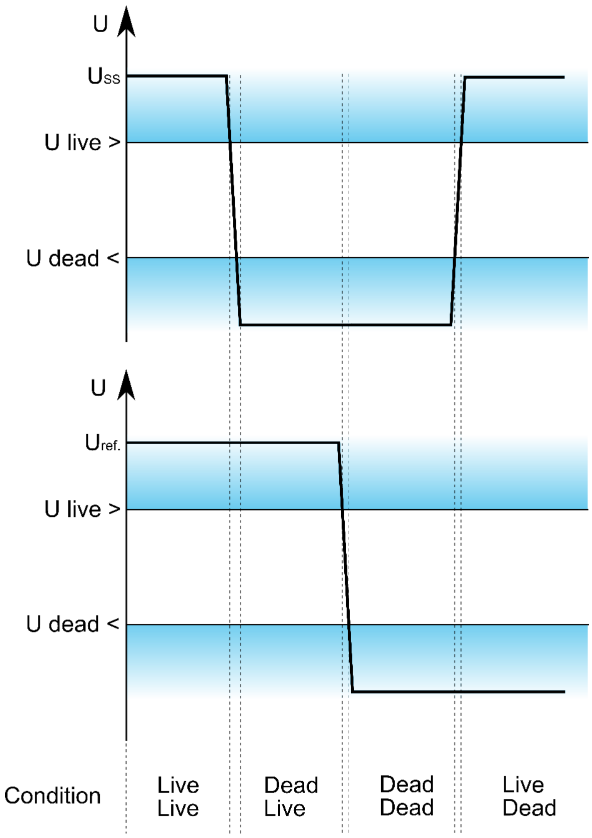
The two systems are synchronized when these three aspects are matched. All three cannot, of course, ever be exactly the same so the function requires the user to set the maximum difference between the measured voltages.

The outputs of the function are the SYN OK, BYPASS, and BLOCKED signals. The synchrocheck function uses a total of eight (8) separate setting groups which can be selected from one common source.

Depending on how the measured voltage compares to the set *U live>* and *U dead<* parameters, either system can be in a "live" or a "dead" state. The parameter *SYNx U conditions* is used to determine the conditions (in addition to the three aspects) which are required for the systems to be considered synchronized.

The image below shows the different states the systems can be in.

Figure. 5.5.5. - 146. System states.



Measured input

The function block uses analog current measurement values and always uses peak-to-peak measurements from samples. The monitored magnitude is equal to fundamental frequency RMS values.

Table. 5.5.5. - 187. Measurement inputs of the synchrocheck 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

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the synchronization is OK, a SYN OK signal is generated.

If the blocking signal is active when the SYN OK activates, a BLOCKED signal is generated and the function does not process the situation further. If the SYN OK function has been activated before the blocking signal, it resets.

The blocking of the function causes an HMI display event and a-time stamped blocking event with information of the startup voltage values and its fault type to be issued.

The blocking signal can also be tested in the commissioning phase by a software switch signal when the relay's testing mode "Enable stage forcing" is activated (*General → Device*). The variables the user can set are binary signals from the system.

Setting parameters

NOTE! Before these settings can be accessed, a voltage channel (U3 or U4) must be set into the synchrocheck mode ("SS") in the voltage transformer settings (*Measurements → VT Module*).

The general settings can be found at the synchrocheck function's *INFO* tab, while the synchrocheck stage settings can be found in the *Settings* tab (*Control → Control functions → Synchrocheck*).

Table. 5.5.5. - 188. General settings.

Name	Range	Step	Default	Description
Use SYNx	0: No 1: Yes	-	0: No	Activated/de-activates the individual stages (SYN1, 2, and 3) of the synchrocheck function. Activating a stage reveals the parameter settings for the configuration.
SYN1 (U4) V Reference	0: Not in use 1: UL12 2: UL23 3: UL31 4: UL1 5: UL2 6: UL3	-	0: Not in use	Selects the reference voltage of the stage. Please note that the available references depend on the selected mode. All references available: - 3LN+U4 - 2LL+U0+U4 Reference options 0...3 available: - 3LL+U4 - 2LL+U3+U4
SYN1 Switching	0: Not in use 1: Use SynSW	-	0: Not in use	Disables or enables synchroswitching. Synchroswitching is available only for SYN1. When synchroswitching is used, the function automatically closes the breaker when both sides of the breaker are synchronized. This setting is only visible when "Use SYN1" is activated.
SYN1 Switching bk time	0.000...1800.000 s	0.005 s	0.05 s	Displays the estimated time between a close command give to a breaker and the breaker entering the closed state. This time is used to time the closing of the breaker so that both sides are as synchronized as possible when the breaker is actually closed. This setting is only visible when "SYN1 switching" is activated.
SYN1 Switching object	0: Object 1 1: Object 2 2: Object 3 3: Object 4 4: Object 5	-	0: Object 1	When synchroswitching is enabled, this parameter defines which object receives the breaker's closing command. This setting is only visible when "SYN1 switching" is activated.
Estimated BRK closing time	0.000…360.000 s	0.005 s	-	Displays the time difference between a breaker close command being given by the relay's output contact and the breaker being closed.
Networks rotating time	0.000…360.000 s	0.005 s	-	Displays the time it takes for both sides of the network to fully rotate.
Networks placement atm	-360.000…360.000 deg	0.001 deg	-	Indicates the angle difference between the two sides of the breaker at the moment.
SYN2 (U3) V Reference	0: Not in use 1: UL12 2: UL23 3: UL31 4: UL1 5: UL2 6: UL3	-	0: Not in use	Selects the reference voltage of the stage. Please note that the available references depend on the selected mode. All references available: - 2LL+U3+U0 Reference options 0...3 available: - 2LL+U3+U4

SYN3 V Reference	0: Not in use 1: U3–U4	-	0: Not in use	Enables and disables the SYN3 stage. Operable in the 2LL+U3+U4 mode, with references UL12, UL23 and UL31 can be connected to the channels..

Table. 5.5.5. - 189. Synchrocheck stage settings.

Name	Range	Step	Default	Description
SYNx U conditions	0: LL only 1: LD only 2: DL only 3: LL & LD 4: LL & DL 5: LL & DD 6: LL & LD & DL 7: LL & LD & DD 8: LL & DL & DD 9: Bypass	-	0: LL only	Determines the allowed states of the supervised systems.
SYNx U live >	0.10…100.00 %Un	0.01 %Un	20 %Un	The voltage limit of the live state.
SYNx U dead <	0.00…100.00 %Un	0.01 %Un	20 %Un	The voltage limit of the dead state.
SYNx U diff <	2.00…50.00 %Un	0.01 %Un	2.00 %Un	The maximum allowed voltage difference between the systems.
SYNx angle diff <	3.00…90.00 deg	0.01 deg	3 deg	The maximum allowed angle difference between the systems.
SYNx freq diff <	0.05…0.50 Hz	0.01 Hz	0.1 Hz	The maximum allowed frequency difference between the systems.

Events and registers

The synchrocheck function (abbreviated "SYN" in event block names) generates events and registers from status changes such as SYN OK, BYPASS, and BLOCKED. The user can select the status ON or OFF for messages in the main event buffer. The function offers three (3) independent stages; the events are segregated for each stage operation.

The triggering event of the function is recorded with a time stamp and with process data values.

Table. 5.5.5. - 190. Event codes.

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
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

The function registers its operation into the last twelve (12) time-stamped registers. The table below presents the structure of the function's register content.

Table. 5.5.5. - 191. Register content.

Name	Range
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event code	2880...2927 Descr.

SYNx Ref1 voltage	The reference voltage of the selected stage.
SYNx Ref2 voltage	The reference voltage of the selected stage.
SYNx Volt Cond	The voltage condition of the selected stage.
SYNx Volt status	The voltage status of the selected stage.
SYNx Vdiff	The voltage difference of the selected stage.
SYNx Vdiff cond	The set condition of the voltage difference of the selected stage.
SYNx Adiff	The angle difference of the selected stage.
SYNx Adiff cond	The set condition of the angle difference of the selected stage.
SYNx fdiff	The frequency difference of the selected stage.
SYNx fdiff cond	The set condition of the frequency difference of the selected stage.
Setting group in use	Setting group 1...8 active.

5.5.6. Milliampere outputs

The milliamp current loop is the prevailing process control signal in many industries. It is an ideal method of transferring process information because a current does not change as it travels from a transmitter to a receiver. It is also much more simple and cost-effective.

The benefits of 4...20 mA loops:

- the dominant standard in many industries
- the simplest option to connect and configure
- uses less wiring and connections than other signals, thus greatly reducing initial setup costs
- good for travelling long distances, as current does not degrade over long connections like voltage does
- less sensitive to background electrical noise
- detects a fault in the system incredibly easily since 4 mA is equal to 0 % output.

Milliampere (mA) outputs

Relays support up to two (2) independent mA option cards. Each card has four (4) mA output channels and one (1) mA input channel. If the device has an mA option card, enable mA outputs at *Control → Device IO → mA outputs*. The outputs are activated in groups of two: channels 1 and 2 are activated together, as are channels 3 and 4 (see the image below).

Figure. 5.5.6. - 147. Activating mA output channels.

Table. 5.5.6. - 192. Main settings (output channels).

Name		Range	Default	Description
mA option card 1	Enable mA output channels 1 and 2	0: Disabled 1: Enabled	0: Disabled	Enables and disables the outputs of the mA output card 1.
	Enable mA output channels 3 and 4			

mA option card 2	Enable mA output channels 5 and 6	0: Disabled 1: Enabled	0: Disabled	Enables and disables the outputs of the mA output card 2.
	Enable mA output channels 7 and 8			

Table. 5.5.6. - 193. Settings for mA output channels.

Name	Range	Step	Default	Description
Enable mA output channel	0: Disabled 1: Enabled	-	0: Disabled	Enables and disables the selected mA output channel. If the channel is disabled, the channel settings are hidden.
Magnitude selection for mA output channel	0: Currents 1: Voltages 2: Powers 3: Impedance and admittance 4: Other	-	0: Currents	Defines the measurement category that is used for mA output control.
Magnitude of mA output channel	(dependent on the measurement category selection)	-	(dependent on the measurement category selection)	Defines the measurement magnitude used for mA output control. The available measurements depend on the selection of the "Magnitude selection for mA output channel" parameter.
Input value 1	$-10^7 \dots 10^7$	0.001	0	The first input point in the mA output control curve.
Scaled mA output value 1	0.0000…24.0000 mA	0.0001 mA	0 mA	The mA output value when the measured value is equal to or less than Input value 1.
Input value 2	$-10^7 \dots 10^7$	0.001	1	The second input point in the mA output control curve.
Scaled mA output value 2	0.0000…24.0000 mA	0.0001 mA	0 mA	The mA output value when the measured value is equal to or greater than Input value 2.

Figure. 5.5.6. - 148. Example of the effects of mA output channel settings.

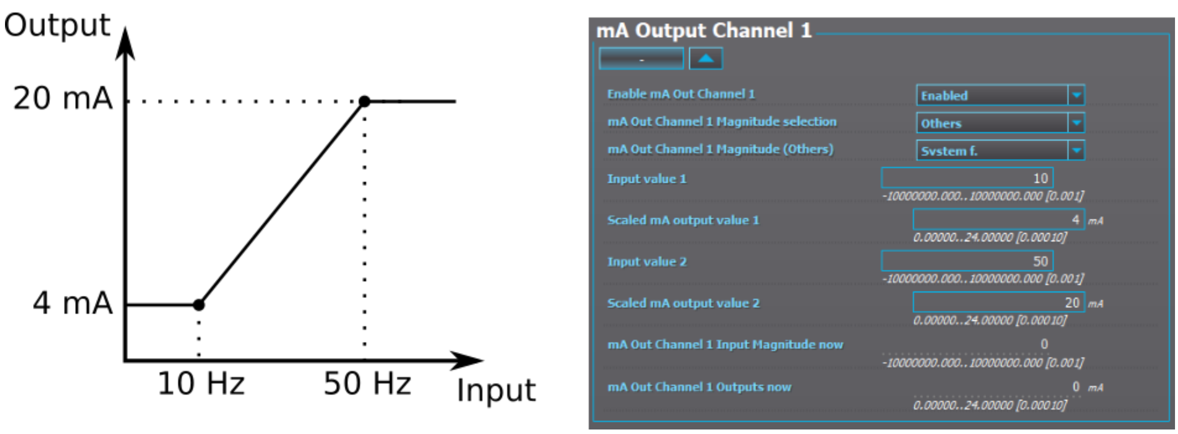


Table. 5.5.6. - 194. Hardware indications.

Name	Range	Step	Description

Hardware in mA output channels 1...4	0: None 1: Slot A 2: Slot B 3: Slot C 4: Slot D 5: Slot E 6: Slot F 7: Slot G 8: Slot H 9: Slot I 10: Slot J 11: Slot K 12: Slot L 13: Slot M 14: Slot N 15: Too many cards installed	-	Indicates the option card slot where the mA output card is located.
Hardware in mA output channels 5...8			

Table. 5.5.6. - 195. Measurement values reported by mA output cards.

Name	Range	Step	Description
mA in Channel 1	0.0000…24.0000 mA	0.0001 mA	Displayes the measured mA value of the selected input channel.
mA in Channel 2			
Input magnitude of the mA output channel	$-10^7 \dots 10^7$	0.001	Displayes the input value of the selected mA output channel at that moment.
Output magnitude of the mA output channel	0.0000…24.0000 mA	0.0001 mA	Displayes the output value of the selected mA output channel at that moment.

Milliampere input

Relays support up to two (2) independent mA option cards. Each card has four (4) mA output channels and one (1) mA input channel. If the device has an mA option card, enable the mA input at *Measurement → AI (mA, DI volt) scaling*. Activating "Analog input scaling" allows for the creation of a scaling curve (see the image below).

Figure. 5.5.6. - 149. Activating analog input scaling to create a scaling curve.

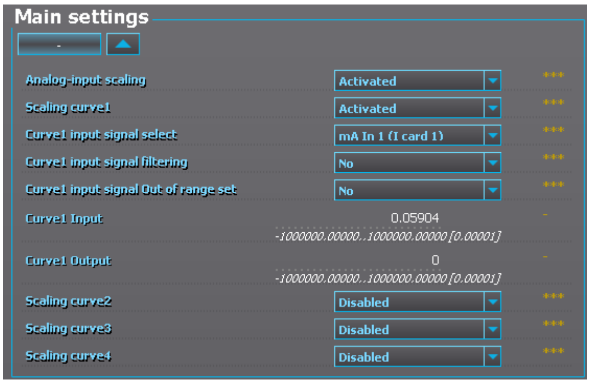


Table. 5.5.6. - 196. Main settings (input channel).

Name	Range	Default	Description
Analog input scaling	0: Disabled 1: Activated	0: Disabled	Enables and disables the mA input.
Scaling curve 1...4	0: Disabled 1: Activated	0: Disabled	Enables and disables the scaling curve and the mA input measurement.

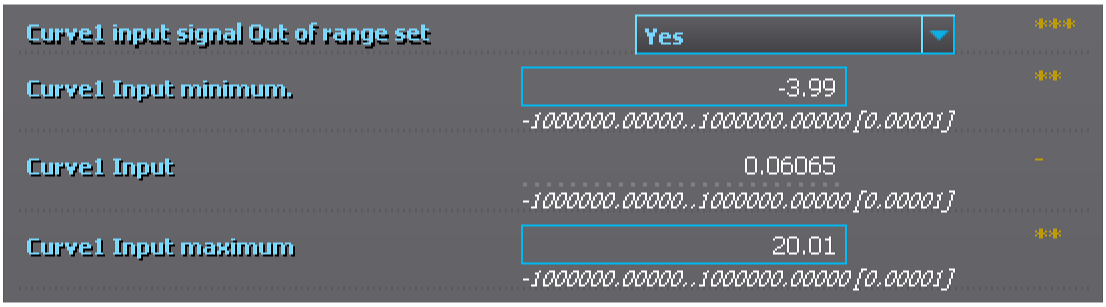
Curve 1...4 input signal select	0: RTD S1 resistance … 15: RTD S16 resistance 16: mA in 1 (I card 1) 17: mA in 2 (I card 2)	0: RTD S1 resistance	Defines the measurement category used for mA input control.

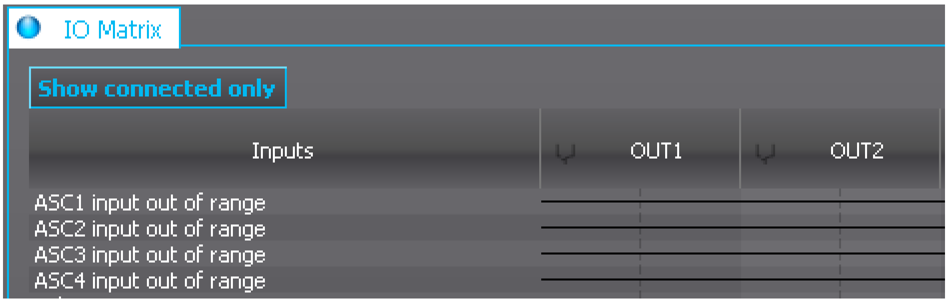
The input signal filter (see the image below) calculates the average of received mA signals according to the set time constant. This is why rapid changes and disturbances (such as fast spikes) are smothered.

The Nyquist rate states that the filter time constant must be at least double the period time of the disturbance process signal. For example, the value for the filter time constant is 2 seconds for a 1 second period time of a disturbance oscillation.

$$H(s) = \frac{Wc}{S+Wc} = \frac{1}{1+s/Wc}$$

When the curve signal is out of range, it activates the "Out of range" alarm, which can be used inside logic or with other relay functions. The signal can be assigned directly to an output relay or to an LED in the I/O matrix. The "Out of range" signal is activated, when the measured mA signal falls below the set input minimum limit, or when it exceeds the input maximum limit. The "Out of range" signal is very useful when e.g. a 4…20 mA input signal is used (see the image below).





If for some reason the mA input signal is lost, the value is fixed to the last actual measured cycle value. The value does not go down to the minimum if it has been something else at the time of the signal breaking.

Table. 5.5.6. - 197. Output settings and indications.

Name	Range	Step	Default	Description

Curve 1...4 update cycle	5...10 000 ms	5 ms	150 ms	Defines the length of the mA input measurement update cycle. If the user wants a fast operation, this setting should be fairly low.
Scaled value handling	0: Floating point 1: Integer out (Floor) 2: Integer (Ceiling) 3: Integer (Nearest)	-	0: Floating point	Rounds the milliampere signal output as selected.
Input value 1	0...4000	0.000 01	0	The measured milliampere input value at Curve Point 1.
Scaled output value 1	$-10^7...10^7$	0.000 01	0	Scales the measured milliampere signal at Point 1.
Input value 2	0...4000	0.000 01	1	The measured milliampere input value at Curve Point 2.
Scaled output value 1	$-10^7...10^7$	0.000 01	0	Scales the measured milliampere signal at Point 2.
Add curvepoint 3...20	0: Not used 1: Used	-	0: Not used	Allows the user to create their own curve with up to twenty (20) curve points, instead of using a linear curve between two points.

5.6. Monitoring functions

5.6.1. Current transformer supervision

The current transformer supervision function (abbreviated CTS in this document) is used for monitoring the CTs as well as the wirings between the device and the CT inputs for malfunctions and wire breaks. An open CT circuit can generate dangerously high voltages into the CT secondary side, and cause unintended activations of current balance monitoring functions.

The function constantly monitors the instant values and the key calculated magnitudes of the phase currents. Additionally, the residual current circuit can be monitored if the residual current is measured from a dedicated residual current CT. The user can enable and disable the residual circuit monitoring at will.

The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

The outputs of the function are the CTS ALARM and BLOCKED signals. The function uses a total of eight (8) separate setting groups which can be selected from one common source. Also, the operating mode of the function can be changed via setting group selection.

The operational logic consists of the following:

- input magnitude processing
- threshold comparator
- block signal check
- time delay characteristics
- output processing.

The following conditions have to met simultaneously for the function alarm to activate:

- None of the three-phase currents exceeds the I_{set} *high limit* setting.
- At least one of the three-phase currents exceeds the I_{set} *low limit* setting.
- At least one of the three-phase currents are below the I_{set} *low limit* setting.

- The ratio between the calculated minum and maximum of the three-phase currents is below the I_{set} *ratio* setting.
- The ratio between the negative sequence and the positive sequence exceeds the *I2/I1 ratio* setting.
- The calculated difference (IL1+IL2+IL3+I0) exceeds the I_{sum} *difference* setting (optional).
- The above-mentioned condition is met until the set time delay for alarm.

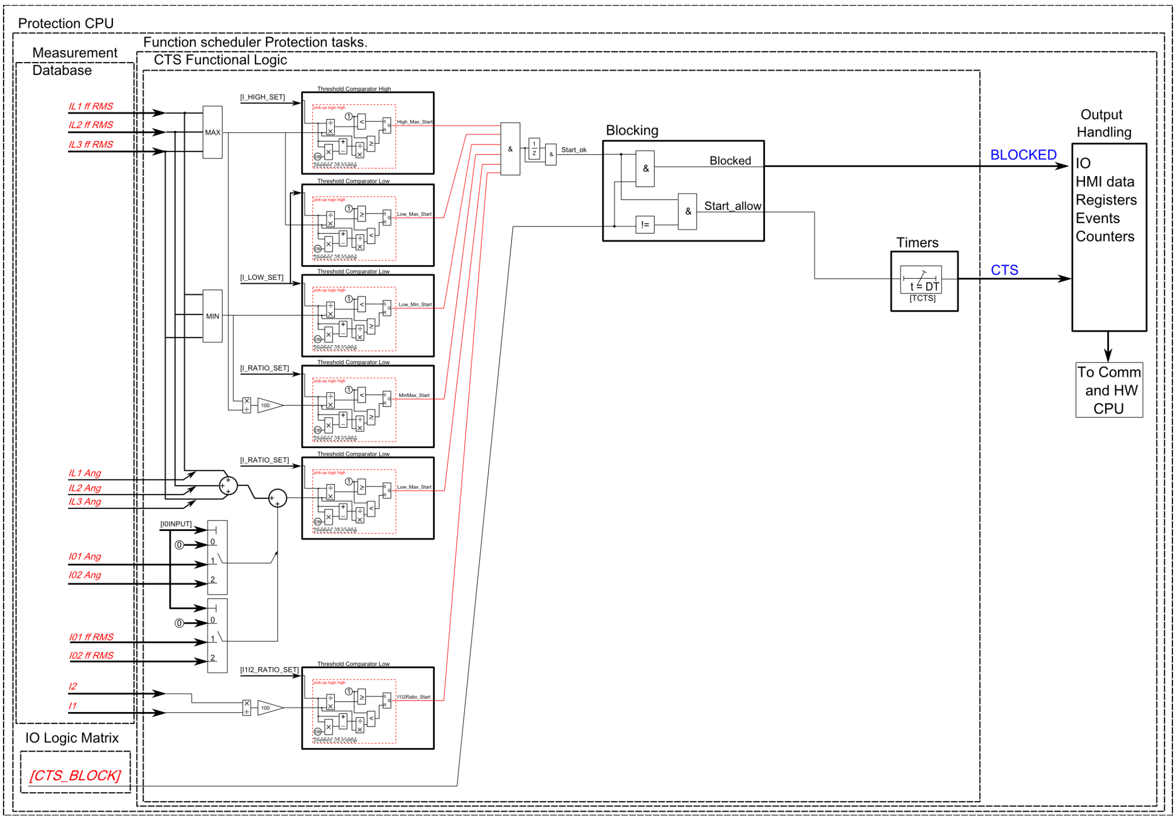
The inputs of the function are the following:

- setting parameters
- measured and pre-processed current magnitudes.

The output signals can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the two (2) output signal. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the CTS ALARM and BLOCKED events.

The following figure presents a simplified function block diagram of the current transformer supervision function.

Figure. 5.6.1. - 150. Simplified function block diagram of the CTS function.



Measured input

The function block uses analog current measurement values, the fundamental frequency magnitude of the current measurement inputs, and the calculated poisitive and negative sequence currents. The user can select what is used for the residual current measurement: nothing, the I01 fundamental frequency, or the I02 fundamental frequency.

Table. 5.6.1. - 198. Measured inputs of 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 current's positive sequence component	5 ms
I2	Phase current's 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

The selection of the AI channel in use is made with a setting parameter. In all possible input channel variations the pre-fault condition is presented with a 20 ms averaged history value from -20 ms from START or TRIP event.

Table. 5.6.1. - 199. Residual current input signals.

Name	Range	Step	Default	Description
I0 input selection	0: Not in use 1: I01 2: I02	-	0: Not in use	Selects the measurement input for the residual current. If the residual current is measured with a separate CT, the residual current circuit can be monitored with the CTS function as well. However, this does not apply to summing connections (Holmgren, etc.). If the phase current CT is summed with I01 or I02, this selection should be set to "Not in use".

Pick-up

The I_{set} and $I0_{set}$ setting parameters control the current-dependent pick-up and activation of the current transformer supervision function. They define the minimum allowed measured current before action from the function. The function constantly calculates the ratio between the setting values and the measured magnitude (I_m) for each of the three phases and for the selected residual current input. The reset ratio of 97 % is built into the function and is always relative to the I_{set} value. The setting value is common for all measured amplitudes, and when the I_m exceeds the I_{set} value (in single, dual or all voltages) it triggers the pick-up operation of the function.

Table. 5.6.1. - 200. Pick-up settings.

Name	Range	Step	Default	Description
I_{set} high limit	0.01…40.00 × I_n	0.01 × I_n	1.20 × I_n	Determines the pick-up threshold for phase current measurement. This setting limit defines the upper limit for the phase current's pick-up element. If this condition is met, it is considered as fault and the function is not activated.
I_{set} low limit	0.01…40.00 × I_n	0.01 × I_n	0.10 × I_n	Determines the pick-up threshold for phase current measurement. This setting limit defines the lower limit for the phase current's pick-up element. This condition has to be met for the function to activate.
I_{set} ratio	0.01…100.00 %	0.01 %	10.00 %	Determines the pick-up ratio threshold between the minimum and maximum values of the phase current. This condition has to be met for the function to activate.

I2/I1 ratio	0.01…100.00 %	0.01 %	49.00 %	Determines the pick-up ratio threshold for the negative and positive sequence currents calculated from the phase currents. This condition has to be met for the function to activate. The ratio is 50 % for a full single-phasing fault (i.e. when one of the phases is lost entirely). Setting this at 49 % allows a current of 0.01 × I_n to flow in one phase, wile the other two are at nominal current.
I_{sum} difference	0.01…40.00 × I_n	0.01 × I_n	0.10 × I_n	Determines the pick-up ratio threshold for the calculated residual phase current and the measured residual current. If the measurement circuit is healthy, the sum of these two currents should be 0.
Time delay for alarm	0.000…1800.000 s	0.005 s	0.5 s	Determines the delay between the activation of the function and the alarm.

The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the blocking condition is not active. When the activation of the pick-up is based on binary signals, the activation happens immediately after the monitored signal is activated.

Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's 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 the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup current values and its fault type to be issued.

The blocking signal can also be tested in the commissioning phase by a software switch signal when the relay's testing mode "Enable stage forcing" is activated (*General → Device*).

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

Operating time characteristics

This function supports definite time delay (DT). For detailed information on this delay type please refer to the chapter "General properties of a protection function" and its section "Operating time characteristics for trip and reset".

Typical cases of current transformer supervision

The following nine examples present some typical cases of the current transformer supervision and their setting effects.

Figure. 5.6.1. - 151. All works properly, no faults.

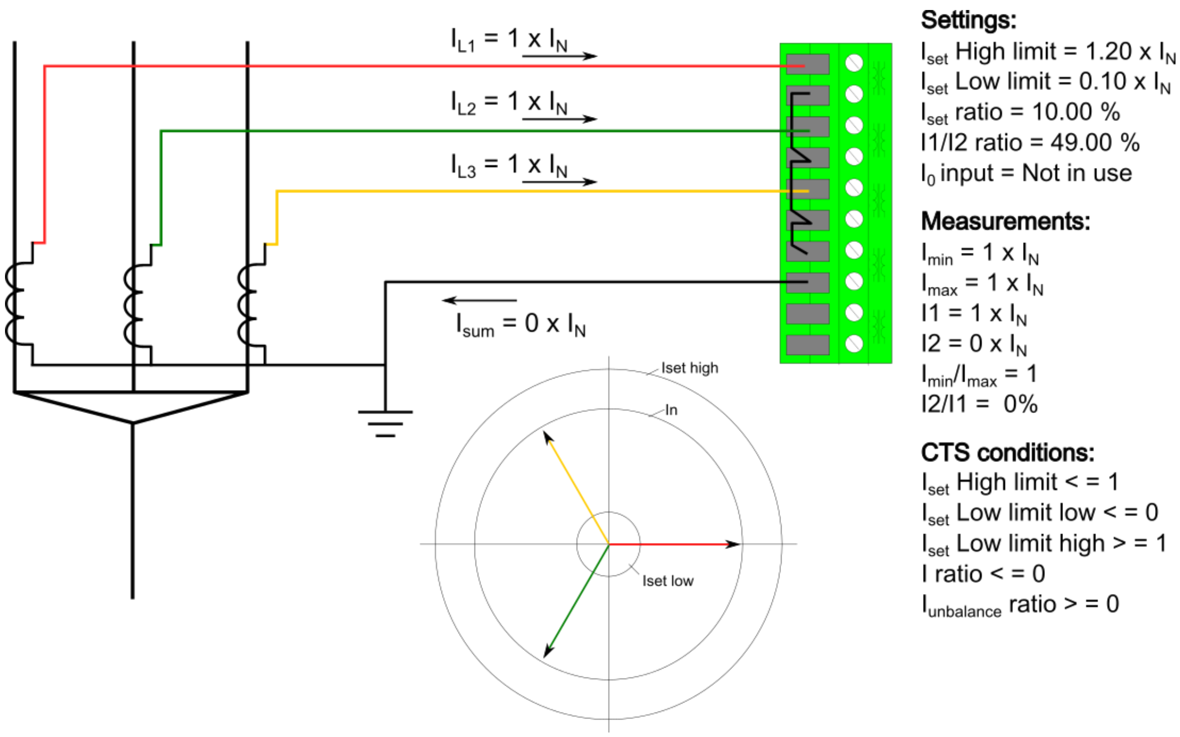
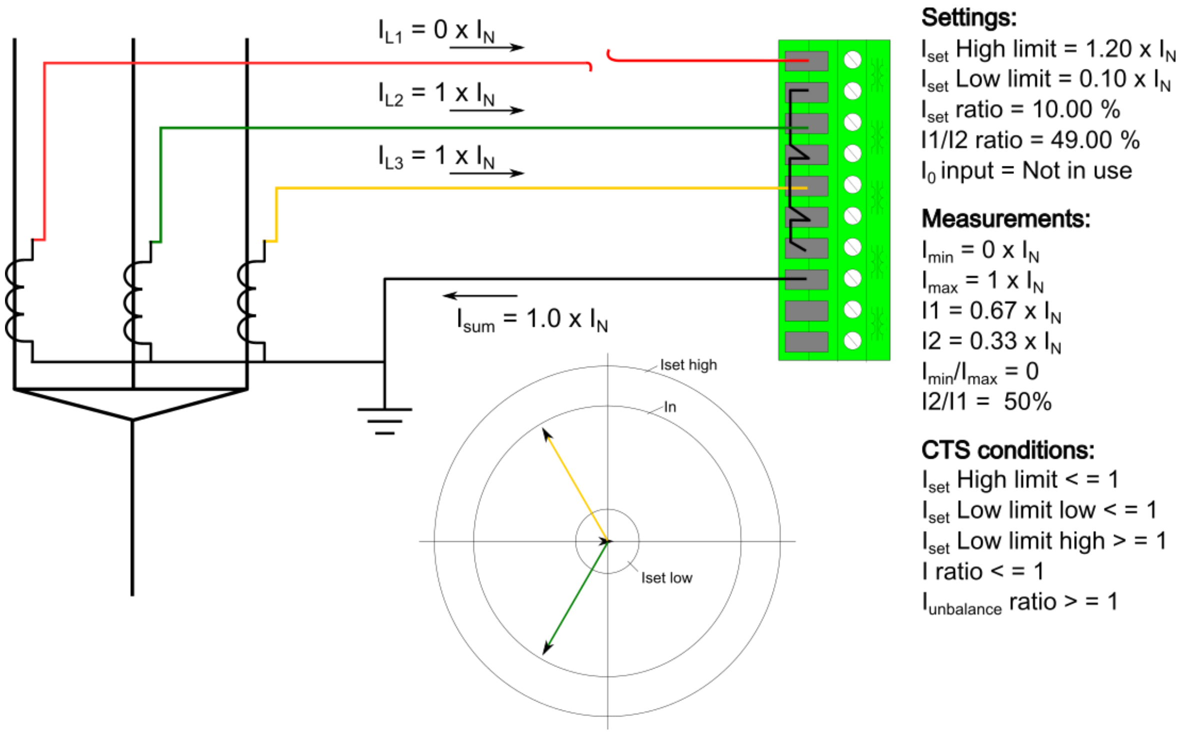
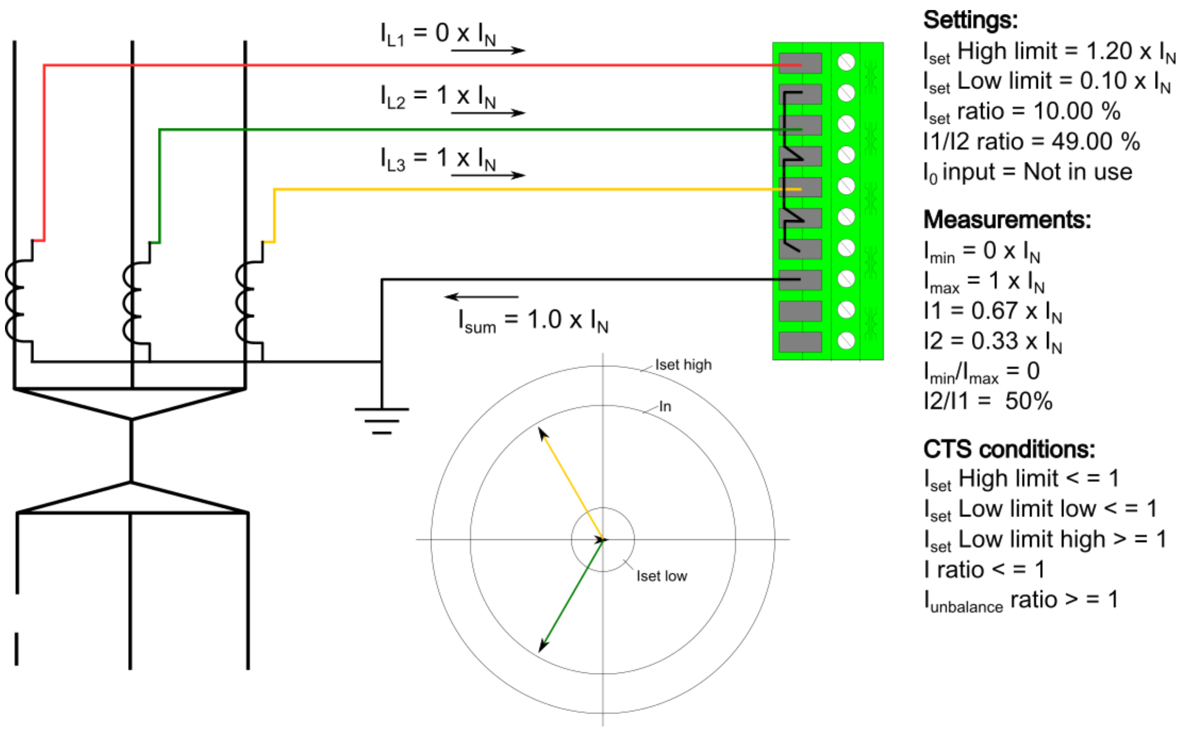


Figure. 5.6.1. - 152. Secondary circuit fault in phase L1 wiring.



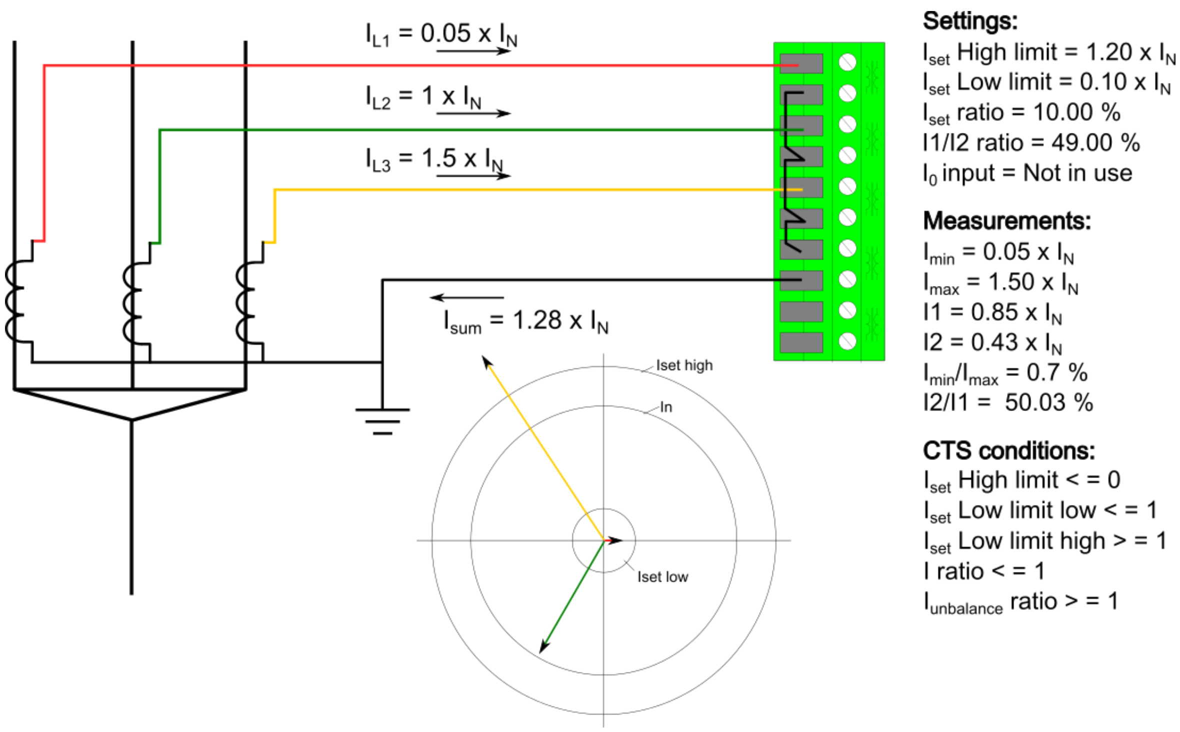
When a fault is detected and all conditions are met, the CTS timer starts counting. If the situation continues until the set time has passed, the function issues an alarm.

Figure. 5.6.1. - 153. Primary circuit fault in phase L1 wiring.



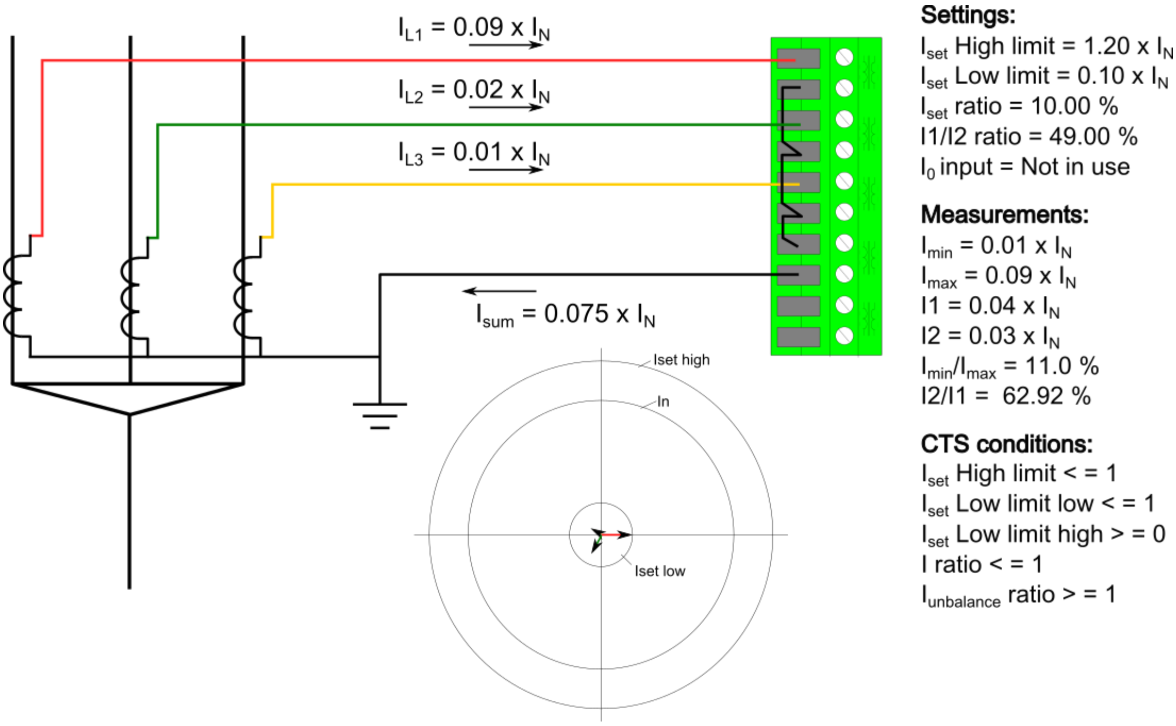
In this example, distinguishing between a primary fault and a secondary fault is impossible. However, the situation meets the function's activation conditions, and if this state (secondary circuit fault) continues until the set time has passed, the function issues an alarm. This means that the function supervises both the primary and the secondary circuit.

Figure. 5.6.1. - 154. No wiring fault but heavy unbalance.



If any of the phases exceed the I_{set} *high limit* setting, the operation of the function is not activated. This behavior is applied to short-circuits and earth faults even when the fault current exceeds the I_{set} *high limit* setting.

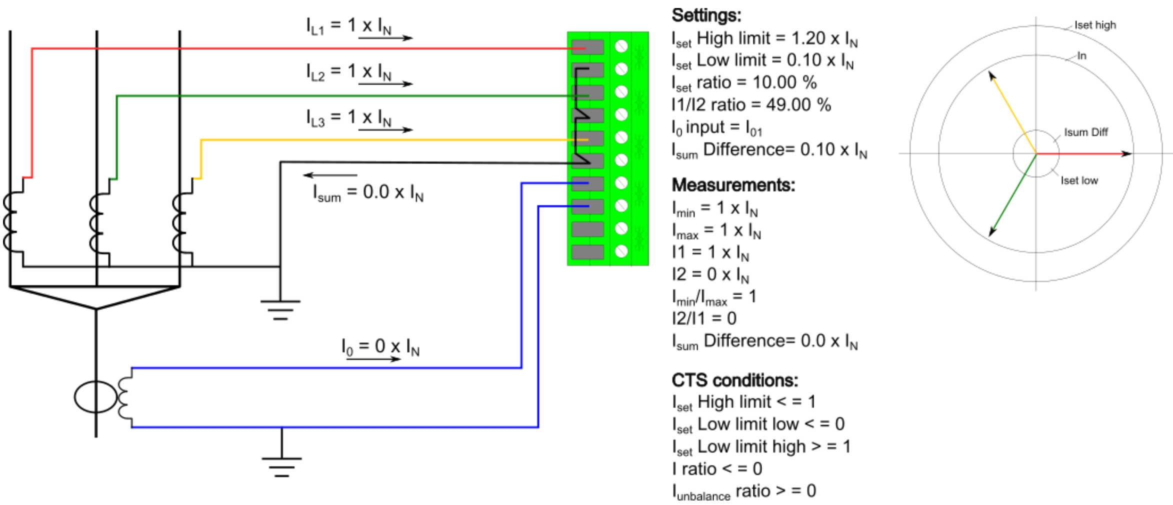
Figure. 5.6.1. - 155. Low current and heavy unbalance.



If all of the measured phase magnitudes are below the *I_{set} low limit* setting, the function is not activated even when the other conditions (inc. the unbalance condition) are met.

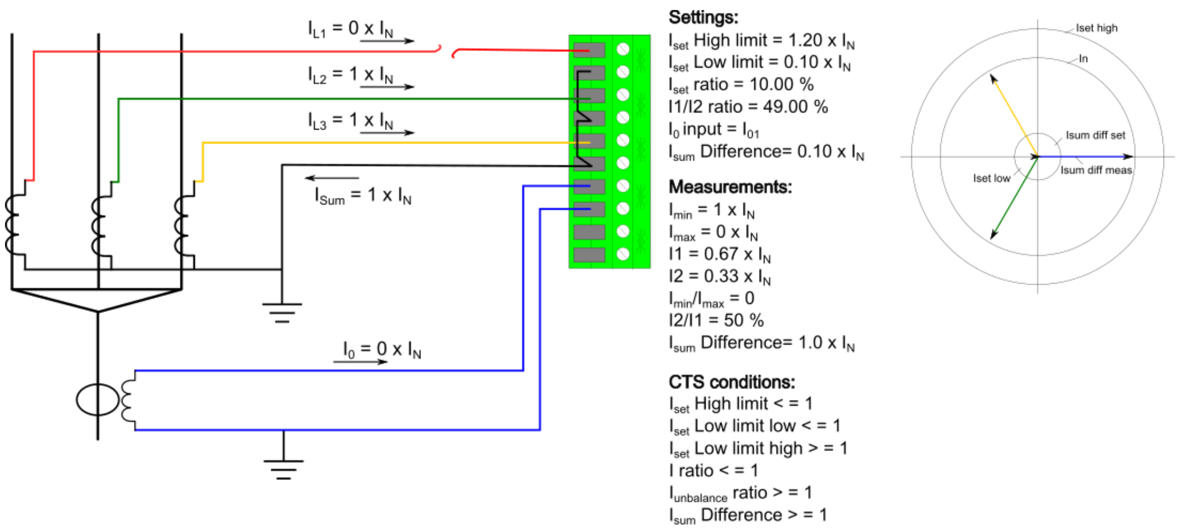
If the *I_{set} high limit* and *I_{set} low limit* setting parameters are adjusted according to the application's normal behavior, the operation of the function can be set to be very sensitive for broken circuit and conductor faults.

Figure. 5.6.1. - 156. Normal situation, residual current also measured.



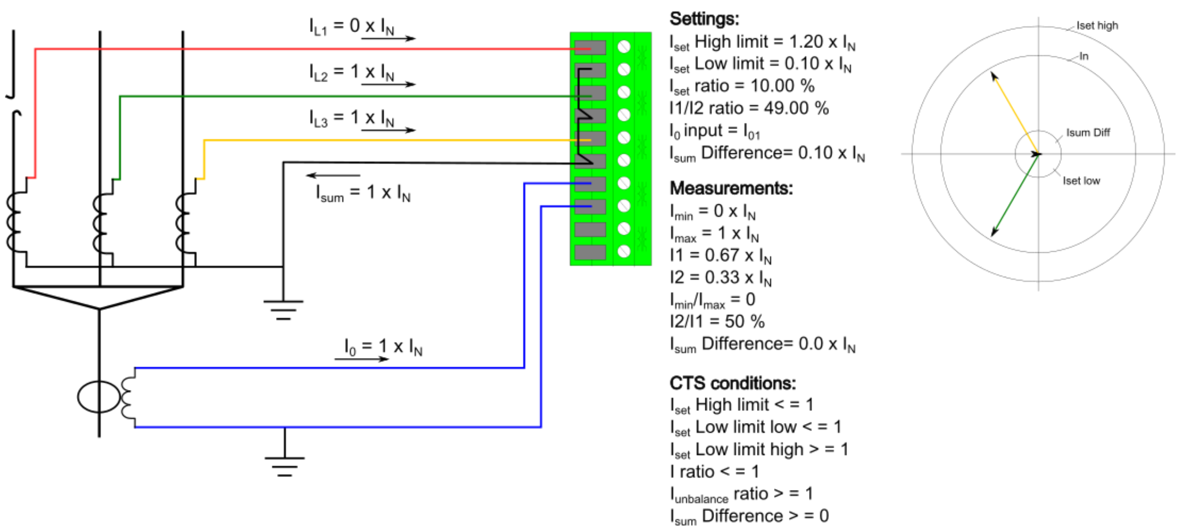
When the residual condition is added with the "I0 input selection", the sum of the current and the residual current are compared against each other to verify the wiring condition.

Figure. 5.6.1. - 157. Broken secondary phase current wiring.



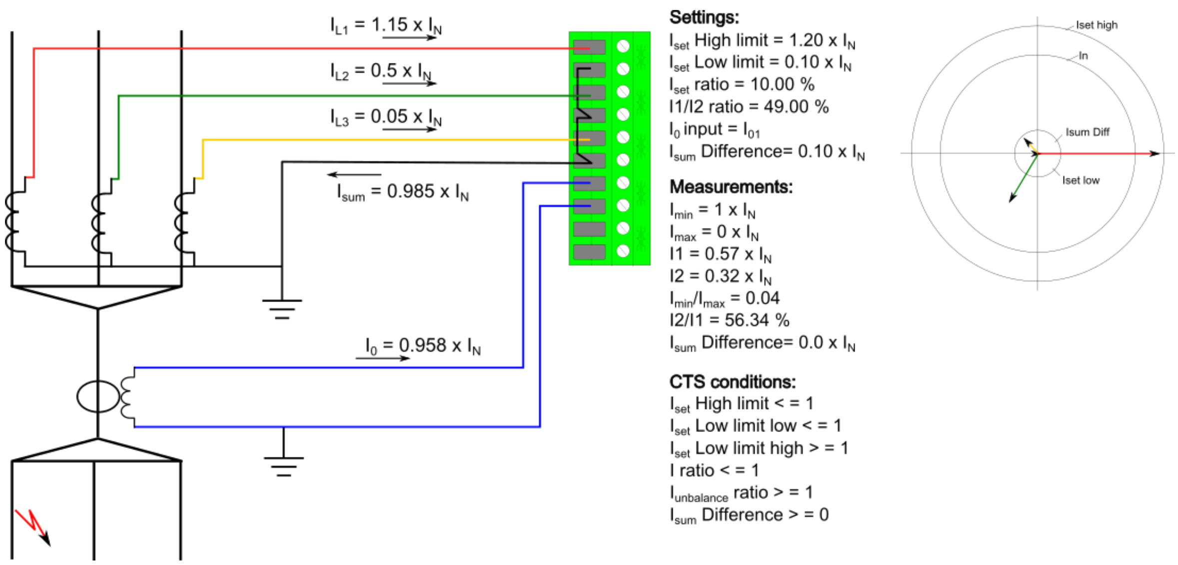
When phase current wire is broken all of the conditions are met in the CTS and alarm shall be issued in case if the situation continues until the set alarming time is met.

Figure. 5.6.1. - 158. Broken primary phase current wiring.



In this example, all other condition are met except the residual difference. That is now 0 × I_n, which indicates a primary side fault.

Figure. 5.6.1. - 159. Primary side high-impedance earth fault.



In this example there is a high-impedance earth fault. It does not activate the function, if the measurement conditions are met, while the calculated and measured residual current difference does not reach the limit. The I_{sum} *difference* setting should be set according to the application in order to reach maximum security and maximum sensitivity for the network earthing.

Events and registers

The current transformer supervision function (abbreviated "CTS" in event block names) generates events and registers from the status changes in ALARM ACTIVATED and BLOCKED signals. The user can select the status ON or OFF for messages in the main event buffer. The function offers two (2) independent stages.

The triggering event of the function is recorded with a time stamp and with process data values.

Table. 5.6.1. - 201. Event codes.

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

The function registers its operation into the last twelve (12) time-stamped registers; this information is available for all provided instances separately. The register of the function records the ON event process data for ACTIVATED, BLOCKED, etc. The table below presents the structure of the function's register content.

Table. 5.6.1. - 202. Register content.

Date and time	Event code	Trigger currents	Time to CTSact	Ftype	Used SG

dd.mm.yyyy hh:mm:ss.mss	3328-3459 Descr.	The phase currents (L1, L2 & L3), the residual currents (I01 & I02), and the sequence currents (I1 & I2) on trigger time.	Time remaining before the function is active.	The status code of the monitored current.	Setting group 1...8 active.

5.6.2. Voltage transformer supervision (60)

Voltage transformer supervision is used to detect errors in the secondary circuit of the voltage transformer during fuse failure. This signal is mostly used as an alarming function or to disable functions that require adequate voltage measurement.

Measured input

The function block uses analog voltage measurement values. Function uses the fundamental frequency magnitude of the voltage measurement inputs and the calculated (positive, negative and zero) sequence currents.

Table. 5.6.2. - 203. Measurement inputs of the voltage transformer supervision 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

The selection of the AI channel in use is made with a setting parameter. In all possible input channel variations the pre-fault condition is presented with a 20 ms averaged history value from -20 ms from START or TRIP event.

Pick-up

The *Voltage low pick-up* and *Voltage high detect* setting parameters control the voltage-dependent pick-up and activation of the voltage transformer supervision function. The function's pick-up activates, if at least one of the three voltages is under the set *Voltage low pick-up* value, or if at least two of the three voltages exceed the set *Voltage high detect* value. The function constantly calculates the ratio between the setting values and the measured magnitude for each of the three phases.

Table. 5.6.2. - 204. Pick-up settings.

Name	Range	Step	Default	Description
Voltage low pickup	0.05…0.50 × U_n	0.01 × U_n	0.05 × U_n	If at least one of the measured voltages is below this set value, the function's pick-up activates.
Voltage high detect	0.01…1.10 × U_n	0.01 × U_n	0.80 × U_n	If at least two of the measured voltages exceed this set value, the function's pick-up activates.
Angle shift limit	2.00…90.00 deg	0.10 deg	5.00 deg	If the difference between the present angle and the angle 40 ms before is below the set value, the function's pick-up activates.
Bus fuse fail check	0: No 1: Yes	-	1: Yes	Selects whether or not the state of the bus fuse is supervised. The supervised signal is determined the "VTS MCB Trip bus" setting (*I/O → Fuse failure inputs*).
Line fuse fail check	0: No 1: Yes	-	1: Yes	Selects whether or not the state of the line fuse is supervised. The supervised signal is determined by the "VTS MCB Trip line" setting (*I/O → Fuse failure inputs*).
Release time delay	0.000…150.000 s	0.005 s	0.06 s	Determines the length of the delay before release.

The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the blocking condition is not active. When the activation of the pick-up is based on binary signals, the activation happens immediately after the monitored signal is activated.

The voltage transformer supervision can also report several different states of the measured voltage. These can be seen in the function's *INFO* tab in the relay's HMI or in AQtivate.

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 a reversed sequence.
Bus Live VTS Ok SEQ Undef	Voltages are within the set limits **BUT** the sequence cannot be defined.
Bus Live VTS problem	Any of the VTS pick-up conditions are met.

Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's 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 the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup voltage values and its fault type to be issued.

The blocking signal can also be tested in the commissioning phase by a software switch signal when the relay's testing mode "Enable stage forcing" is activated (*General → Device*).

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

Operating time characteristics for activation

This function supports definite time delay (DT). For detailed information on this delay type please refer to the chapter "General properties of a protection function" and its section "Operating time characteristics for trip and reset".

Events and registers

The voltage transformer supervision function (abbreviated "VTS" in event block names) generates events and registers from the status changes in ALARM ACTIVATED and BLOCKED signals. The user can select the status ON or OFF for messages in the main event buffer.

The triggering event of the function is recorded with a time stamp and with process data values.

Table. 5.6.2. - 205. Event codes.

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
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

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data for ACTIVATED, BLOCKED, etc. The table below presents the structure of the function's register content.

Table. 5.6.2. - 206. Register content.

Date and time	Event code	Volt 1, 2, 3, 4 status	System status	Input A, B, C, D angle diff	Trip time remaining	Used SG
dd.mm.yyyy hh:mm:ss.mss	3392-3403 Descr.	0: No voltage 1: Voltage OK 2: Low voltage	0: Bus dead 1: Bus live, VTS OK, Seq. OK 2: Bus live, VTS OK, Seq. reversed 3: Bus live, VTS OK, Seq. undefined 4: Bus live, VTS fault	0.00...360.00 deg	0...1800 s	Setting group 1...8 active

5.6.3. Disturbance recorder (DR)

The disturbance recorder is a high-capacity (64 MB) and fully digital recorder integrated to the protection relay. The maximum sample rate of the recorder's analog channels is 64 samples per cycle. The recorder also supports 32 digital channels simultaneously with the twenty (20) measured analog channels.

The recorder provides a great tool to analyze the performance of the power system during network disturbance situations. The recorder's output is in general COMTRADE format and it is compatible with most viewers and injection devices. The files are based on the IEEE standard C37.111-1999. Captured recordings can be injected as playback with secondary testing tools that support the COMTRADE file format. Playback of files might help to analyze the fault, or can be simply used for educational purposes.

Analog and digital recording channels

Up to 20 analog recording channels and 95 digital channels are supported. The available analog channels vary according to the device type.

Table. 5.6.3. - 207. Analog recording channels.

Signal	Description
IL1	Phase current I_{L1}
IL2	Phase current I_{L2}
IL3	Phase current I_{L3}
I01c	Residual current I_{01} coarse*
I01f	Residual current I_{01} fine*
I02c	Residual current I_{02} coarse*
I02f	Residual current I_{02} fine*
IL1”	Phase current I_{L1} (CT card 2)
IL2”	Phase current I_{L2} (CT card 2)
IL3”	Phase current I_{L3} (CT card 2)
I01”c	Residual current I_{01} coarse* (CT card 2)
I01”f	Residual current I_{01} fine* (CT card 2)
I02”c	Residual current I_{02} coarse* (CT card 2)
I02”f	Residual current I_{02} fine* (CT card 2)
U1(2)VT1	Line-to-neutral U_{L1} or line-to-line voltage U_{12} (VT card 1)
U2(3)VT1	Line-to-neutral U_{L2} or line-to-line voltage U_{23} (VT card 1)
U3(1)VT1	Line-to-neutral U_{L3} or line-to-line voltage U_{31} (VT card 1)
U0(ss)VT1	Zero sequence voltage U_0 or synchrocheck voltage U_{SS} (VT card 1)
F tracked 1	Tracked frequency of reference 1
F tracked 2	Tracked frequency of reference 2
F tracked 3	Tracked frequency of reference 3
ISup	Current measurement module voltage supply supervision (CT card 1)

ISup''	Current measurement module voltage supply supervision (CT card 2)
USup	Voltage measurement module voltage supply supervision (VT card 2)
IL1'''	Phase current I_{L1} (CT card 3)
IL2'''	Phase current I_{L2} (CT card 3)
IL3'''	Phase current I_{L3} (CT card 3)
I01'''c	Residual current I_{01} coarse* (CT card 3)
I01'''f	Residual current I_{01} fine* (CT card 3)
I02'''c	Residual current I_{02} coarse* (CT card 3)
I02'''f	Residual current I_{02} fine* (CT card 3)
ISup_3	Current measurement module voltage supply supervision (CT card 3)
UL1(2)VT2	Line-to-neutral U_{L1} or line-to-line voltage U_{12} (VT card 2)
UL2(3)VT2	Line-to-neutral U_{L2} or line-to-line voltage U_{23} (VT card 2)
UL3(1)VT2	Line-to-neutral U_{L3} or line-to-line voltage U_{31} (VT card 2)
U0(SS)VT2	Zero sequence voltage U_0 or synchrocheck voltage U_{SS} (VT card 2)
USup_2	Voltage measurement module voltage supply supervision (VT card 2)

***NOTE**: There are two signals for each current channel in the disturbance recorder: coarse and fine. A coarse signal is capable of sampling in the full range of the current channel but suffers a loss of accuracy at very low currents (< 3 A). A fine signal is capable of sampling at very low currents and with high accuracy but cuts off at higher currents (I01 peaks at 15 A, I02 peaks at 8 A).

Table. 5.6.3. - 208. Digital recording channels – Measurements.

Signal	Description	Signal	Description
Currents			
Pri.Pha.curr.ILx	Primary phase current ILx (IL1, IL2, IL3)	Pha.curr.ILx TRMS Pri	Primary phase current TRMS (IL1, IL2, IL3)
Pha.angle ILx	Phase angle ILx (IL1, IL2, IL3)	Pos./Neg./Zero seq.curr.	Positive/Negative/Zero sequence current
Pha.curr.ILx	Phase current ILx (IL1, IL2, IL3)	Sec.Pos./Neg./Zero seq.curr.	Secondary positive/negative/zero sequence current
Sec.Pha.curr.ILx	Secondary phase current ILx (IL1, IL2, IL3)	Pri.Pos./Neg./Zero seq.curr.	Primary positive/negative/zero sequence current
Pri.Res.curr.I0x	Primary residual current I0x (I01, I02)	Pos./Neg./Zero seq.curr.angle	Positive/Negative/Zero sequence current angle
Res.curr.angle I0x	Residual current angle I0x (I01, I02)	Res.curr.I0x TRMS	Residual current TRMS I0x (I01, I02)
Res.curr.I0x	Residual current I0x (I01, I02)	Res.curr.I0x TRMS Sec	Secondary residual current TRMS I0x (I01, I02)
Sec.Res.curr.I0x	Secondary residual current I0x (I01, I02)	Res.curr.I0x TRMS Pri	Primary residual current TRMS I0x (I01, I02)
Pri.cal.I0	Primary calculated I0	Pha.Lx ampl. THD	Phase Lx amplitude THD (L1, L2, L3)
Sec.calc.I0	Secondary calculated I0	Pha.Lx pow. THD	Phase Lx power THD (L1, L2, L3)
calc.I0	Calculated I0	Res.I0x ampl. THD	Residual I0x amplitude THD (I01, I02)
calc.I0 Pha.angle	Calculated I0 phase angle	Res.I0x pow. THD	Residual I0x power THD (I01, I02)
Pha.curr.ILx TRMS	Phase current TRMS ILx (IL1, IL2, IL3)	P-P curr.ILx	Phase-to-phase current ILx (IL1, IL2, IL3)

Pha.curr.ILx TRMS Sec	Secondary phase current TRMS (IL1, IL2, IL3)	P-P curr.I0x	Phase-to-phase current I0x (I01, I02)
Voltages			
Ux Volt p.u.	Ux voltage in per-unit values (U1, U2, U3, U4)	System volt ULxx mag	Magnitude of the system voltage ULxx (UL12, UL23, UL31)
Ux Volt pri	Primary Ux voltage (U1, U2, U3, U4)	System volt ULxx mag(kV)	Magnitude of the system voltage ULxx in kilovolts (UL12, UL23, UL31)
Ux Volt sec	Secondary Ux voltage (U1, U2, U3, U4)	System volt ULxx ang	Angle of the system voltage ULxx (UL12, UL23, UL31)
Ux Volt TRMS p.u.	Ux voltage TRMS in per-unit values (U1, U2, U3, U4)	System volt ULx mag	Magnitude of the system voltage ULx (U1, U2, U3, U4)
Ux Volt TRMS pri	Primary Ux voltage TRMS (U1, U2, U3, U4)	System volt ULx mag(kV)	Magnitude of the system voltage ULx in kilovolts (U1, U2, U3, U4)
Ux Volt TRMS sec	Secondary Ux voltage TRMS (U1, U2, U3, U4)	System volt ULx ang	Angle of the system voltage ULx (U1, U2, U3, U4)
Pos/Neg./Zero seq.Volt.p.u.	Positive/Negative/Zero sequence voltage in per-unit values	System volt U0 mag	Magnitude of the system voltage U0
Pos./Neg./Zero seq.Volt.pri	Primary positive/negative/zero sequence voltage	System volt U0 mag(kV)	Magnitude of the system voltage U0 in kilovolts
Pos./Neg./Zero seq.Volt.sec	Secondary positive/negative/zero sequence voltage	System volt U0 mag(%)	Magnitude of the system voltage U0 in percentages
Ux Angle	Ux angle (U1, U2, U3, U4)	System volt U0 ang	Angle of the system voltage U0
Pos./Neg./Zero Seq volt.Angle	Positive/Negative/Zero sequence voltage angle	Ux Angle difference	Ux angle difference (U1, U2, U3)
Resistive and reactive currents			
ILx Resistive Current p.u.	ILx resistive current in per-unit values (IL1, IL2, IL3)	Pos.seq. Resistive Current Pri.	Primary positive sequence resistive current
ILx Reactive Current p.u.	ILx reactive current in per-unit values (IL1, IL2, IL3)	Pos.seq. Reactive Current Pri.	Primary positive sequence reactive current
Pos.Seq. Resistive Current p.u.	Positive sequence resistive current in per-unit values	I0x Residual Resistive Current Pri.	Primary residual resistive current I0x (I01, I02)
Pos.Seq. Reactive Current p.u.	Positive sequence reactive current in per-unit values	I0x Residual Reactive Current Pri.	Primary residual reactive current I0x (I01, I02)
I0x Residual Resistive Current p.u.	I0x residual resistive current in per-unit values (I01, I02)	ILx Resistive Current Sec.	Secondary resistive current ILx (IL1, IL2, IL3)
I0x Residual Reactive Current p.u.	I0x residual ractive current in per-unit values (I01, I02)	ILx Reactive Current Sec.	Secondary reactive current ILx (IL1, IL2, IL3)
ILx Resistive Current Pri.	Primary resistive current ILx (IL1, IL2, IL3)	I0x Residual Resistive Current Sec.	Secondary residual resistive current I0x (I01, I02)
ILx Reactive Current Pri.	Primary reactive current ILx (IL1, IL2, IL3)	I0x Residual Reactive Current Sec.	Secondary residual reactive current I0x (I01, I02)
Power, GYB, frequency			
Lx PF	Lx power factor (L1, L2, L3)	Curve x Input	Input of Curve x (1, 2, 3, 4)
POW1 3PH Apparent power (S)	Three-phase apparent power	Curve x Output	Output of Curve x (1, 2, 3, 4)
POW1 3PH Apparent power (S MVA)	Three-phase apparent power in megavolt-amperes	Enablefbasedfunctions(VT1)	Enable frequency-based functions

POW1 3PH Active power (P)	Three-phase active power	Track.sys.f.	Tracked system frequency
POW1 3PH Active power (P MW)	Three-phase active power in megawatts	Sampl.f. used	Used sample frequency
POW1 3PH Reactive power (Q)	Three-phase reactive power	Tr f CH x	Tracked frequency (channels A, B, C)
POW1 3PH Reactive power (Q MVar)	Three-phase reactive power in megavars	Alg f Fast	Fast frequency algorithm
POW1 3PH Tan(phi)	Three-phase tangent phi	Alg f avg	Average frequency algorithm
POW1 3PH Cos(phi)	Three-phase cosine phi	Frequency based protections blocked	When true ("1"), all frequency-based protections are blocked.
3PH PF	Three-phase power factor	f atm. Protections (when not measurable returns to nominal)	Frequency at the moment. If the system nominal is set to 50 Hz, this will show "50 Hz".
Neutral conductance G (Pri)	Primary neutral conductance	f atm. Display (when not measurable is 0 Hz)	Frequency at the moment. If the frequency is not measurable, this will show "0 Hz".
Neutral susceptance B (Pri)	Primary neutral susceptance	f meas qlty	Quality of tracked frequency
Neutral admittance Y (Pri)	Primary neutral admittance	f meas from	Indicates which of the three voltage or current channel frequencies is used by the relay.
Neutral admittance Y (Ang)	Neutral admittace angle	SS1.meas.frqs	Synchrocheck – the measured frequency from voltage channel 1
I01 Resistive component (Pri)	Primary resistive component I01	SS2.meas.frqs	Synchrocheck – the measured frequency from voltage channel 2
I01 Capacitive component (Pri)	Primary capacitive component I01	Enable f based functions	Status of this signal is active when frequency-based protection functions are enabled.

Table. 5.6.3. - 209. Digital recording channels – Binary signals.

Signal	Description	Signal	Description
DIx	Digital input 1...11	Timer x Output	Output of Timer 1...10
Open/close control buttons	Active if buttons I or 0 in the unit's front panel are pressed.	Internal Relay Fault active	If the unit has an internal fault, this signal is active.
Status PushButton x On	Status of Push Button 1...12 is ON	(Protection, control and monitoring event signals)	(see the individual function description for the specific outputs)
Status PushButton x Off	Status of Push Button 1...12 is OFF	Always True/False	"Always false" is always "0". Always true is always "1".
Forced SG in use	Stage forcing in use	OUTx	Output contact statuses
SGx Active	Setting group 1...8 active	GOOSE INx	GOOSE input 1...64
Double Ethernet LinkA down	Double ethernet communication card link A connection is down.	GOOSE INx quality	Quality of GOOSE input 1...64
Double Ethernet LinkB down	Double ethernet communication card link B connection is down.	Logical Input x	Logical input 1...32

MBIO ModA Ch x Invalid	Channel 1...8 of MBIO Mod A is invalid	Logical Output x	Logical output 1...64
MBIO ModB Ch x Invalid	Channel 1...8 of MBIO Mod B is invalid	NTP sync alarm	If NTP time synchronization is lost, this signal will be active.
MBIO ModB Ch x Invalid	Channel 1...8 of MBIO Mod C is invalid	Ph.Rotating Logic control 0=A-B-C, 1=A-C-B	Phase rotating order at the moment. If true ("1") the phase order is reversed.

NOTE! Digital channels are measured every 5 ms.

Recording settings and triggering

Disturbance recorder can be triggered manually or automatically by using the dedicated triggers. Every signal listed in "Digital recording channels" can be selected to trigger the recorder.

The device has a maximum limit of 100 for the number of recordings. Even when the recordings are very small, their number cannot exceed 100. The number of analog and digital channels together with the sample rate and the time setting affect the recording size. See calculation examples below in the section titled "Estimating the maximum length of total recording time".

Table. 5.6.3. - 210. Recorder control settings.

Name	Range	Step	Default	Description
Recorder enabled	0: Enabled 1: Disabled	-	0: Enabled	Enables and disables the disturbance 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.
Clear record+	0…2^{32}-1	1	-	Clears selected recording. If "1" is inserted, first recording will be cleared from memory. If "10" is inserted, tenth (10th) recording will be cleared from memory.
Manual trigger	0: - 1: Trig	-	0: -	Triggers disturbance recording manually. This parameter will return back to "-" automatically.
Clear all records	0: - 1: Clear	-	0: -	Clears all disturbance recordings.
Clear newest record	0: - 1: Clear	-	0: -	Clears the newest stored disturbance recording.
Clear oldest record	0: - 1: Clear	-	0: -	Clears the oldest stored disturbance recording.
Max. number of recordings	0…100	1	-	Displays the maximum number of recordings that can be stored in the device's memory with settings currently in use. The maximum number of recordings can go up to 100.
Max. length of a recording	0.000...1800.000 s	0.001 s	-	Displays the maximum length of a single recording.
Max. location of the pre-trigger	0.000...1800.000 s	0.001 s	-	Displays the highest pre-triggering time that can be set with the settings currently in use.
Recordings in memory	0…100	1	-	Displays how many recordings are stored in the memory.

Table. 5.6.3. - 211. Recorder trigger setting.

Name	Description
Recorder trigger	Selects the trigger input(s). Clicking the "Edit" button brings up a pop-up window, and checking the boxes enable the selected triggers.

Table. 5.6.3. - 212. Recorder settings.

Name	Range	Step	Default	Description
Recording length	0.100...1800.000 s	0.01 s	1 s	Sets the length of a recording.
Recording mode	0: FIFO 1: Keep olds	-	0: FIFO	Selects what happens when the memory is full. "FIFO" (= first in, first out) replaces the oldest stored recording with the latest one. "Keep olds" does not accept new recordings.
Analog channel samples	0: 64 s/c 1: 32 s/c 2: 16 s/c 3: 8 s/c	-	0: 64 s/c	Selects the sample rate of the disturbance recorder. The samples are saved from the measured wave according to this setting.
Digital channel samples	5 ms (fixed)	-	5 ms (fixed)	The fixed sample rate of the recorded digital channels.
Pre-triggering time	0.1…15.0 s	0.1 s	0.5 s	Sets the recording length before the trigger.
Analog recording CH1...CH20	0…8 freely selectable channels	-	-	Selects the analog channel for recording. Please see the list of all available analog channels in the section titled "Analog and digital recording channels".
Automatically get recordings	0: Disabled 1: Enabled	-	0: Disabled	Enables and disables the automatic transfer of recordings. The recordings are taken from the relay's protection CPU and transferred to the relay's FTP directory in the communication CPU; the FTP client then automatically transfers them further to the SCADA system. Please note that when this setting is enabled, all new disturbance recordings will be pushed to the FTP. Up to six (6) recordings can be stored in the FTP at once. Once those six recordings have been retrieved and removed, more recordings will then be pushed to the FTP.
Recorder digital channels	0…32 freely selectable channels	-	-	Selects the analog channel for recording. Please see the list of all available digital channels in the section titled "Analog and digital recording channels".

Note! The disturbance recorder is not ready unless the "Max. length of a recording" parameter is showing some value other than zero. At least one trigger input has to be selected in the "Recorder Trigger" setting to fulfill this term.

Estimating the maximum length of total recording time

Once the disturbance recorder's settings have been made and loaded to the relay, the device automatically calculates and displays the total length of recordings. However, if the user wishes to confirm this calculation, they can do so with the following formula. Please note that the formula assumes there are no other files in the FTP that share the 64 MB space.

$$\frac{\text{Total sample reserve}}{(f_n * (Ch_{an} + 1) * SR) + (200\ Hz * Ch_{dig})}$$

Where:

- total sample reserve = the number of samples available in the FTP when no other files are saved; calculated by dividing the total number of available bytes by 4 bytes (=the size of one sample); e.g. 64 306 588 bytes/4 bytes = 16 076 647 samples.
- f_n = the nominal frequency (Hz).
- Ch_{an} = the number of analog channels recorded; "+ 1" stands for the time stamp for each recorded sample.
- *SR* = the selected sample rate (s/c).
- 200 Hz = the rate at which digital channels are always recorded, i.e. 5 ms.
- Ch_{dig} = the number of digital channels recorded.

For example, let us say the nominal frequency is 50 Hz, the selected sample rate is 64 s/c, nine (9) analog channels and two (2) digital channels record. The calculation is as follows:

$$\frac{16\ 076\ 647\ \text{samples}}{(50\ \text{Hz} * (9 + 1) * 64) + (200\ \text{Hz} * 2)} \approx 496\ \text{s}$$

Therefore, the maximum recording length in our example is approximately 496 seconds.

Application example

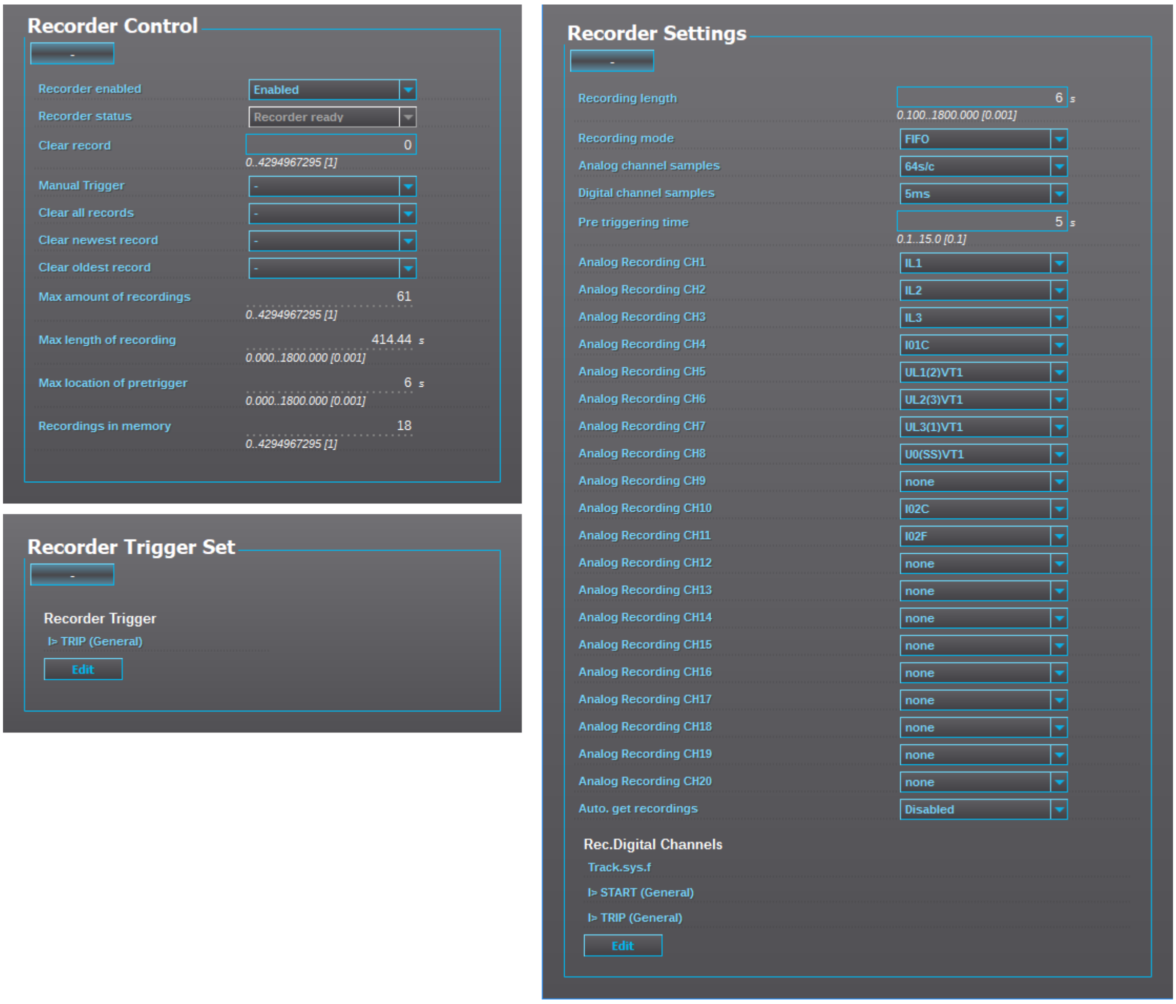
This chapter presents an application example of how to set the disturbance recorder and analyze its output. The recorder is configured by using the AQtivate software or relay HMI, and the results are analyzed with the AQviewer software (is automatically downloaded and installed with AQtivate). Registered users can download the latest tools from the Arcteq website (arcteq.fi./downloads/).

In this example, we want the recordings to be made according to the following specifications:

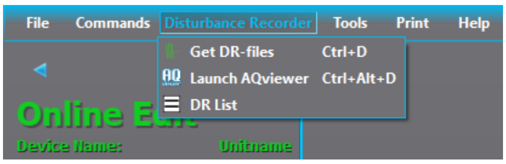
- the recording length is 1.0 s
- the sample rate is 64 s/c (therefore, with a 50 Hz system frequency a sample is taken every 312.5 µs)
- the analog channels 1...8 are used
- digital channels are tracked every 5 ms
- the first activation of the overcurrent stage trip (I> TRIP) triggers the recorder
- the pre-triggering time is 200 ms (ie. how long is recorded before the I> TRIP signal) and the post-triggering time is 800 ms

The image below shows how these settings are placed in AQtivate.

Figure. 5.6.3. - 160. Disturbance recorder settings.



When there is at least one recording in the device's memory, that recording can be analyzed by using the AQviewer software (see the image below). However, the recording must first be made accessible to AQViewer. The user can read it from the device's memory (*Disturbance recorder → Get DR-files*). Alternatively, the user can load the recordings individually (*Disturbance recorder → DR List*) from a folder in the PC's hard disk drive; the exact location of the folder is described in *Tools → Settings → DR path*.



The user can also launch the AQviewer software from the *Disturbance recorder* menu.

AQviewer

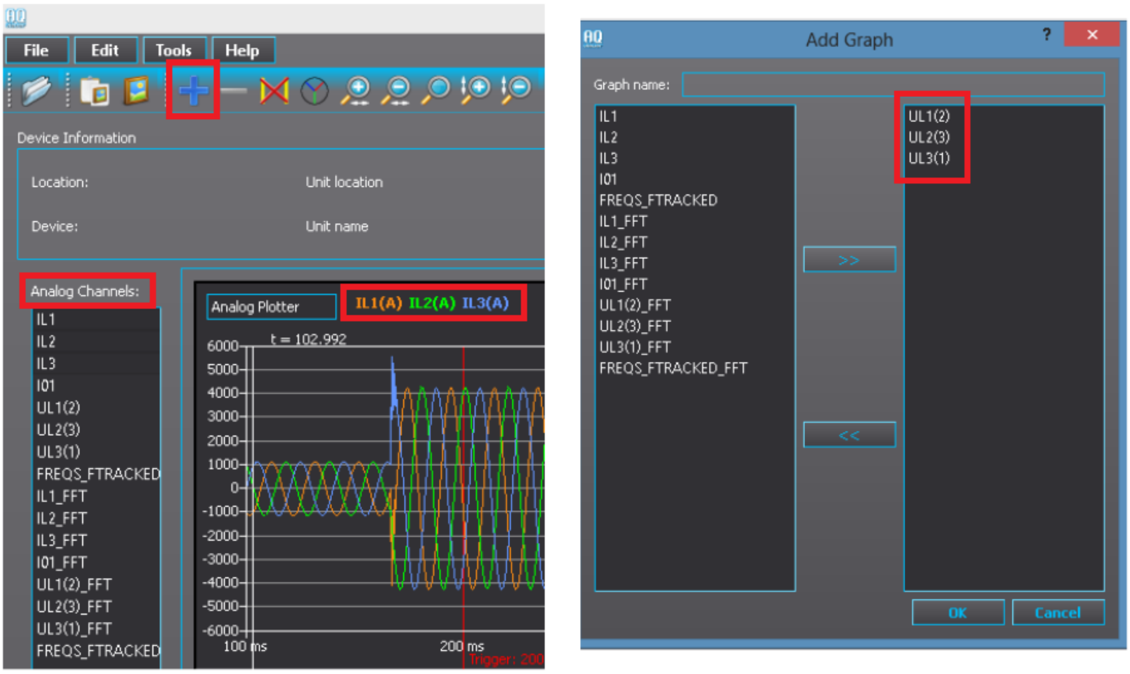
Opening folders

Disturbance recordings can be opened by clicking on the "Open folder" icon or by going to *File → Open* (see the image below). The recordings are packed COMTRADE files; a -zip file includes *.cfg and *.dat files. AQviewer can open both original packed .zip files and COMTRADE files directly as they are are located in same directory.

Adding signals to plotters

By default, the default plotter is empty. Choose the measured signals ("Analog channels") on the left to move them to the plotter. In the image below (on the left) the phase currents IL1, IL2 and IL3 are selected; AQViewer color-codes them automatically. If you want to add another plotter, choose the blue "+" icon (in the main toolbar on the top). Please note that the "Add plotter" text appears when you move the cursor on top of the icon. Once clicked, the "Add graph" pop-up window appears (see the image below on the right). In the example the line-to-neutral voltages UL1, UL2 and UL3 are selected and moved to the window on the right. Confirm the selection by clicking the "OK" button.

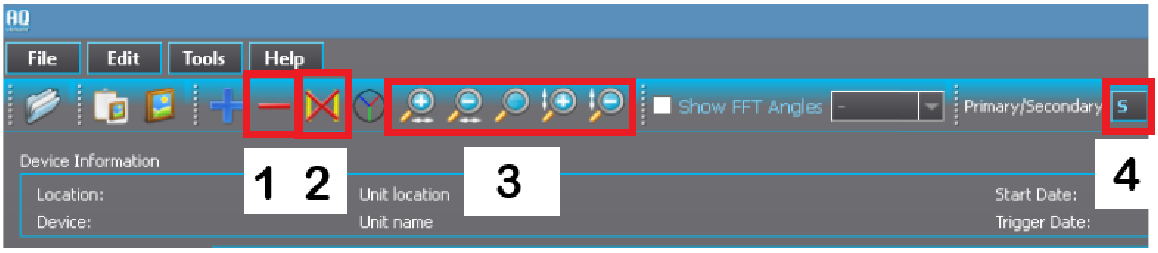
Figure. 5.6.3. - 161. Adding another plotter



General use and zooming

1. You can remove plotters individually by using the red "—" icon (numbered "1" in the image below). Please note that the "Remove plotters" text appears when you move the cursor on top of the icon.
2. You can add cursors to measure time by staying on top of any plotter and double-clicking the left mouse button. You can add up to five (5) cursors simultaneously. You can remove cursors by clicking on the icon (numbered "2" in the image below). Please note that the "Remove all cursors" text appears when you move the cursor on top of the icon.

3. You can zoom in manually by placing the cursor on top of a plotter, holding down the left mouse button and moving the cursor to create the area you want to zoom in. You can also zoom in (and out) by using the horizontal and vertical magnifying glass "+" and "—" icons (numbered "3" in the image below). If you want to reset the zooming, click on the middle magnifying glass icon. You can also zoom in and out the amplitude of individual plotters by holding down **Shift** and scrolling the mouse wheel up and down, respectively.
4. You can toggle between primary (P) and secondary (S) signals (numbered "4" in the image below).



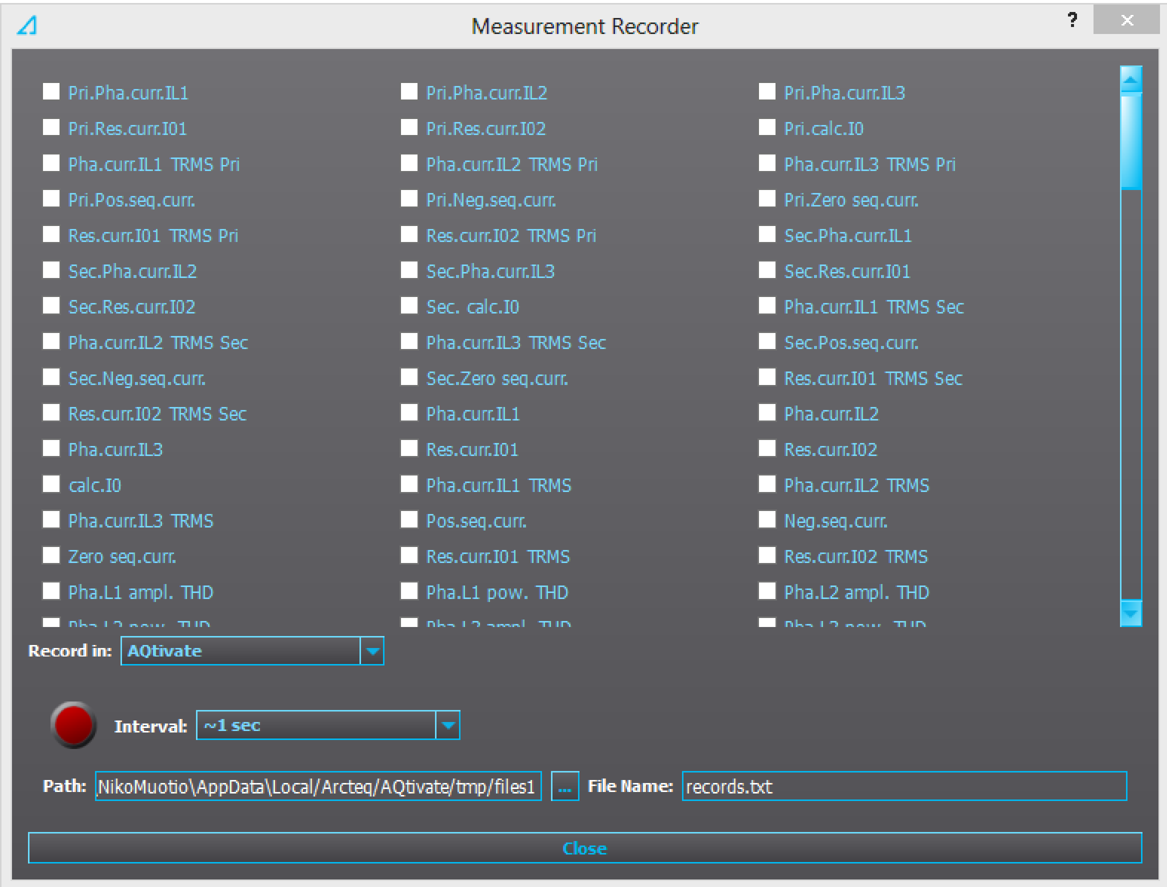
Events

The disturbance recorder function (abbreviated "DR" in event block names) generates events and registers from the status changes of the function: the recorder generates an event each time it is triggered (manually or by dedicated signals). Events cannot be masked off. The user can select the status ON or OFF for messages in the main event buffer.

Table. 5.6.3. - 213. Event codes.

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

5.6.4. Measurement recorder



Measurements can be recorded to a file with the measurement recorder. The chosen measurements are recorded at selected intervals. In the "Measurement recorder" window, the measurements the user wants to be recorded can be selected by checking their respective checkboxes. In order for the measurement recorder to activate, a connection to a relay must be established via the AQtivate software and its Live Edit mode must be enabled (see the AQtivate 200 manual for more information). Navigate to the measurement recorder through *Tools → Miscellaneous tools → Measurement recorder*. The recording interval can be changed from the "Interval" drop-down menu. From the "Record in" drop-down menu the user can also choose whether the measurements are recorded in AQtivate or in the relay.

If the recording is done in AQtivate, both the AQtivate software and its Live Edit mode have to be activated. The user can change the recording file location by editing the "Path" field. File names can also be changed with the "File name" field. Hitting the "Record" button (the big red circle) starts the recorder. Please note that closing the "Measurement recorder" window does not stop the recording; that can only be done by hitting the "Stop" button (the big blue circle).

If the recording is done in the relay, only the recording interval needs to be set before recording can be started. AQtivate estimates the maximum recording time, which depends on the recording interval. When the measurement recorder is running, the measurements can be viewed in graph form with the AQtivate PRO software (see the image below).

Figure. 5.6.4. - 162. Measurement recorder values viewed with AQtivate PRO.

Table. 5.6.4. - 214. 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.

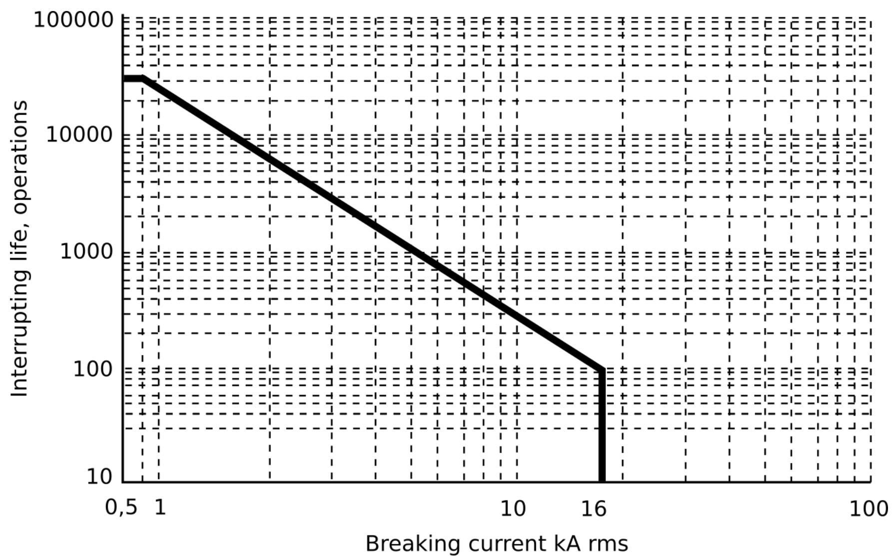
Pos.Seq.Curr.angle	System Volt UL3 mag (kV)	TM> T at the moment
Neg.Seq.Curr.angle	System Volt U0 mag	TM> Max.Temp.Rise All.
Zero.Seq.Curr.angle	System Volt U0 mag (kV)	TM> Temp.Rise atm.
Pri.Pha.Curr.I"L1	System Volt U1 mag	TM> Hot Spot estimate
Pri.Pha.Curr.I"L2	System Volt U1 mag (kV)	TM> Hot Spot 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	

5.6.5. Circuit breaker wear

The circuit breaker wear function is used for monitoring the circuit breaker's lifetime and its maintenance needs caused by interrupting currents and mechanical wear. The function uses the circuit breaker's manufacturer-supplied data for the breaker operating cycles in relation to the interrupted current magnitudes. The function is integrated into the object control function and can be enabled and set under that function's settings. However, the circuit breaker wear function is an independent function and it initializes as an independent instance which has its own events and settings not related to the object it is linked to.

Figure. 5.6.5. - 163. Example of the circuit breaker interrupting life operations.



The function is triggered from the circuit breaker's "Open" command output and it monitors the three-phase current values in both the tripping moment and the normal breaker opening moment. The maximum value of interrupting life operations for each phase is calculated from these currents. The value is cumulatively deducted from the starting operations starting value. The user can set up two separate alarm levels, which are activated when the value of interrupting life operations is below the setting limit. The "Trip contact" setting defines the output that triggers the current monitoring at the breaker's "Open" command.

The outputs of the function are the ALARM 1 and ALARM 2 signals.

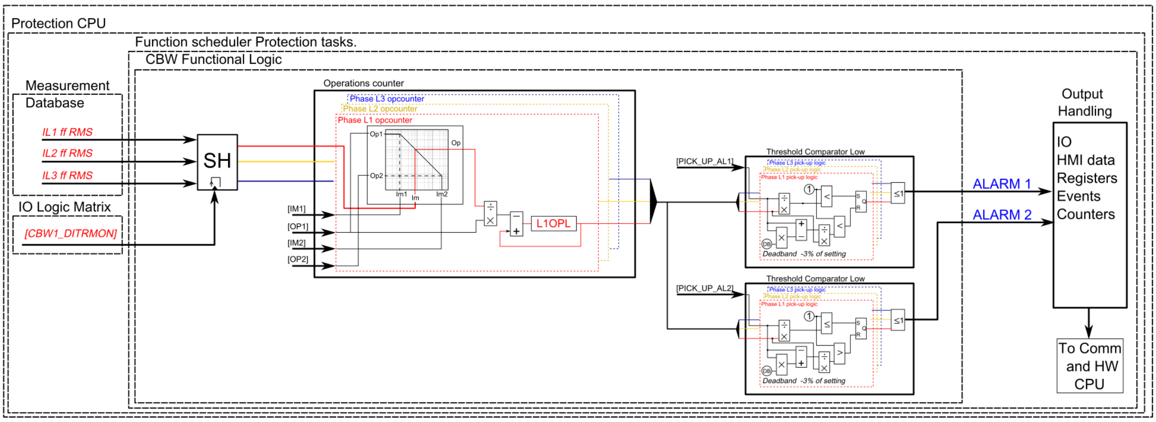
The inputs for the function are the following:

- setting parameters
- binary output signals
- measured and pre-processed current magnitudes.

The function's output signals can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the two (2) output signal. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the "Open" operations as well as the ALARM 1 and ALARM 2 events. The function can also monitor the operations left for each phase.

The following figure presents a simplified function block diagram of the circuit breaker wear function.

Figure. 5.6.5. - 164. Simplified function block diagram of the circuit breaker wear function.



Measured input

The function block uses analog current measurement values and always uses the fundamental magnitude of the current measurement input.

Table. 5.6.5. - 215. Measurement inputs of the circuit breaker wear 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 to change them by switching the setting group.

Table. 5.6.5. - 216. General settings.

Name	Description	Range	Step	Default
THD in side	Defines which current measurement module is used by the function.	1:Side 1 2:Side 2	-	1:Side 1

Circuit breaker characteristics settings

The circuit breaker characteristics are set by two operating points, defined by the nominal breaking current, the maximum allowed breaking current and their respective operation settings. This data is provided by the circuit breaker's manufacturer.

Table. 5.6.5. - 217. Settings for circuit breaker characteristics.

Name	Range	Step	Default	Description
Operations 1	0…200 000	1	50 000	The number of interrupting life operations at the nominal current (Close - Open).
Operations 2	0…200 000	1	100	The number of interrupting life operations at the rated breaking current (Open).
Current 1 (I_{nom})	0…100.00 kA	0.01 kA	1 kA	The rated normal current (RMS).
Current 2 (I_{max})	0…100.00 kA	0.01 kA	20 kA	The rated short-circuit breaking current (RMS).

Pick-up for alarming

For the alarm stages Alarm 1 and Alarm 2, the user can set the pick-up level for the number of operations left. The pick-up setting is common for all phases and the alarm stage picks up if any of the phases goes below this setting.

Table. 5.6.5. - 218. Pick-up settings.

Name	Range	Step	Default	Description
Alarm 1	0: Disabled 1: Enabled	-	0: Disabled	Enable and disable the Alarm 1 stage.
Alarm 1 Set	0…200 000	1	1 000	Defines the pick-up threshold for remaining operations. When the number of remaining operations is below this setting, the ALARM 1 signal is activated.
Alarm 2	0: Disabled 1: Enabled	-	0: Disabled	Enable and disable the Alarm 2 stage.
Alarm 2 Set	0…200 000	1	100	Dfines the pick-up threshold for remaining operations. When the number of remaining operations is below this setting, the ALARM 2 signal is activated.

Setting example

Let us examine the settings, using a low-duty vacuum circuit breaker (ISM25_LD_1/3) manufactured by Tavrida as an example. The image below presents the technical specifications provided by the manufacturer, with the data relevant to our settings highlighted in red:

Rated voltage, kV	24
Rated current, A	800
Rated power frequency test voltage, kV	50
Rated frequency, Hz	50/60
Rated impulse test voltage, kV peak	125
Partial discharge level at 1,1 rated voltage kV, pC	<10
Rated short-circuit breaking current, kA	16
Rated short-circuit making current, kA peak	41.5
Short time withstand current, 4s, kA	16
Mechanical life, CO cycles, not less than	30,000
Interrupting life operations, not less than	
at rated current	30,000
at breaking current	100
at other currents	see Fig.41
Closing time, ms, not more than	35
Opening time, ms, not more than	15
Breaking time, ms, not more than	25
Main contact resistance, μOhm, not more than	40
Maximum ambient temperature, C°	+55
Minimum ambient temperature, C°	-40
Design class (according to IEC 60932)	1
Electrical endurance class at rated IEEE/IEC duty	E2
Mechanical endurance class at rated IEEE/IEC duty	M2
Capacitive current switching class	C2
"Mechanical vibration and shock withstand capability, IEC 60721, IEC 60068"	Class 4M4
Maximum altitude above sea level, m	3000*
Maximum humidity, non condensing	98 %
Weight, kg - LD_1	35
Weight, kg - LD_6	55

Now, we set the stage as follows:

Parameter	Setting
Current 1	0.80 kA
Operation 1	30 000 operations
Current 2	16.00 kA
Operations 2	100 operations
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 is issued when the cumulative interruption counter for any of the three phases dips below the set 1000 remaining operations ("Alarm 1 Set"). Similarly, when any of the counters dips below 100 remaining operations, Alarm 2 is issued.

Events and registers

The circuit breaker wear function (abbreviated "CBW" in event block names) generates events and registers from the status changes in Retrip, CBW-activated and CBW-blocked signals as well as in internal pick-up comparators. The user can select the status ON or OFF for messages in the main event buffer.

The triggering event of the function is recorded with a time stamp and with process data values.

Table. 5.6.5. - 219. Event codes.

Event number	Event channel	Event block name	Event code	Description
3712	58	CBW1	0	CBWEAR1 Triggered
3713	58	CBW1	1	CBWEAR1 Alarm 1 ON
3714	58	CBW1	2	CBWEAR1 Alarm 1 OFF
3715	58	CBW1	3	CBWEAR1 Alarm 2 ON
3716	58	CBW1	4	CBWEAR1 Alarm 2 OFF

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data. The table below presents the structure of the function's register content.

Table. 5.6.5. - 220. Register content.

Date and time	Event code	Trigger current	All.Op.ITrg	Deduct. Op	Op.Left
dd.mm.yyyy hh:mm:ss.mss	3712-3716 Descr.	Phase currents on trigger time	Allowed operations with trigger current	Deducted operations from the cumulative sum	Operations left

5.6.6. Total harmonic distortion (THD)

The total harmonic distortion (THD) function is used for monitoring the content of the current harmonic. The THD is a measurement of the harmonic distortion present, and it is defined as the ratio between the sum of all harmonic components' powers and the power of the fundamental frequency.

Harmonics can be caused by different sources in electric networks such as electric machine drives, thyristor controls, etc. The function's monitoring of the currents can be used to alarm of the harmonic content rising too high; this can occur when there is an electric quality requirement in the protected unit, or when the harmonics generated by the process need to be monitored.

The function constantly measures the phase and residual current magnitudes as well as the harmonic content of the monitored signals up to the 31^{st} harmonic component. When the function is activated, the measurements are also available for the mimic and the measurement views in the HMI carousel. The user can also set the alarming limits for each measured channel if the application so requires.

The monitoring of the measured signals can be selected to be based either on an amplitude ratio or on the above-mentioned power ratio. The difference is in the calculation formula (as shown below):

Figure. 5.6.6. - 165. THD calculation formulas.

$$THD_P = \frac{{I_{x2}}^2 + {I_{x3}}^2 + {I_{x4}}^2 \ldots {I_{x31}}^2}{{I_{x1}}^2}$$

, where
I = measured current,
x= measurement input,
n = harmonic number

$$THD_A = \sqrt{\frac{{I_{x2}}^2 + {I_{x3}}^2 + {I_{x4}}^2 \ldots {I_{x31}}^2}{{I_{x1}}^2}}$$

, where
I = measured current,
x= measurement input,
n = harmonic number

While both of these formulas exist, the power ratio (THD_P) is recognized by the IEEE, and the amplitude ratio (THD_A) is recognized by the IEC.

The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running. This only applies if the alarming is activated.

The outputs of the function are the START and ALARM ACT signals for the phase current ("THDPH") and the residual currents ("THDI01" and "THDI02") as well as BLOCKED signals. The function uses a total of eight (8) separate setting groups which can be selected from one common source.

The operational logic consists of the following:

- input magnitude processing
- threshold comparator
- block signal chec
- time delay characteristics
- output processing.

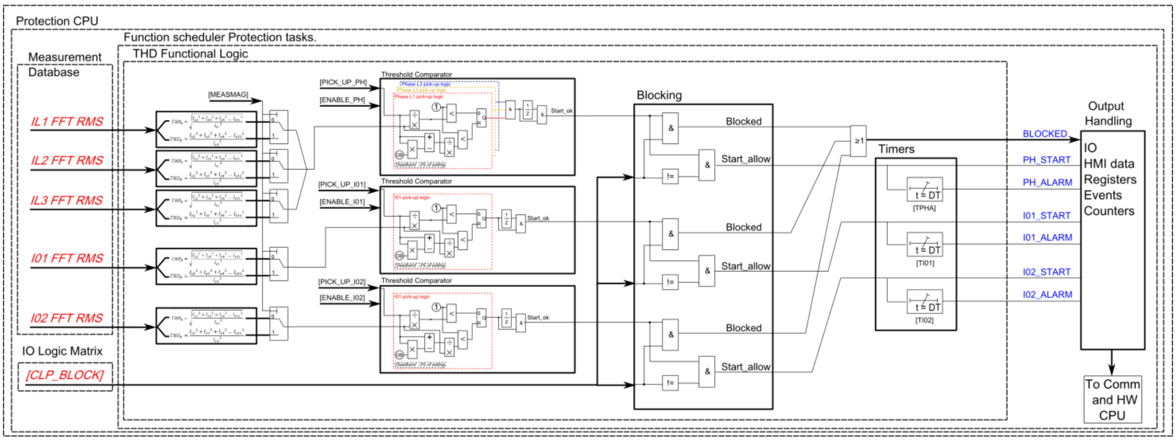
The inputs of the function are the following:

- setting parameters
- digital inputs and logic signals
- measured and pre-processed current magnitudes

The function outputs can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the two (2) output signals. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, ALARM ACT and BLOCKED events.

The following figure presents a simplified function block diagram of the total harmonic distortion monitor function.

Figure. 5.6.6. - 166. Simplified function block diagram of the total harmonic distortion monitor function.



Measured input

The function block uses analog current measurement values. The function always uses FFT measurement of the whole harmonic specter of 32 components from each measured current channel. From these measurements the function calculates either the amplitude ratio or the power ratio. A -20 ms averaged value of the selected magnitude is used for pre-fault data registering.

Table. 5.6.6. - 221. Measurement inputs of the total harmonic distortion monitor 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

The selection of the calculation method is made with a setting parameter (common for all 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 to change them by editing the setting group.

Table. 5.6.6. - 222. General settings.

Name	Range	Step	Default	Description
THD> in side	0: CT1 1: CT2	-	0: CT1	Defines which current measurement module the function uses.
Measurement magnitude	1: Amplitude 2: Power	-	1: Amplitude	Defines which available measured magnitude the function uses.

Pick-up

The $Phase_{THD}$, $I01_{THD\ and}$and $I02_{THD}$ setting parameters control the the pick-up and activation of the function. They define the maximum allowed measured current before action from the function. Before the function activates alarm signals, their corresponding pick-up elements need to be activated with the setting parameters *Enable phase THD alarm*, *Enable I01 THD alarm* and *Enable I02 THD alarm*. The function constantly calculates the ratio between the setting values and the measured magnitude for each of the three phases. The reset ratio of 97 % is built into the function and is always relative to the settingvalue. The setting value is common for all measured phases. When the I_m exceeds the I_{set} value (in single, dual or all phases), it triggers the pick-up operation of the function.

Table. 5.6.6. - 223. Pick-up settings.

Name	Range	Step	Default	Description
Enable phase THD alarm	0: Enabled 1: Disabled	-	0: Enabled	Enables and disables the THD alarm function from phase currents.
Enable I01 THD alarm	0: Enabled 1: Disabled	-	0: Enabled	Enables and disables the THD alarm function from residual current input I01.
Enable I02 THD alarm	0: Enabled 1: Disabled	-	0: Enabled	Enables and disables the THD alarm function from residual current input I02.
Phase THD pick-up	0.10…100.00 %	0.01 %	10.00 %	The pick-up setting for the THD alarm element from the phase currents. At least one of the phases' measured THD value has to exceed this setting in order for the alarm signal to activate.
I01 THD pick-up	0.10…100.00 %	0.01 %	10.00 %	The pick-up setting for the THD alarm element from the residual current I01. The measured THD value has to exceed this setting in order for the alarm signal to activate.
I02 THD pick-up	0.10…100.00 %	0.01 %	10.00 %	The pick-up setting for the THD alarm element from the residual current I02. The measured THD value has to exceed this setting in order for the alarm signal to activate.

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

Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's 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 the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup current values and its fault type to be issued.

The blocking signal can also be tested in the commissioning phase by a software switch signal when the relay's testing mode "Enable stage forcing" is activated (*General* → *Device*).

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

Operating time characteristics for activation and reset

The behavior of the function's operating timers can be set for activation as well as for the monitoring and release of the cold load pick-up situations.

The following table presents the setting parameters for the function's time characteristics.

Table. 5.6.6. - 224. Settings for operating time characteristics.

Name	Range	Step	Default	Description
Phase THD alarm delay	0.000…1800.000 s	0.005 s	10.000 s	Defines the delay for the alarm timer from the phase currents' measured THD.
I01 THD alarm delay	0.000…1800.000 s	0.005 s	10.000 s	Defines the delay for the alarm timer from the residual current I01's measured THD.
I02 THD alarm delay	0.000…1800.000 s	0.005 s	10.000 s	Defines the delay for the alarm timer from the residual current I02's measured THD.

Events and registers

The total harmonic distortion monitor function (abbreviated "THD" in event block names) generates events and registers from the status changes in the alarm function when it is activated. The recorded signals are START and ALARM signals for the monitoring elements as well as common BLOCKED signals. The user can select the status ON or OFF for messages in the main event buffer.

The triggering event of the function (THD START, ALARM or BLOCKED) is recorded with a time stamp and with process data values.

Table. 5.6.6. - 225. Event codes.

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

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data for ACTIVATED, BLOCKED, etc. The table below presents the structure of the function's register content.

Table. 5.6.6. - 226. Register content.

Date and time	Event code	L1h, L2h, L3h pretriggering current	L1h, L2h, L3h Fault current	L1h, L2h, L3h Prefault current	Used SG
dd.mm.yyyy hh:mm:ss.mss	3520-3533 Descr.	Start -200 ms THD averages of each phase.	Trip -20 ms THD averages of each phase.	Trip -200 ms averages of each phase.	Setting group 1...8 active.

5.6.7. Measurement value recorder

The measurement value recorder function records the value of the selected magnitudes at the time of a pre-defined trigger signal. An typical application is the recording of fault currents or voltages at the time of the breaker trips; it can also be used to record the values from any trigger signal set by the user. The user can select whether the function records per-unit values or primary values. Additionally, the user can set the function to record overcurrent fault types or voltage fault types. The function operates instantly from the trigger signal.

The measurement value recorder function has an integrated fault display which shows the current fault values when the tripped by one of the following functions: I> (non-directional overcurrent), Idir> (directional overcurrent), I0> (non-directional earth fault), I0dir> (directional earth fault), f< (underfrequency), f> (overfrequency), U< (undervoltage) or U> (overvoltage). When any of these functions trip, the fault values and the fault type are displayed in the Mimic view. The view can be enabled by activating the "VREC Trigger on"setting (*Tools → Events and logs → Set alarm events*). The resetting of the fault values is done by the input selected in the *General* menu.

Measured input

The function block uses analog current and voltage measurement values. Based on these values, the relay calculates the primary and secondary values of currents, voltages, powers, and impedances as well as other values.

The user can set up to eight (8) magnitudes to be recorded when the function is triggered. An overcurrent fault type, a voltage fault type, and a tripped stage can be recorded and reported straight to SCADA.

NOTE!

The available measurement values depend on the relay type. If only current analog measurements are available, the recorder can solely use signals which only use current. The same applies, if only voltage analog measurements are available.

Currents	Description
IL1 (ff), IL2 (ff), IL3 (ff), I01 (ff), I02 (ff)	The fundamental frequency current measurement values of phase currents and of residual currents.
IL1TRMS, IL2TRMS, IL3TRMS, I01TRMS, I02TRMS	The TRMS current measurement values of phase currents and of residual currents.
IL1,2,3 & I01/I02 2nd h., 3rd h., 4th h., 5th h., 7th h., 9th h., 11th h., 13th h., 15th h., 17th h., 19th h.	The magnitudes of phase 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.
I1, I2, I0Z	The positive sequence current, the negative sequence current and the zero sequence current.

I0CalcMag	The residual current calculated from phase currents.
IL1Ang, IL2Ang, IL3Ang, I01Ang, I02Ang, I0CalcAng, I1Ang, I2Ang	The angles of each measured current.
Voltages	Description
UL1Mag, UL2Mag, UL3Mag, UL12Mag, UL23Mag, UL31Mag U0Mag, U0CalcMag	The magnitudes of phase voltages, of phase-to-phase voltages, and of residual voltages.
U1 Pos.seq V mag, U2 Neg.seq V mag	The positive sequence voltage and the negative sequence voltage.
UL1Ang, UL2Ang, UL3Ang, UL12Ang, UL23Ang, UL31Ang U0Ang, U0CalcAng	The angles of phase voltages, of phase-to-phase voltages, and of residual voltages.
U1 Pos.seq V Ang, U2 Neg.seq V Ang	The positive sequence angle and the negative sequence angle.
Powers	Description
S3PH, P3PH, Q3PH	The three-phase apparent, active and reactive powers.
SL1, SL2, SL3, PL1, PL2, PL3, QL1, QL2, QL3	The phase apparent, active and reactive powers.
tanfi3PH, tanfiL1, tanfiL2, tanfiL3	The tan (φ) of three-phase powers and phase powers.
cosfi3PH, cosfiL1, cosfiL2, cosfiL3	The 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	The phase-to-phase and phase-to-neutral resistances, reactances and impedances.
Z12Ang, Z23Ang, Z31Ang, ZL1Ang, ZL2Ang, ZL3Ang	The phase-to-phase and phase-to-neutral impedance angles.
Rseq, Xseq, Zseq RseqAng, XseqAng, ZseqAng	The positive sequence resistance, reactance and impedance values and angles.
GL1, GL2, GL3, G0 BL1, BL2, BL3, B0 YL1, YL2, YL3, Y0	The conductances, susceptances and admittances.
YL1angle, YL2angle, YL3angle Y0angle	The admittance angles.
Others	Description
System f.	The tracking frequency in use at that moment.
Ref f1	The reference frequency 1.
Ref f2	The reference frequency 2.
M thermal T	The motor thermal temperature.
F thermal T	The feeder thermal temperature.
T thermal T	The transformer thermal temperature.
RTD meas 1…16	The RTD measurement channels 1…16.
Ext RTD meas 1…8	The external RTD measurement channels 1…8 (ADAM module).

Reported values

When triggered, the function holds the recorded values of up to eight channels, as set. In addition to this tripped stage, the overcurrent fault type and the voltage fault types are reported to SCADA.

Table. 5.6.7. - 227. Reported values.

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 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	-	The tripped stage.
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	-	The 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	-	The voltage fault type.
Magnitude 1…8	0.000…1800.000 A/V/p.u.	0.001 A/V/p.u.	The recorded value in one of the eight channels.

Events

The measurement value recorder function (abbreviated "VREC" in event block names) generates events from the function triggers. The user can select the status ON or OFF for messages in the main event buffer.

Table. 5.6.7. - 228. Event codes.

Event number	Event channel	Event block name	Event code	Description
9984	156	VREC1	0	Recorder triggered ON
9985	156	VREC1	1	Recorder triggered OFF

6. System integration

6.1. Communication protocols

6.1.1. NTP

When enabled, the NTP (Network Time Protocol) service can use external time sources to synchronize the device's system time. The NTP client service uses an Ethernet connection to connect to the NTP time server. NTP can be enabled by setting the primary time server and the secondary time server parameters to the address of the system's NTP time source(s).

Table. 6.1.1. - 229. Server settings.

Name	Range	Description
Primary time server address	0.0.0.0...255.255.255.255	Defines the address of the primary NTP server. Setting this parameter at "0.0.0.0" means that the server is not in use.
Secondary time server address	0.0.0.0...255.255.255.255	Defines the address of the secondary (or backup) NTP server. Setting this parameter at "0.0.0.0" means that the server is not in use.

Table. 6.1.1. - 230. Status.

Name	Range	Description
NTP quality for events	0: No sync 1: Synchronized	Displays the status of the NTP time synchronization at the moment. **NOTE:** This indication is not valid if another time synchronization method is used (external serial).
NTP-processed message count	$0...2^{32}–1$	Displays the number of messages processed by the NTP protocol.

Additionally, the time zone of the relay can be set by connecting to the relay and the selecting the time zone at *Commands → Set time zone* (AQtivate).

6.1.2. Modbus/TCP and Modbus/RTU

The device supports both Modbus/TCP and Modbus/RTU communication. Modbus/TCP uses the Ethernet connection to communicate with Modbus/TCP clients. Modbus/RTU is a serial protocol that can be selected for the available serial ports.

The following Modbus function types are supported:

- Read multiple holding registers (function code 3)
- Write single holding register (function code 6)
- Write multiple holding registers (function code 16)
- Read/Write multiple registers (function code 23)

The following data can be accessed using both Modbus/TCP and Modbus/RTU:

- Device measurements
- Device I/O
- Commands
- Events
- Time

Once the configuration file has been loaded, the user can access the Modbus map of the relay via the AQtivate software (*Tools → Communication → Modbusmap*). Please note that holding registers start from 1. Some masters might begin numbering holding register from 0 instead of 1; this will cause an offset of 1 between the relay and the master.

Table. 6.1.2. - 231. Modbus/TCP settings.

Parameter	Range	Description
Modbus/TCP Enable	0: Disabled 1: Enabled	Enables and disables the Modbus/TCP on the Ethernet port.
IP port	0…65 535	Defines the IP port used by Modbus/TCP. The standard port (and the default setting) is 502.

Table. 6.1.2. - 232. Modbus/RTU settings.

Parameter	Range	Description
Slave address	1…247	Defines the Modbus/RTU slave address for the unit.

Additionally, the user can adjust the measurement update interval with the following parameters (found at *Measurement → Measurement update*). These parameters do not affect the operating times of protection functions, only the frequency of measurement reporting to Modbus.

Table. 6.1.2. - 233. Settings for measurement update interval.

Name	Range	Step	Default	Description
Current measurement update interval	500…10 000 ms	5 ms	2 000 ms	Defines the measurement update interval of all current-related measurements.
Voltage measurement update interval	500…10 000 ms	5 ms	2 000 ms	Defines the measurement update interval of all voltage-related measurements.
Power measurement update interval	500…10 000 ms	5 ms	2 000 ms	Defines the measurement update interval of all power-related measurements.
Impedance measurement update interval	500…10 000 ms	5 ms	2 000 ms	Defines the measurement update interval of all impedance-related measurements.

6.1.3. Modbus I/O

The Modbus I/O protocol can be selected to communicate on the available serial ports. The Modbus I/O is actually a Modbus/RTU master implementation that is dedicated to communicating with serial Modbus/RTU slaves such as RTD input modules. Up to three (3) Modbus/RTU slaves can be connected to the same bus polled by the Modbus I/O implementation. These are named I/O Module A, I/O Module B and I/O Module C. Each of the modules can be configured using parameters in the following two tables.

Table. 6.1.3. - 234. Module settings.

Name	Range	Description
I/O module X address	0…247	Defines the Modbus unit address for the selected I/O Module (A, B, or C). If this setting is set to "0", the selected module is not in use.
Module x type	0: ADAM-4018+ 1: ADAM-4015	Selects the module type.
Channels in use	Channel 0…Channel 7 (or None)	Selects the number of channels to be used by the module.

Table. 6.1.3. - 235. Channel settings.

Name	Range	Step	Default	Description

T.C. type	0: +/- 20 mA 1: 4…20 mA 2: Type J 3: Type K 4: Type T 5: Type E 6: Type R 7: Type S	-	1: 4…20 mA	Selects the thermocouple or the mA input connected to the I/O module. Types J, K, T and E are nickel-alloy thermocouples, while Types R and S are platinum/rhodium-alloy thermocouples.
Input value	-101.0…2000.0	0.1	-	Displays the input value of the selected channel.
Input status	0: Invalid 1: OK	-	-	Displays the input status of the selected channel.

6.1.4. IEC 61850

The user can enable the IEC 61850 protocol in device models that support this protocol. The AQ-200 series devices use Edition 1 of IEC 61850. The following services are supported by IEC 61850 in Arcteq devices:

- Dataset (predefined data sets can be edited with the IEC 61850 tool in AQtivate)
- Report Control Blocks (both buffered and unbuffered reporting)
- Control ('direct operate with normal security' control sequences)
- Disturbance recording file transfer
- GOOSE
- Time synchronization

The device's current IEC 61850 setup can be viewed with the IEC61850 tool (*Tools → IEC 61850*). By browsing the 61850 tree one can see the full list of available logical nodes in the Arcteq implementation.

IEC 61850 main toolbar

Figure. 6.1.4. - 167. Main toolbar.

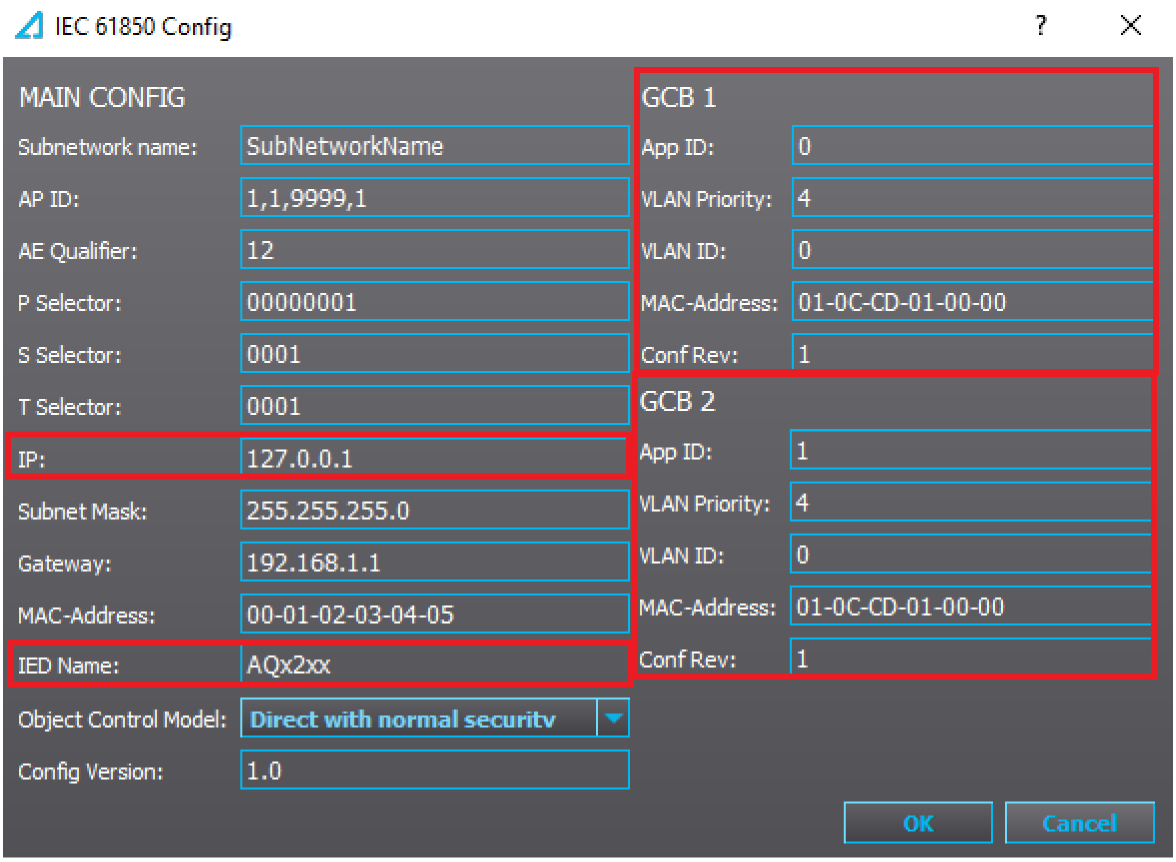
The buttons available in the main toolbar of the IEC 61850 tool are (as per image):

1. Open .CID/.ICD file
   Open an existing .CID or .ICD file from the PC's hard drive.
2. Save .CID/.ICD file
   If CID file was opened from PC's hard drive, saves all changes to that .CID or .ICD file.
3. Save to .aqs
   Saves the .CID or .ICD file into the .aqs currently open (remember to save the .aqs file as well [*File → Save*] to keep the changes!).
4. Save .CID/.ICD as...
   Saves the .CID or .ICD file on the PC's hard drive as a separate .CID or .ICD file.
5. Export dataset info
   Exports the dataset information into a .txt file which can then be viewed in table format with tools such as Excel.
6. Configurations
   Opens the main configurations pop-up window.
7. Edit datasets
   Opens the dataset editing window.
8. Send to relay
   Sends the .CID/.ICD configurations to the relay (requires a connection to the relay).
9. Import GOOSE settings
   Imports predefined GOOSE settings from another .CID/.ICD file.
10. Get default .CID/.ICD file from the relay
    Retrieves the default .CID/.ICD file from the relay.

Configurations

The main configurations dialog window is opened by pressing the sixth button ("Configurations") in the main toolbar. The most Important parameters here are the "IED name" and the "IP" settings. Additionally, if the intention is to use the GOOSE publisher service, the parameters for GCB1 and GCB2 should also be set. See the following image of the main configuration window for the basic settings and the settings for GOOSE publishing.

Figure. 6.1.4. - 168. Configurations window.

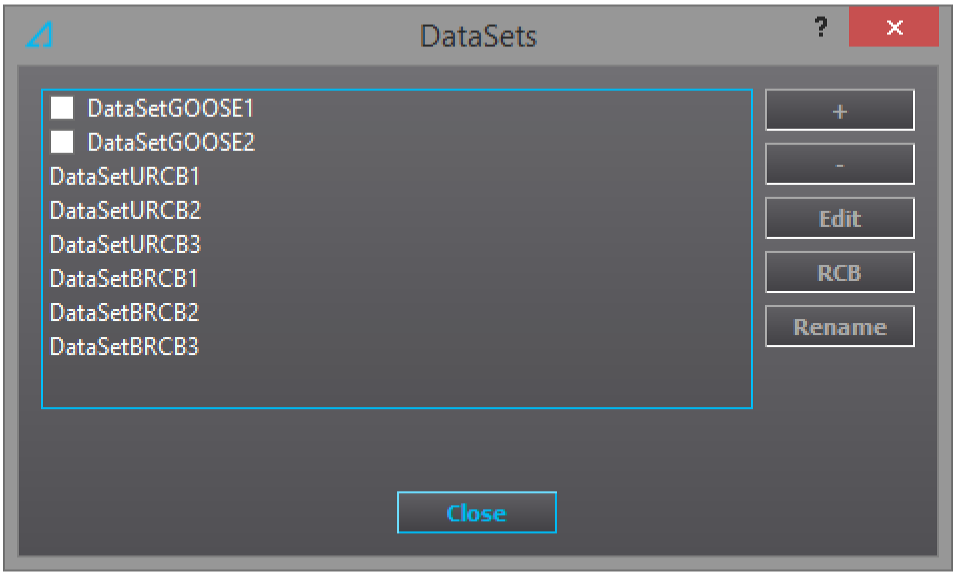


Data sets

The data set editing window is opened by pressing the seventh button on the main toolbar. Data sets can be added and removed by using the "+" and "-" buttons, respectively. When a data set has been added, it must be assigned to a Report Control Block with the "RCB" button. This opens a new pop-up window. The assigning can be either to unbuffered reporting (URCBs) or to buffered reporting (BRCBs).

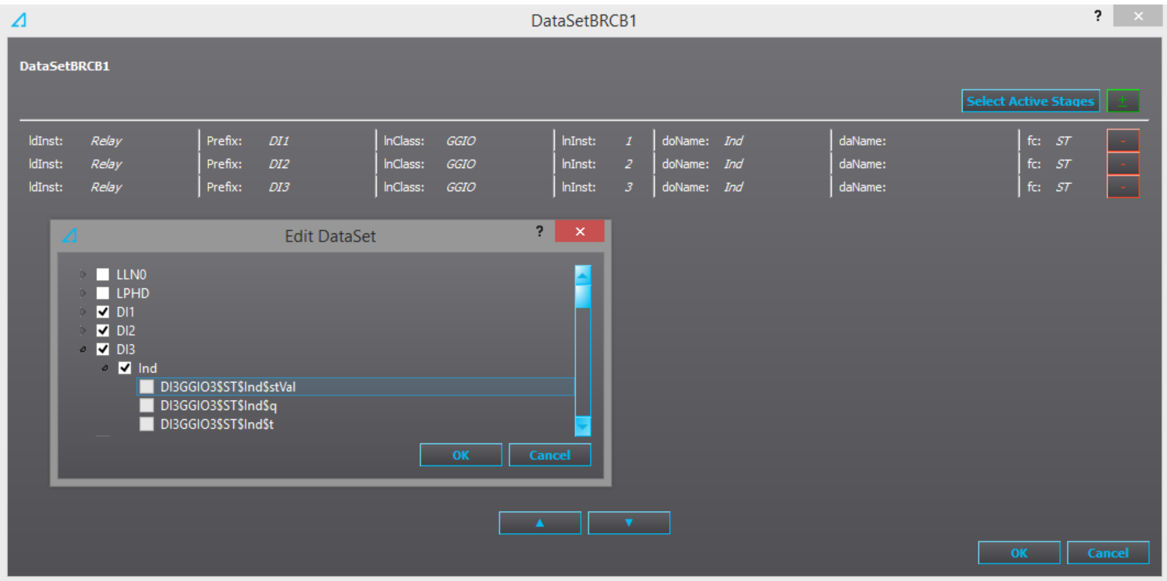
If both of the GOOSE publisher data sets are un-checked, the GOOSE publisher service is disabled (see the image below).

Figure. 6.1.4. - 169. Data set editing window.



All of these data sets can be edited. The data set editing dialog is opened by clicking on the selected data set to be edited and then clicking the "Edit" button. The editing dialog shows all currently configured entries of the data set. An entry can be removed from the data set by clicking the red "-" button located at the end of the entry's row. New entries can be added and old ones edited by clicking the green "+" button at the top right of the window. For URCB and BRCB data sets it is recommended that the data is selected on the doName (data object) level (see the image below). This way all available information (such as status, quality, and time) is always sent in the report. Data can also be selected on daName (data attribute) level, which selects each individual piece of data. This approach may be preferred for GOOSE data sets.

Figure. 6.1.4. - 170. Data selection on the data attribute level.



Settings.

The general setting parameters for the IEC 61850 protocol are visible both in AQtivate and in the local HMI. The settings are described in the table below.

Table. 6.1.4. - 236. General settings.

Name	Range	Step	Default	Description
IEC 61850 enable	0: Disabled 1: Enabled	-	0: Disabled	Enables and disables the IEC 61850 communication protocol.
IP port	0…65 535	1	102	Defines the IP port used by the IEC 61850 protocol. The standard (and default) port is 102.
General deadband	0.1…10.0 %	0.1 %	2 %	Determines the general data reporting deadband settings.
Active energy deadband	0.1…1000.0 kWh	0.1 kWh	2 kWh	Determines the data reporting deadband settings for this measurement.
Reactive energy deadband	0.1…1000.0 kVar	0.1 kVar	2 kVar	Determines the data reporting deadband settings for this measurement.
Active power deadband	0.1…1000.0 kW	0.1 kW	2 kW	Determines the data reporting deadband settings for this measurement.
Reactive power deadband	0.1…1000.0 kVar	0.1 kVar	2 kVar	Determines the data reporting deadband settings for this measurement.
Apparent power deadband	0.1…1000.0 kVA	0.1 kVA	2 kVA	Determines the data reporting deadband settings for this measurement.
Power factor deadband	0.01…0.99	0.01	0.05	Determines the data reporting deadband settings for this measurement.
Frequency deadband	0.01…1.00 Hz	0.01 Hz	0.1 Hz	Determines the data reporting deadband settings for this measurement.
Current deadband	0.01…50.00 A	0.01 A	5 A	Determines the data reporting deadband settings for this measurement.
Residual current deadband	0.01…50.00 A	0.01 A	0.2 A	Determines the data reporting deadband settings for this measurement.
Voltage deadband	0.01…5000.00 V	0.01 V	200 V	Determines the data reporting deadband settings for this measurement.
Residual voltage deadband	0.01…5000.00 V	0.01 V	200 V	Determines the data reporting deadband settings for this measurement.
Angle measurement deadband	0.1…5.0 deg	0.1 deg	1 deg	Determines the data reporting deadband settings for this measurement.
Integration time	0…10 000 ms	1 ms	0 ms	Displays the integration time of the protocol. If this parameter is set to "0 ms", no integration time is in use.
GOOSE reconfigure	0: - 1: Reconfigure	-	0: -	Reconfigures the GOOSE.
GOOSE subscriber enable	0: Disabled 1: Enabled	-	0: Disabled	Enabled and disables the GOOSE subscriber.

For more information on the IEC 61850 communication protocol support, please refer to the conformance statement documents (www.arcteq.fi/downloads/ → AQ-200 series → Resources).

6.1.5. GOOSE

Arcteq relays support both GOOSE publisher and GOOSE subscriber. GOOSE subscriber is enabled with the "GOOSE subscriber enable" parameter at *Communication → Protocols → IEC 61850/GOOSE*. The GOOSE inputs are configured using either the local HMI or the AQtivate software.

There are up to 64 GOOSE inputs available for use. Each of the GOOSE inputs also has a corresponding input quality signal which can also be used in internal logic. The quality is good, when the input quality is low (that is, when the quality is marked as "0"). The value of the input quality can increase as a result of a GOOSE time-out or a configuration error, for example. The status and quality of the various logical input signals can be viewed at the *GOOSE IN status* and *GOOSE IN quality* tabs at *Control → Device I/O → Logical signals*.

GOOSE input settings

The table below presents the different settings available for all 64 GOOSE inputs.

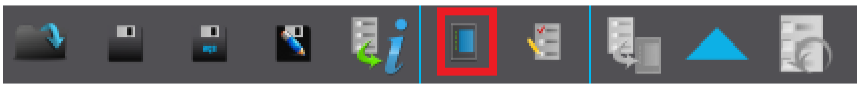
Table. 6.1.5. - 237. GOOSE input settings.

Name	Range	Step	Default	Description
In use	0: No 1: Yes	-	0: No	Enables and disables the GOOSE input in question.
Application ID ("AppID")	0×0… 0×3FFF	0×1	0×0	Defines the application ID that will be matched with the publisher's GOOSE control block.
Configuration revision ("ConfRev")	1…2^{32}-1	1	1	Defines the configuration revision that will be matched with the publisher's GOOSE control block.
Data index ("DataIdx")	0…99	1	-	Defines the data index of the value in the matched published frame. It is the status of the GOOSE input.
NextIdx is quality	0: No 1: Yes	-	0: No	Selects whether or not the next received input is the quality bit of the GOOSE input.
Data type	0: Boolean 1: Integer 2: Unsigned 3: Floating point	-	0: Boolean	Selects the data type of the GOOSE input.

Setting the publisher

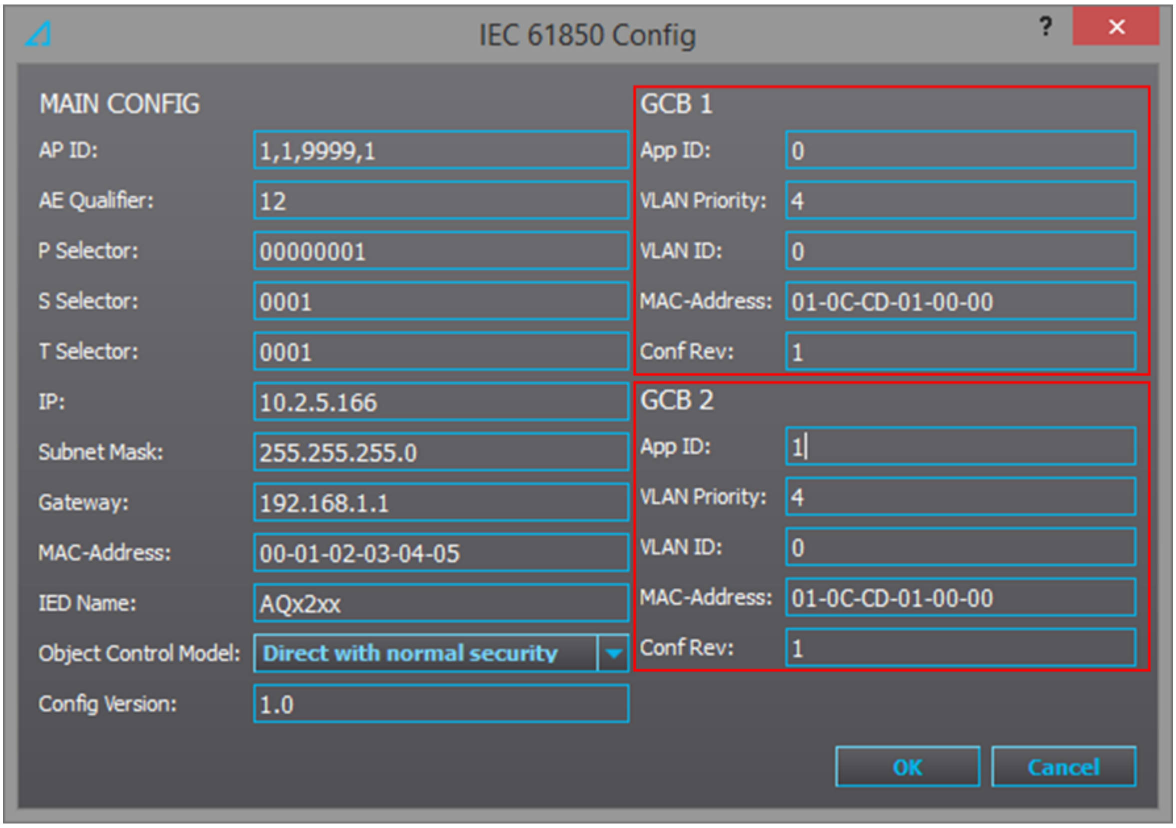
The configuration of the GOOSE publisher is done using the IEC 61850 tool in AQtivate (*Tools → Communication → IEC 61850*). In order for the GOOSE publishing service to be used, both of the GCBs and the GOOSE data sets must be set.

The GOOSE control blocks are accessed by clicking the sixth icon on the main toolbar, "Configurations" (see the image below).



The GOOSE control block settings are located on the right side of the Configurations pop-up window (see the image below). Both GCB1 and GCB 2 must be set. The important parameters are "App ID" (should be unique for the system) and "ConfRev" (checked by the subscriber). If VLAN switches have been used to build the sub-networks, both the "VLAN priority" and the "VLAN ID" parameters must be set to match the system specifications.

Figure. 6.1.5. - 171. Settings for both available GOOSE publishing data sets.



The GOOSE data sets define the data that is sent by the publisher. GOOSE publisher can only send binary data and quality information of the binary signals. The binary signal and the quality information for that binary singal are mapped together to the GOOSE input signals on the receiving side. In order for the quality information of each GOOSE input to be used in the relay logic, both the quality information and the GOOSE reception time-out supervision have to be of good quality, or else the quality signal activates.

6.1.6. IEC 103

IEC 103 is shortened form of the international standard IEC 60870-5-103. The AQ-200 series units are able to run as a secondary (slave) station. The IEC 103 protocol can be selected for the serial ports that are available in the device. A primary (master) station can then communicate with the Arcteq device and receive information by polling from the slave device. The transfer of disturbance recordings is not supported.

NOTE: Once the configuration file has been loaded, the IEC 103 map of the relay can be found in the AQtivate software (*Tools → IEC 103 map*).

The following table presents the setting parameters for the IEC 103 protocol.

Name	Range	Step	Default	Description
Slave address	1…254	1	1	Defines the IEC 103 slave address for the unit.
Measurement interval	0…60 000 ms	1 ms	2000 ms	Defines the interval for the measurements update.

6.1.7. DNP3

DNP3 is a protocol standard which is controlled by the DNP Users Group (www.dnp.org). The implementation of a DNP3 slave is compliant with the DNP3 subset (level) 2, but it also contains some functionalities of the higher levels. For detailed information please refer to the DNP3 Device Profile document (www.arcteq.fi/downloads/ → AQ-200 series → Resources).

Settings

The following table describes the DNP3 setting parameters.

Table. 6.1.7. - 238. Settings.

Name	Range	Step	Default	Description
DNP3 TCP enable	0: Disabled 1: Enabled	-	0: Disabled	Enables and disables the DNP3 TCP communication protocol when the Ethernet port is used for DNP3. If a serial port is used, the DNP3 protocol can be enabled from *Communication → DNP3*.
IP port	0…65 535	1	20 000	Defines the IP port used by the protocol.
Slave address	1…65 519	1	1	Defines the DNP3 slave address of the unit.
Master address	1…65 534	1	2	Defines the address for the allowed master.
Link layer time-out	0…60 000 ms	1 ms	0 ms	Defines the length of the time-out for the link layer.
Link layer retries	1…20	1	1	Defines the number of retries for the link layer.
Diagnostic - Error counter	0…2^{32}-1	1	-	Counts the total number of errors in received and sent messages.
Diagnostic - Transmitted messages	0…2^{32}-1	1	-	Counts the total number of transmitted messages.
Diagnostic - Received messages	0…2^{32}-1	1	-	Counts the total number of received messages.

Default variations

Table. 6.1.7. - 239. Default variations.

Name	Range	Default	Description
Group 1 variation (BI)	0: Var 1 1: Var 2	0: Var 1	Selects the variation of the binary signal.
Group 2 variation (BI change)	0: Var 1 1: Var 2	1: Var 2	Selects the variation of the binary signal change.
Group 3 variation (DBI)	0: Var 1 1: Var 2	0: Var 1	Selects the variation of the double point signal.
Group 4 variation (DBI change)	0: Var 1 1: Var 2	1: Var 2	Selects the variation of the double point signal.
Group 20 variation (CNTR)	0: Var 1 1: Var 2 2: Var 5 3: Var 6	0: Var 1	Selects the variation of the control signal.

Group 22 variation (CNTR change)	0: Var 1 1: Var 2 2: Var 5 3: Var 6	2: Var 5	Selects the variation of the control signal change.
Group 30 variation (AI)	0: Var 1 1: Var 2 2: Var 3 3: Var 4 4: Var 5	4: Var 5	Selects the variation of the analog signal.
Group 32 variation (AI change)	0: Var 1 1: Var 2 2: Var 3 3: Var 4 4: Var 5 5: Var 7	4: Var 5	Selects the variation of the analog signal change.

Setting the analog change deadbands

Table. 6.1.7. - 240. Analog change deadband settings.

Name	Range	Step	Default	Description
General deadband	0.1…10.0 %	0.1 %	2 %	Determines the general data reporting deadband settings.
Active energy deadband	0.1…1000.0 kWh	0.1 kWh	2 kWh	Determines the data reporting deadband settings for this measurement.
Reactive energy deadband	0.1…1000.0 kVar	0.1 kVar	2 kVar	Determines the data reporting deadband settings for this measurement.
Active power deadband	0.1…1000.0 kW	0.1 kW	2 kW	Determines the data reporting deadband settings for this measurement.
Reactive power deadband	0.1…1000.0 kVar	0.1 kVar	2 kVar	Determines the data reporting deadband settings for this measurement.
Apparent power deadband	0.1…1000.0 kVA	0.1 kVA	2 kVA	Determines the data reporting deadband settings for this measurement.
Power factor deadband	0.01…0.99	0.01	0.05	Determines the data reporting deadband settings for this measurement.
Frequency deadband	0.01…1.00 Hz	0.01 Hz	0.1 Hz	Determines the data reporting deadband settings for this measurement.
Current deadband	0.01…50.00 A	0.01 A	5 A	Determines the data reporting deadband settings for this measurement.
Residual current deadband	0.01…50.00 A	0.01 A	0.2 A	Determines the data reporting deadband settings for this measurement.
Voltage deadband	0.01…5000.00 V	0.01 V	200 V	Determines the data reporting deadband settings for this measurement.
Residual voltage deadband	0.01…5000.00 V	0.01 V	200 V	Determines the data reporting deadband settings for this measurement.
Angle measurement deadband	0.1…5.0 deg	0.1 deg	1 deg	Determines the data reporting deadband settings for this measurement.
Integration time	0…10 000 ms	1 ms	-	Displays the integration time of the protocol.

6.1.8. IEC 101/104

The standards IEC 60870-5-101 and IEC 60870-5-104 are closely related. Both are derived from the IEC 60870-5 standard. On the physical layer the IEC 101 protocol uses serial communication whereas the IEC 104 protocol uses Ethernet communication. The IEC 101/104 implementation works as a slave in the unbalanced mode.

For detailed information please refer to the IEC 101/104 interoperability document (www.arcteq.fi/downloads/ → AQ-200 series → Resources → "AQ-200 IEC101 & IEC104 interoperability").

IEC 101 settings

Table. 6.1.8. - 241. IEC 101 settings.

Name	Range	Step	Default	Description
Common address of ASDU	0…65 534	1	1	Defines the common address of the application service data unit (ASDU) for the IEC 101 communication protocol.
Common address of ASDU size	1…2	1	2	Defines the size of the common address of ASDU.
Link layer address	0…65 534	1	1	Defines the address for the link layer.
Link layer address size	1…2	1	2	Defines the address size of the link layer.
Information object address size	2…3	1	3	Defines the address size of the information object.
Cause of transmission size	1…2	1	2	Defines the cause of transmission size

IEC 104 settings

Table. 6.1.8. - 242. IEC 104 settings.

Name	Range	Step	Default	Description
IEC 104 enable	0: Disabled 1: Enabled	-	0: Disabled	Enables and disables the IEC 104 communication protocol.
IP port	0…65 535	1	2404	Defines the IP port used by the protocol.
Common address of ASDU	0…65 534	1	1	Defines the common address of the application service data unit (ASDU) for the IEC 104 communication protocol.

Measurement scaling coefficients

The measurement scaling coefficients are available for the following measurements, in addition to the general measurement scaling coefficient:

- Active energy
- Reactive energy
- Active power
- Reactive power
- Apparent power
- Power factor
- Frequency
- Current
- Residual current
- Voltage
- Residual voltage
- Angle

The range is the same for all of the scaling coefficients. By default, there is no scaling.

- No scaling
- 1/10
- 1/100
- 1/1000
- 1/10 000
- 1/100 000
- 1/1 000 000
- 10
- 100
- 1000
- 10 000
- 100 000
- 1 000 000

Deadband settings.

Table. 6.1.8. - 243. Analog change deadband settings.

Name	Range	Step	Default	Description
General deadband	0.1…10.0 %	0.1 %	2 %	Determines the general data reporting deadband settings.
Active energy deadband	0.1…1000.0 kWh	0.1 kWh	2 kWh	Determines the data reporting deadband settings for this measurement.
Reactive energy deadband	0.1…1000.0 kVar	0.1 kVar	2 kVar	Determines the data reporting deadband settings for this measurement.
Active power deadband	0.1…1000.0 kW	0.1 kW	2 kW	Determines the data reporting deadband settings for this measurement.
Reactive power deadband	0.1…1000.0 kVar	0.1 kVar	2 kVar	Determines the data reporting deadband settings for this measurement.
Apparent power deadband	0.1…1000.0 kVA	0.1 kVA	2 kVA	Determines the data reporting deadband settings for this measurement.
Power factor deadband	0.01…0.99	0.01	0.05	Determines the data reporting deadband settings for this measurement.
Frequency deadband	0.01…1.00 Hz	0.01 Hz	0.1 Hz	Determines the data reporting deadband settings for this measurement.
Current deadband	0.01…50.00 A	0.01 A	5 A	Determines the data reporting deadband settings for this measurement.
Residual current deadband	0.01…50.00 A	0.01 A	0.2 A	Determines the data reporting deadband settings for this measurement.
Voltage deadband	0.01…5000.00 V	0.01 V	200 V	Determines the data reporting deadband settings for this measurement.
Residual voltage deadband	0.01…5000.00 V	0.01 V	200 V	Determines the data reporting deadband settings for this measurement.
Angle measurement deadband	0.1…5.0 deg	0.1 deg	1 deg	Determines the data reporting deadband settings for this measurement.
Integration time	0…10 000 ms	1 ms	-	Displays the integration time of the protocol.

6.1.9. SPA

The device can act as a SPA slave. SPA can be selected as the communication protocol for the COM B port (RS485 port in the CPU module). When the device includes a serial RS-232 card connector, the SPA protocol can also be selected as the communication protocol for the COM E and COM F ports. Please refer to the chapter "Construction and installation" in the device manual to see the connections for these modules.

The data transfer rate of SPA is 9600 bps, but it can also be set to 19 200 bps or 38 400 bps. As a slave the device sends data on demand or by sequenced polling. The available data can be measurements, circuit breaker states, function starts, function trips, etc. The full SPA signal map can be found in AQtivate (*Tools → SPA map*).

The SPA event addresses can be found at *Tools → Events and logs → Event list*.

NOTE!

To access SPA map and event list, an .aqs configuration file should be downloaded from the relay.

6.2. Analog fault registers

At *Communication → General I/O → Analog fault registers* the user can set up to twelve (12) channels to record the measured value when a protection function starts or trips. These values can be read in two ways: locally from this same menu, or through a communication protocol if one is in use.

The following table presents the setting parameters available for the 12 channels.

Table. 6.2. - 244. Fault register settings.

Name	Range	Step	Default	Description
Select record source	0: Not in use 1…12: I>, I>>, I>>>, I>>>> (IL1, IL2, IL3) 13…24: Id>, Id>>, Id>>>, Id>>>> (IL1, IL2, IL3) 25…28: I0>, I0>>, I0>>>, I0>>>> (I0) 29…32: I0d>, I0d>>, I0d>>>, I0d>>>> (I0) 33: FLX	-	0: Not in use	Selects the protection function and its stage to be used as the source for the fault register recording. The user can choose between non-directional overcurrent, directional overcurrent, non-directional earth fault, directional earth fault, and fault locator functions.
Select record trigger	0: TRIP signal 1: START signal 2: START and TRIP signals	-	0: TRIP signal	Selects what triggers the fault register recording: the selected function's TRIP signal, its START signal, or either one.
Recorded fault value	- 1000 000.00…1 000 000.00	0.01	-	Displays the recorded measurement value at the time of the selected fault register trigger.

6.3. Real time measurements to communication

With the *Real-time signals to communication* menu the user can report to SCADA measurements that are not normally available in the communication protocols mapping. Up to eight (8) magnitudes can be selected. The recorded value can be either a per-unit value or a primary value (set by the user).

Measurable values

Function block uses analog current and voltage measurement values. The relay uses these values as the basis when it calculates the primary and secondary values of currents, voltages, powers, impedances and other values.

Table. 6.3. - 245. Available measured values.

Signals	Description
Currents	

IL1 (ff), IL2 (ff), IL3 (ff), I01 (ff), I02 (ff)	Fundamental frequency current measurement values of phase currents and residual currents.
IL1 (TRMS), IL2 (TRMS), IL3 (TRMS), I01 (TRMS), I02 (TRMS)	TRMS current measurement values of phase currents and residual currents.
IL1, IL2, IL3, I01, I02 & 2nd h., 3rd h., 4th h., 5th h., 7th h., 9th h., 11th h., 13th h., 15th h., 17th h., 19th h.	Magnitudes of the phase current components: 2nd harmonic, 3rd harmonic, 4th harmonic, 5th harmonic 7th, harmonic 9th, harmonic 11th, harmonic 13th, harmonic 15th, harmonic 17th, harmonic 19th 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.
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 and phase-to-neutral resistances, reactances and impedances.
Z12Ang, Z23Ang, Z31Ang, ZL1Ang, ZL2Ang, ZL3Ang	Phase-to-phase and 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 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.
Ext RTD meas 1…8	External RTD measurement channels 1…8 (ADAM module).

Settings

Table. 6.3. - 246. Settings.

Name	Range	Step	Default	Description
Measurement value recorder mode	0: Disabled 1: Activated	-	0: Disabled	Activates and disables the real-time signals to communication.
Scale current values to primary	0: No 1: Yes	-	0: No	Selects whether or not values are scaled to primary.
Slot X magnitude selection	0: Currents 1: Voltages 2: Powers 3: Impedance (ZRX) and admittance (YGB) 4: Others	-	0: Currents	Selects the measured magnitude catecory of the chosen slot.
Slot X magnitude	Described in table above ("Available measured values")	-	-	Selects the magnitude in the previously selected category.
Magnitude X	-10 000 000.000…10 000 000.000	0.001	-	Displays the measured value of the selected magnitude of the selected slot. The unit depends on the selected magnitude (either amperes, volts, or per-unit values).

7. Connections and application examples

7.1. Connections AQ-T257

Figure. 7.1. - 172. AQ-T257 variant without add-on modules.

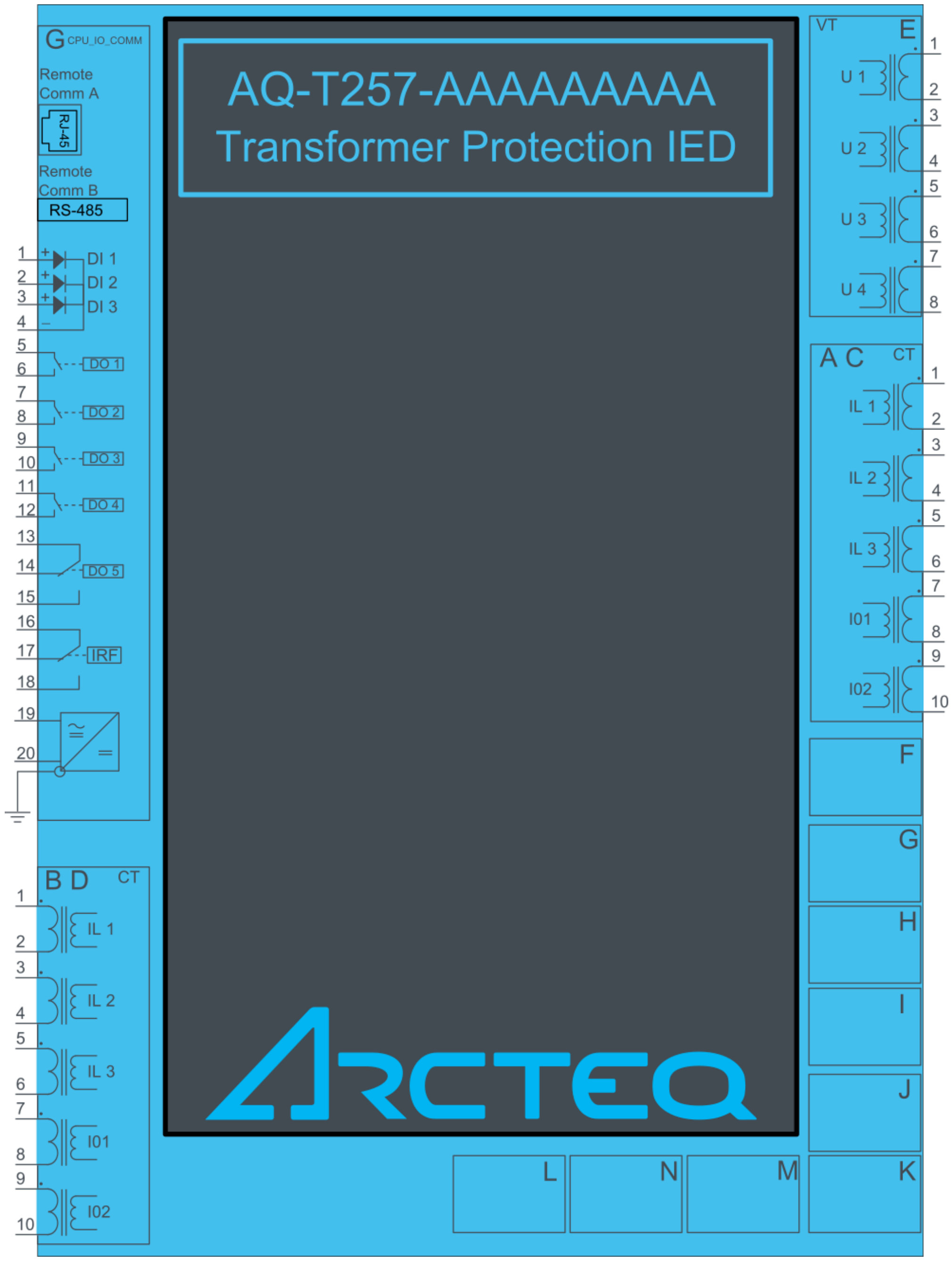


Figure. 7.1. - 173. AQ-T257 variant with digital input and output modules.

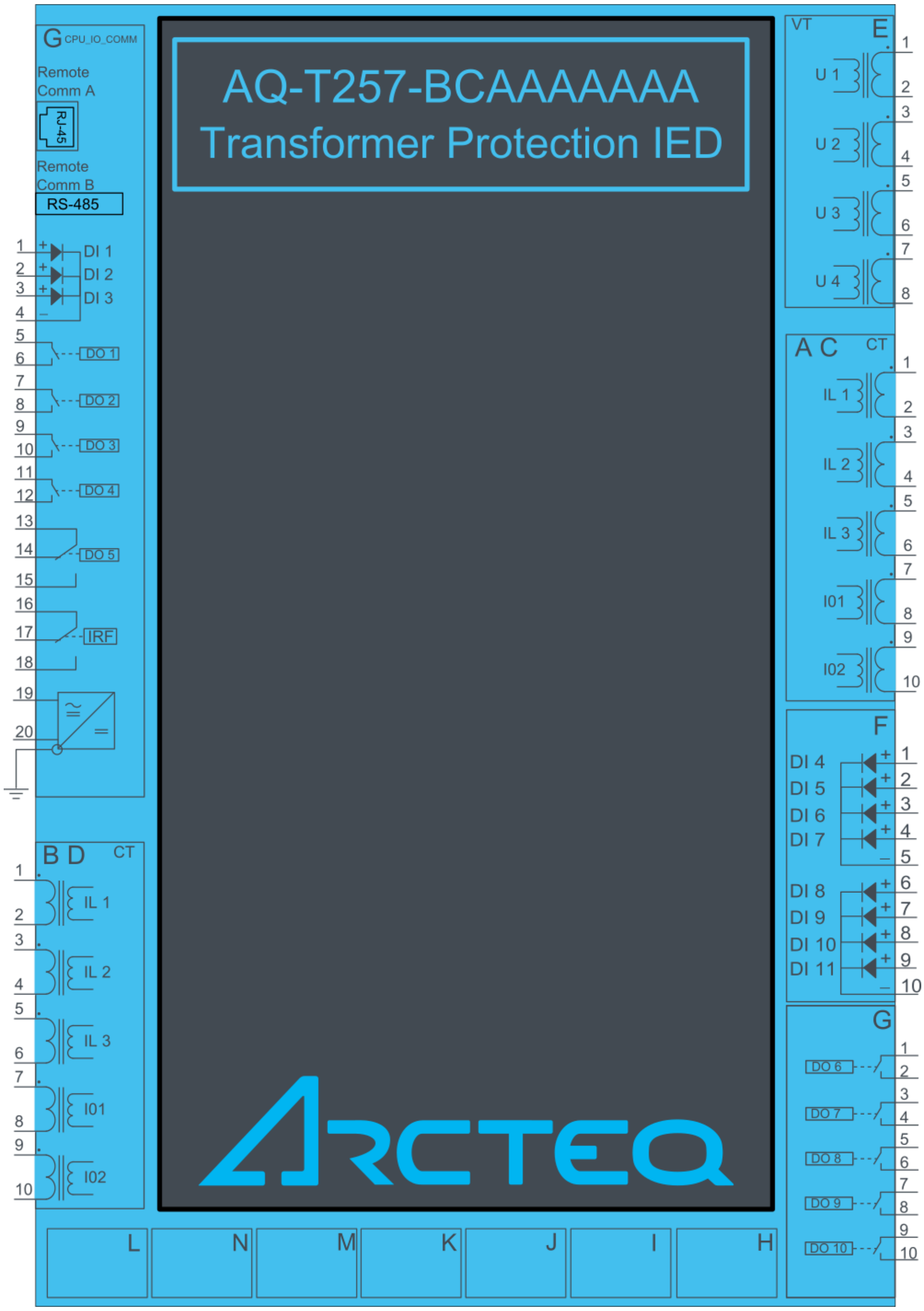
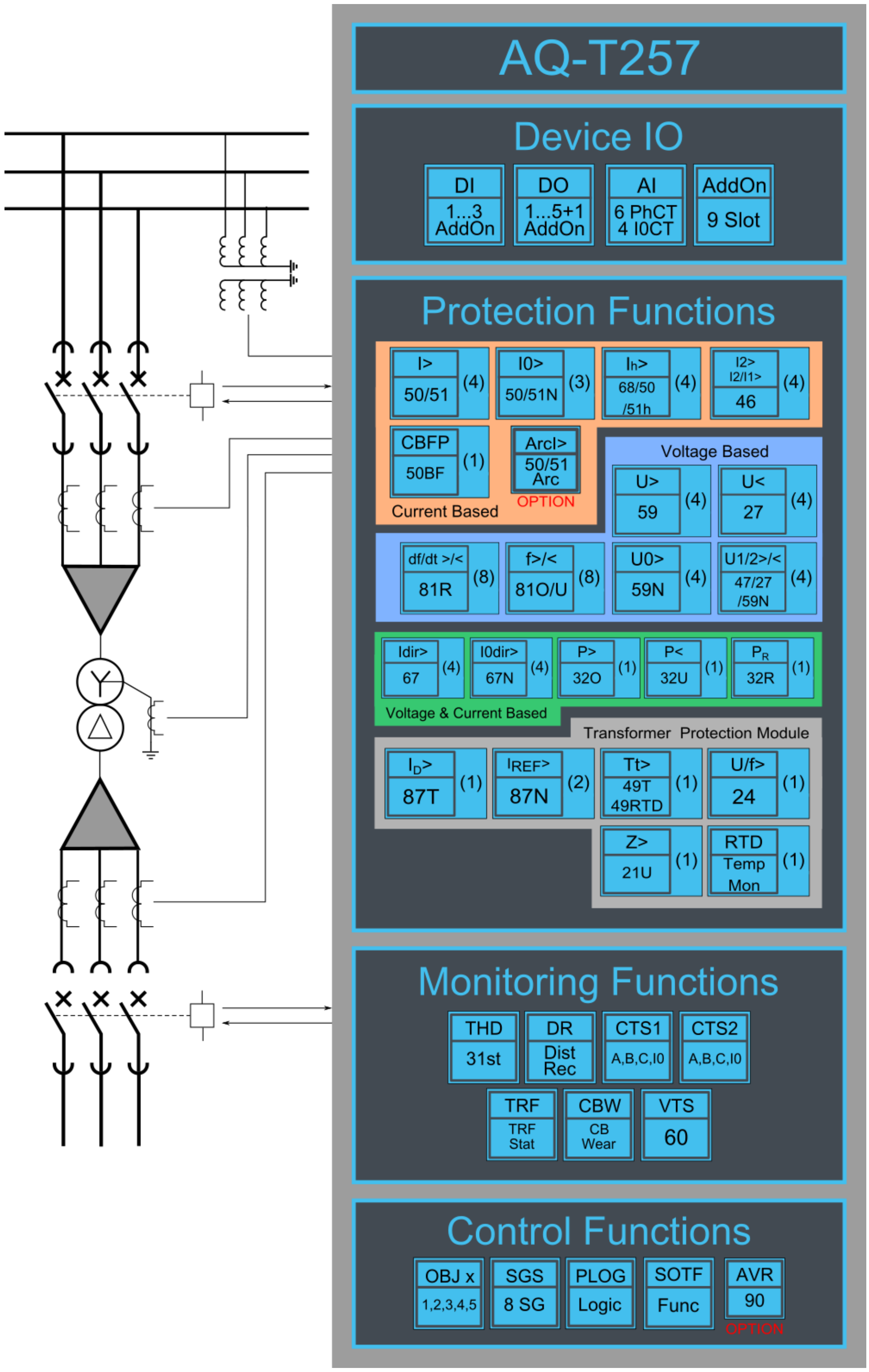


Figure. 7.1. - 174. AQ-T257 application example with function block diagram.

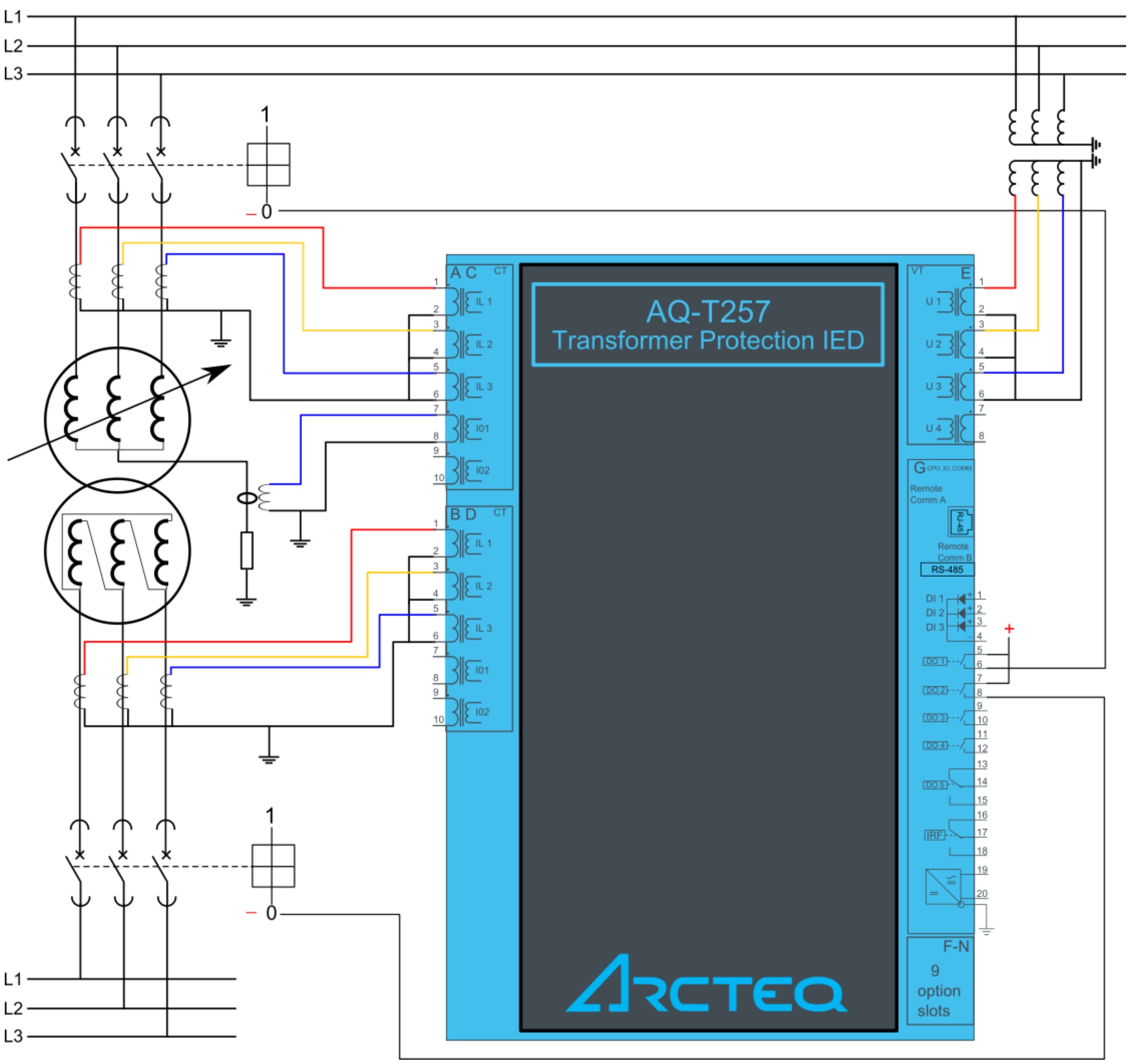


7.2. Application example and its connections

This chapter presents an application example for the two-winding transformer differential IED. The example is a regular differential scheme with restricted earth fault protection on the high-voltage side.

As can be seen in the image below, the example application has two current transformers. The first (upper) CT has the three phase current as well as the residual current (I01) connected. The second CT also has the three phase currents but no residual current connected. Additionally, there is also a voltage transformer with the measurement mode "3LN" selected, which means that there are three line-to-neutral voltages connected.

Figure. 7.2. - 175. Application example and its connections.



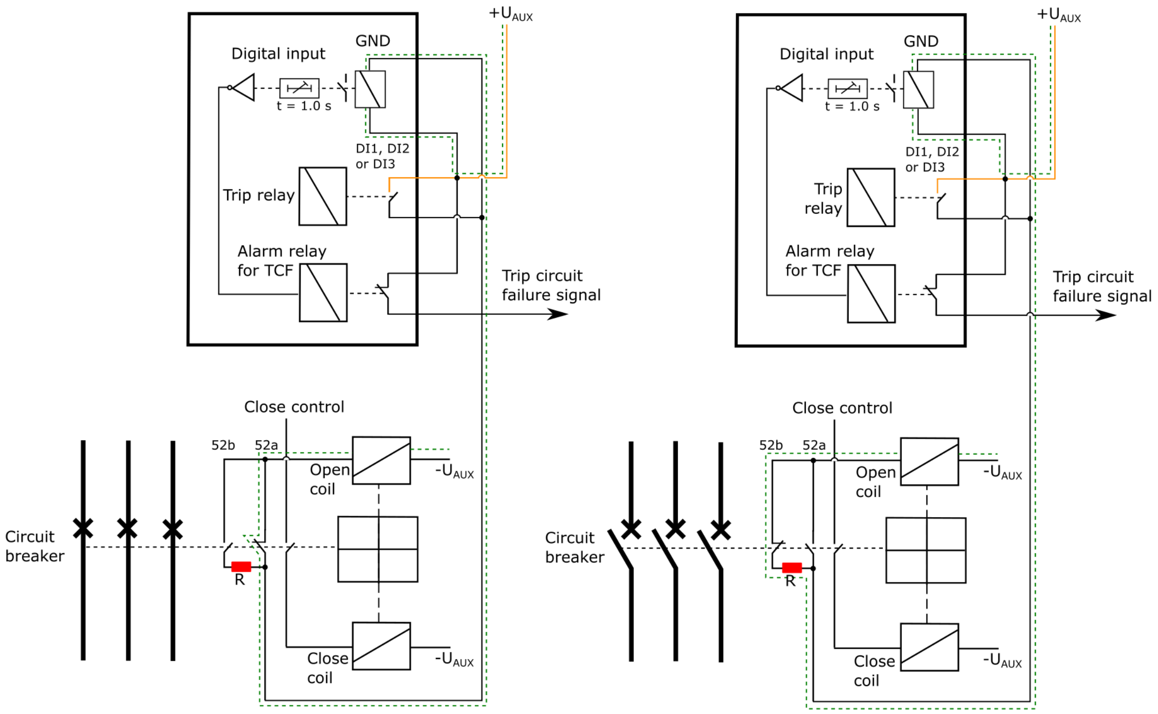
7.3. Trip circuit supervision (95)

Trip circuit supervision is used to monitor the wiring from auxiliary power supply, through the IED's digital output, and all the way to the open coil of the breaker. One should be aware that the trip circuit is in a healthy state when the breaker is closed.

Trip circuit supervision with one digital input and one non-latched trip output

The figure below presents an application scheme for trip circuit supervision with one digital input and a non-latched trip output. With this connection the current keeps flowing to the open coil of the breaker via the breaker's closing auxiliary contacts (52b) even after the circuit breaker is opened. This requires a resistor which reduces the current: this way the coil is not energized and the relay output does not need to cut off the coil's inductive current.

Figure. 7.3. - 176. Trip circuit supervision with one DI and one non-latched trip output.

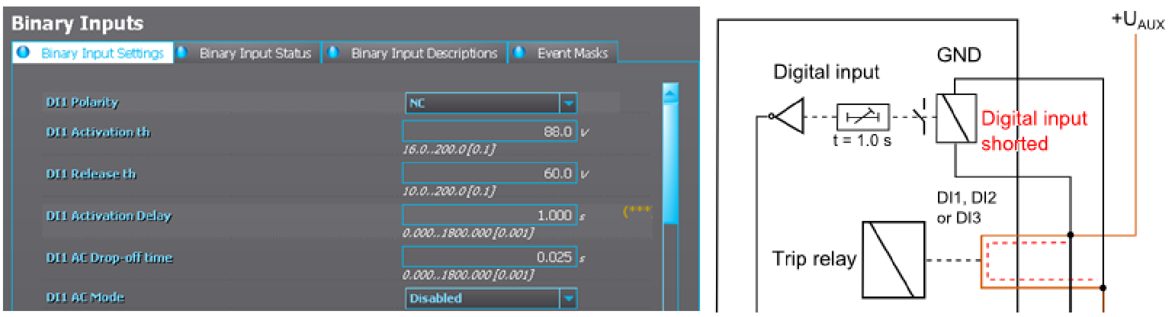


Note that the digital input that monitors the circuit is normally closed, and the same applies to the alarm relay if one is used. For monitoring and especially trip circuit supervision purposes it is recommended to use a normally closed contact to confirm the wiring's condition. An active digital input generates a <2 mA current to the circuit. Normally, a current this small is not able to make the breaker's open coil operate.

When the trip relay is controlled and the circuit breaker is opening, the digital input is shortened by the trip contact as long as the breaker opens. Normally, this takes about 100 ms if the relay is non-latched. A one second activation delay should, therefore, be added to the digital input. An activation delay that is slightly longer than the circuit breaker's operations time should be enough. When circuit breaker failure protection (CBFP) is used, adding its operation time to the digital input activation time is useful. The whole digital input activation time is, therefore, $t_{DI} = t_{CB} + t_{IEDrelease} + t_{CBFP}$.

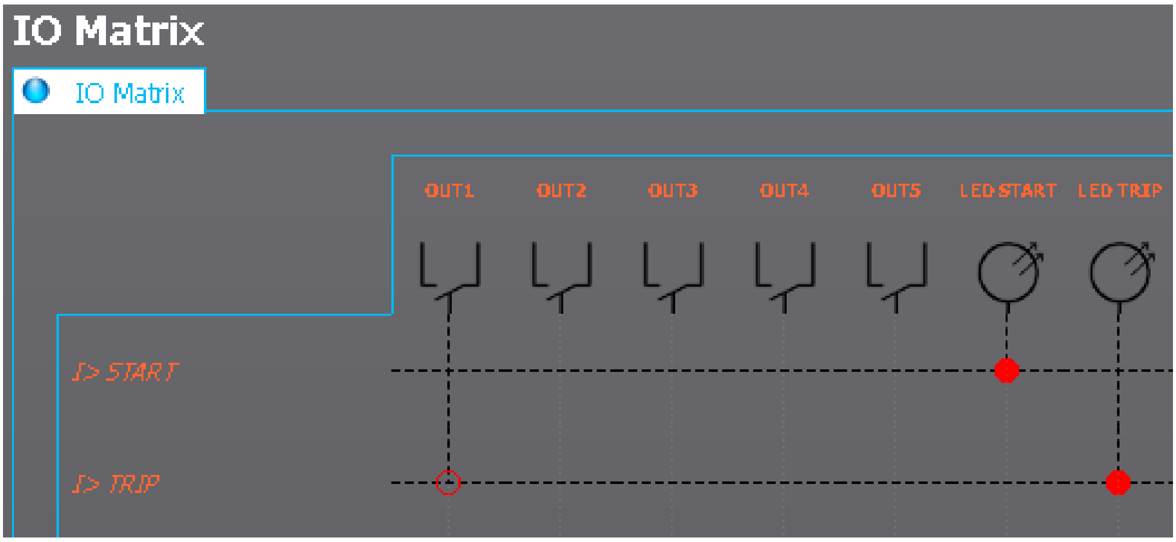
The image below presents the necessary settings when using a digital input for trip circuit supervision. The input's polarity must be NC (normally closed) and a one second delay is needed to avoid nuisance alarm while the circuit breaker is controlled open.

Figure. 7.3. - 177. Settings for a digital input used for trip circuit supervision.



Non-latched outputs are seen as hollow circles in the output matrix, whereas latched contacts are painted. See the image below of an output matrix where a non-latched trip contact is used to open the circuit breaker.

Figure. 7.3. - 178. Non-latched trip contact.



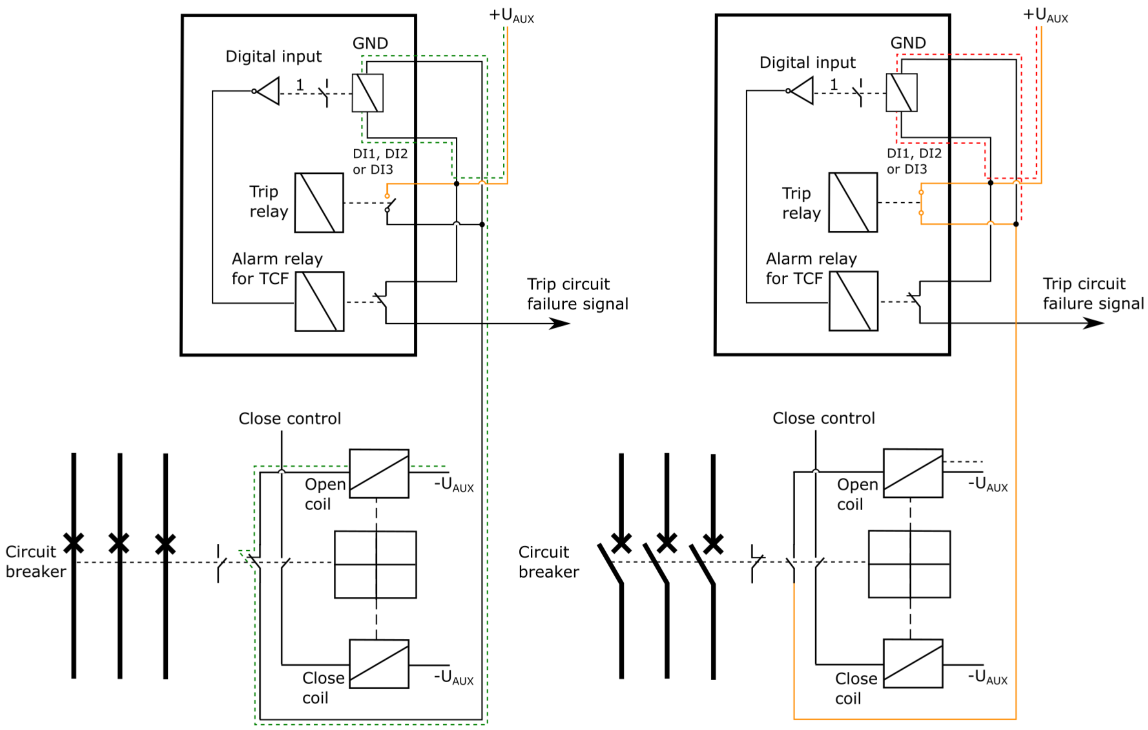
When the auto-reclosing function is used in feeder applications, the trip output contacts must be non-latched. Trip circuit supervision is generally easier and more reliable to build with non-latched outputs.

The open coil remains energized only as long as the circuit breaker is opened and the IED output releases. This takes approximately 100 ms depending on the size and type of the breaker. When the breaker opens, the auxiliary contacts open the inductive circuit; however, the trip contact does not open at the same time. The IED's output relay contact opens in under 50 ms or after a set release delay that takes place after the breaker is opened. This means that the open coil is energized for a while after the breaker has already opened. The coil could even be energized a moment longer if the circuit breaker failure protection has to be used and the incomer performs the trip.

Trip circuit supervision with one digital input and one connected, non-latched trip output

There is one main difference between non-latched and latched control in trip circuit supervision: when using the latched control, the trip circuit (in an open state) cannot be monitored as the digital input is shorted by the IED's trip output.

Figure. 7.3. - 179. Trip circuit supervision with one DI and one latched output contact.

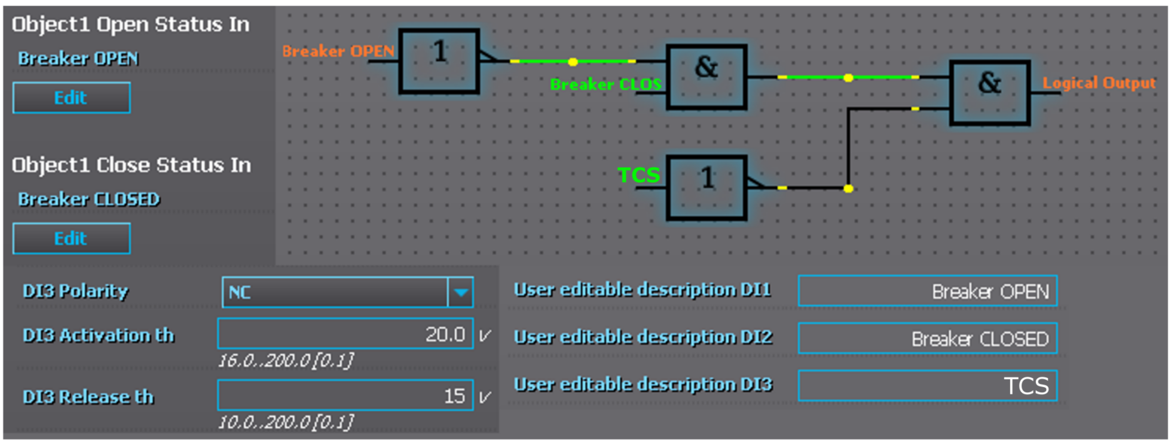


The trip circuit with a latched output contact can be monitored, but only when the circuit breaker's status is "Closed". Whenever the breaker is open, the supervision is blocked by an internal logic scheme. Its disadvantage is that the user does not know whether or not the trip circuit is intact when the breaker is closed again.

The following logic scheme (or similar) blockes the supervision alarm when the circuit breaker is open. The alarm is issued whenever the breaker is closed and whenever the inverted digital input signal ("TCS") activates. A normally closed digital input activates only when there is something wrong with the trip circuit and the auxiliary power goes off. Logical output can be used in the output matrix or in SCADA as the user wants.

The image below presents a block scheme when a non-latched trip output is not used.

Figure. 7.3. - 180. Example block scheme.



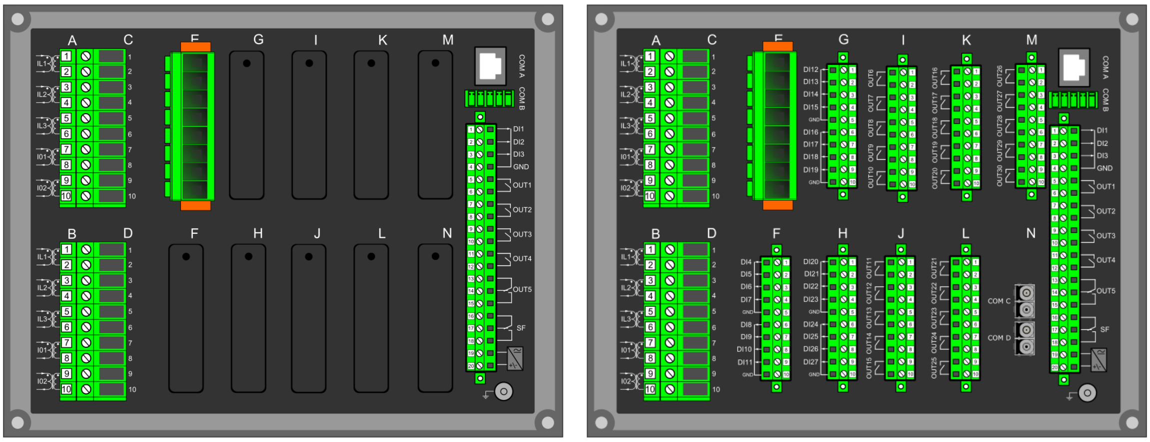
8. Construction and installation

8.1. Construction

AQ-X257 is a member of the modular and scalable AQ-200 series, and it includes nine (9) configurable and modular add-on card slots. As a standard configuration the device includes the CPU module (which consists of the CPU, a number of inputs and outputs, and the power supply) as well as two separate current measurement modules and one separate voltage measurement module.

The images below present the modules of both the non-optioned model (AQ-X257-XXXXXXX-**AAAAAAAAA**, on the left) and the fully optioned model (AQ-X257-XXXXXXX-**BBBCCCCCJ**, on the right).

Figure. 8.1. - 181. Modular construction of AQ-X257.



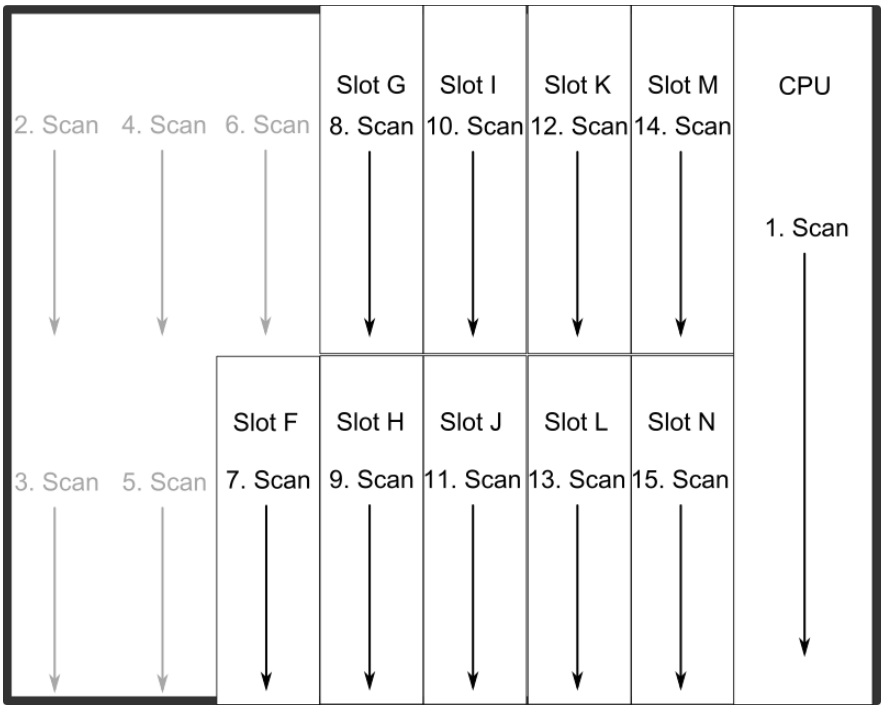
The modular structure of AQ-X257 allows for scalable solutions for different application requirements. In non-standard configurations Slots from F to N accept all available add-on modules, such as digital I/O modules, integrated arc protection or another special module.The only difference between the slots affecting device scalability is that Slots M and N both also support communication options.

When an add-on module is inserted into the device, the start-up scan searches for modules according to their type designation code. If the module location or content is not what the device expects, the IED does not take additional modules into account and instead issues a configuration error message. In field upgrades, therefore, the add-on module must be ordered from Arcteq Relays Ltd. or its representative who can then provide the module with its corresponding unlocking code to allow the device to operate correctly once the hardware configuration has been upgraded. This also means that the module's location in the device cannot be changed without updating the device configuration data which, again, requires the unlocking code.

When an I/O module is inserted into the device, the module location affects the naming of the I/O. The I/O scanning order in the start-up sequence is as follows: the CPU module I/O, Slot F, Slot G, Slot H and so on. This means that the digital input channels DI1, DI2 and DI3 as well as the digital output channels OUT1, OUT2, OUT3, OUT4 and OUT5 are always located in the CPU module. If additional I/O cards are installed, their location and card type affect the I/O naming.

The figure below presents the start-up hardware scan order of the device as well as the I/O naming principles.

Figure. 8.1. - 182. AQ-X257 hardware scanning and I/O naming principles.



1. Scan
   The start-up system; detects and self-tests the CPU module, voltages, communication and the I/O; finds and assigns "DI1", "DI2", "DI3", "OUT1", "OUT2", "OUT3", "OUT4" and "OUT5".
2. Scan
   Scans Slot A, which should always remain empty in AQ-X257 devices. If it is not empty, the device issues an alarm.
3. Scan
   Scans Slot B, which should always remain empty in AQ-X257 devices. If it is not empty, the device issues an alarm.
4. Scan
   Scans Slot C and finds the five channels of the CT module (fixed for AQ-X257). If the CTM is not found, the device issues an alarm.
5. Scan
   Scans Slot D and finds the five channels of the CT module (fixed for AQ-X257). If the CTM is not found, the device issues an alarm.
6. Scan
   Scans Slot E and finds the four channels of the VT module (fixed for AQ-257). If the VTM is not found, the device issues an alarm.
7. Scan
   Scans Slot F, and moves to the next slot if Slot F is empty. If the scan finds an 8DI module (that is, a module with eight digital inputs), it reserves the designations "DI4", "DI5", "DI6", "DI7", "DI8", "DI9", "DI10" and "DI11" to this slot. If the scan finds a DO5 module (that is, a module with five digital outputs), it reserves the designations "OUT6", "OUT7", "OUT8", "OUT9" and "OUT10" to this slot. The I/O is then added if the type designation code (e.g. AQ-P215-PH0AAAA-BBC) matches with the existing modules in the device. If the code and the modules do not match, the device issues and alarm. An alarm is also issued if the device expects to find a module here but does not find one.

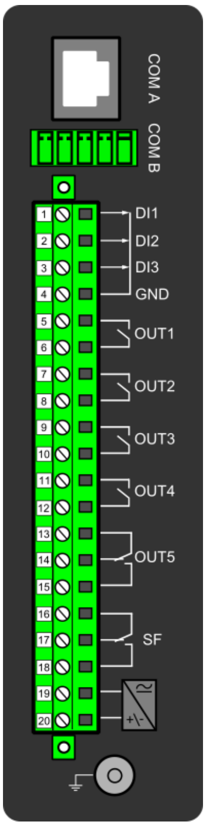
8. Scan
   Scans Slot G, and moves to the next slot if Slot G is empty. If the scan finds an 8DI module, it reserves the designations "DI4", "DI5", "DI6", "DI7", "DI8", "DI9", "DI10" and "DI11" to this slot. If Slot F also has an 8DI module (and therefore has already reserved these designations), the device reserves the designations "DI12", "DI13", "DI14", "DI15", "DI16", "DI17", "DI18" and "DI19" to this slot. If the scan finds a 5DO module, it reserves the designations "OUT6", "OUT7", "OUT8", "OUT9" and "OUT10" to this slot. Again, if Slot F also has a 5DO and has therefore already reserved these designations, the device reserves the designations "OUT11", "OUT12", "OUT13", "OUT14" and "OUT15" to this slot. If the scan finds the arc protection module, it reserves the sensor channels ("S1", "S2", "S3", "S4"), the high-speed outputs ("HSO1", "HSO2"), and the digital input channel ("ArcBI") to this slot.
9. –15. Scan
   A similar operation to Scan 8 (checks which designations have been reserved by modules in previous slots and numbers the new ones accordingly).

Thus far this document has only explained the installation of I/O add-on cards to the option module slots. This is because all other module types are treated in a same way. For example, when an additional communication port is installed into the upper port of the communication module, its designation is Communication port 3 or higher, as Communication ports 1 and 2 already exist in the CPU module (which is scanned, and thus designated, first). After a communication port is detected, it is added into the device's communication space and its corresponding settings are enabled.

With AQ-X257-XXXXXXX-**BBBCCCCCJ** (the first image pair, on the right) has a total of 27 digital input channels available: three (DI1…DI3) in the CPU module, and the rest in Slots F…H in groups of eight. It also has a total of 30 digital output channels available: five (DO1…DO5) in the CPU module, and the rest in Slots I…M in groups of five. Slot N has a double (LC) fiber Ethernet communication option card installed. These same principles apply to all non-standard configurations in the AQ-X257 IED family.

8.2. CPU module

Figure. 8.2. - 183. CPU module.



Connector	Description
COM A	Communication port A, or the RJ-45 port. Used for the AQtivate setting tool connection and for IEC 61850, Modbus/TCP, IEC 104, DNP3 and station bus communications.
COM B	Communication port B, or the RS-485 port. Used for the SCADA communications for the following protocols: Modbus/RTU, Modbus I/O, SPA, DNP3, IEC 101 and IEC 103. The pins have the following designations: Pin 1 = DATA +, Pin 2 = DATA –, Pin 3 = GND, Pins 4 & 5 = Terminator resistor enabled by shorting.
X1-1	Digital input 1, nominal threshold voltage 24 V, 110 V or 220 V.
X1-2	Digital input 2, nominal threshold voltage 24 V, 110 V or 220 V.
X1-3	Digital input 3, nominal threshold voltage 24 V, 110 V or 220 V.
X1-4	Common GND for digital inputs 1, 2 and 3.
X1-5:6	Output relay 1, with a normally open (NO) contact.
X1-7:8	Output relay 2, with a normally open (NO) contact.
X1-9:10	Output relay 3, with a normally open (NO) contact.
X1-11:12	Output relay 4, with a normally open (NO) contact.
X1-13:14:15	Output relay 5, with a changeover contact.
X1-16:17:18	System fault's output relay, with a changeover contact. Pins 16 and 17 are closed when the unit has a system fault or is powered OFF. Pins 16 and 18 are closed when the unit is powered ON and there is no system fault.
X1-19:20	Power supply IN. Either 85…265 VAC/DC (model A; order code "H") or 18…75 DC (model B; order code "L"). **Positive side** (+) **to Pin 20.**
GND	The relay's earthing connector.

By default, the CPU module (combining the CPU, the I/O and the power supply) includes two standard communication ports and the relay's basic digital I/O.

The current consumption of the digital inputs is 2 mA when activated, while the range of the operating voltage is 24 V/110 V/220 V depending on the ordered hardware. All digital inputs are scanned in 5 ms program cycles, and their pick-up and release delays as well as their NO/NC selection can be set with software. The digital output controls are also set by the user with software. By default, the digital outputs are controlled in 5 ms program cycles. All output contacts are mechanical. The rated voltage of the NO/NC outputs is 250 VAC/DC.

The auxiliary voltage is defined in the ordering code: the available power supply models available are A (85…265 VAC/DC) and B (18…75 DC). The power suppy's minimum allowed bridging time for all voltage levels is above 150 ms. The power supply's maximum power consumption is 15 W. The power supply allows a DC ripple of below 15 % and the start-up time of the power supply is below 5 ms. For further details, please refer to the "Auxiliary voltage" chapter in the "Technical data" section of this document.

Digital input settings

The settings described in the table below can be found at *Control → Device I/O → Digital input settings* in the relay settings.

Table. 8.2. - 247. Digital input settings.

Name	Range	Step	Default	Description
DIx Polarity	0: NO (Normally open) 1: NC (Normally closed)	-	0: NO	Selects whether the status of the digital input is 1 or 0 when the input is energized.
DIx Activation delay	0.000…1800.000 s	0.001 s	0.000 s	Defines the delay for the status change from 0 to 1.

DIx AC drop-off time	0.000…1800.000 s	0.001 s	0.000 s	Defines the delay for the status change from 1 to 0.
DIx AC mode	0: Disabled 1: Enabled	-	0: Disabled	Selects whether or not a 30-ms deactivation delay is added to account for alternating current.

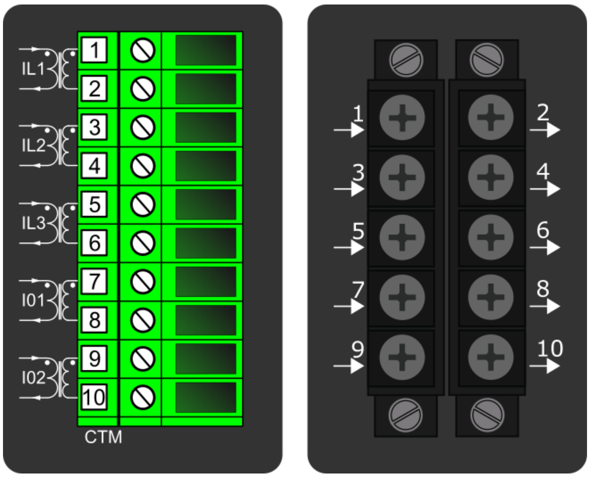
Scanning cycle

All digital inputs are scanned in a 5 ms cycle, meaning that the state of an input is updated every 0…5 milliseconds. When an input is used internally in the device (either in group change or logic), it takes additional 0…5 milliseconds to operate. Theoretically, therefore, it takes 0…10 milliseconds to change the group when a digital input is used for group control or a similar function. In practice, however, the delay is between 2…8 milliseconds about 95 % of the time. When a digital input is connected directly to a digital output (T1…Tx), it takes an additional 5 ms round. Therefore, when a digital input controls a digital output internally, it takes 0…15 milliseconds in theory and 2…13 milliseconds in practice.

Please note that the mechanical delay of the relay is **not** included in these approximations.

8.3. Current measurement module

Figure. 8.3. - 184. Module connections with standard and ring lug terminals.



Connector	Description
CTM 1-2	Phase current measurement for phase L1 (A).
CTM 3-4	Phase current measurement for phase L2 (B).
CTM 5-6	Phase current measurement for phase L3 (C).
CTM 7-8	Coarse residual current measurement I01.
CTM 9-10	Fine residual current measurement I02.

A basic current measurement module with five channels includes three-phase current measurement inputs as well as coarse and fine residual current inputs. The CT module is available with either standard or ring lug connectors.

The current measurement module is connected to the secondary side of conventional current transformers (CTs). The nominal dimensioning current for the phase current inputs is 5 A. The input nominal current can be scaled for secondary currents of 1…10 A. The secondary currents are calibrated to nominal currents of 1 A and 5 A, which provide ±0.5 % inaccuracy when the range is 0.005…4 × I_n.

The measurement ranges are as follows:

- Phase currents 25 mA…250 A (RMS)

- Coarse residual current 5 mA…150 A (RMS)
- Fine residual current 1 mA…75 A (RMS)

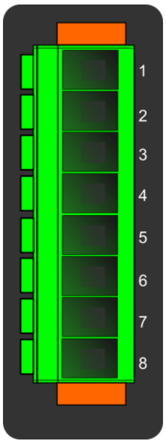
The characteristics of phase current inputs are as follows:

- The angle measurement accuracy is less than ± 0.2 degrees with nominal current.
- The frequency measurement range of the phase current inputs is 6…1800 Hz with standard hardware.
- The quantization of the measurement signal is applied with 18-bit AD converters, and the sample rate of the signal is 64 samples/cycle when the system frequency ranges from 6 Hz to 75 Hz.

For further details please refer to the "Current measurement" chapter in the “Technical data” section of this document.

8.4. Voltage measurement module

Figure. 8.4. - 185. Voltage measurement module.



Connector	Description
VTM 1-2	Configurable voltage measurement input U1.
VTM 3-4	Configurable voltage measurement input U2.
VTM 5-6	Configurable voltage measurement input U3.
VTM 7-8	Configurable voltage measurement input U4.

A basic voltage measurement module with four channels includes four voltage measurement inputs that can be configured freely.

The voltage measurement module is connected to the secondary side of conventional voltage transformers (VTs) or directly to low-voltage systems secured by fuses. The nominal dimensioning voltage can be 100…400 V. Voltages are calibrated in a range of 0…240 V, which provides ± 0.2 % inaccuracy in the same range.

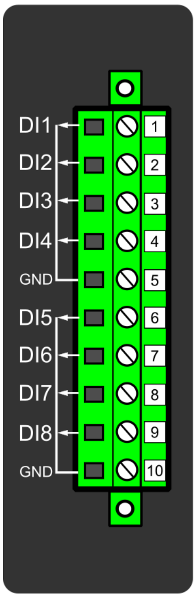
The voltage input characteristics are as follows:

- The measurement range is 0.5…480.0 V per channel.
- The angle measurement accuracy is less than ± 0.5 degrees within the nominal range.
- The frequency measurement range of the voltage inputs is 6…1800 Hz with standard hardware.
- The quantization of the measurement signal is applied with 18-bit AD converters, and the sample rate of the signal is 64 samples/cycle when the system frequency ranges from 6 Hz to 75 Hz.

For further details please refer to the "Voltage measurement" chapter in the “Technical data” section of this document.

8.5. Digital input module (optional)

Figure. 8.5. - 186. Digital input module (DI8) with eight add-on digital inputs.



Connector	Description (x = the number of digital inputs in other modules that preceed this one in the configuration)
X 1	DIx + 1
X 2	DIx + 2
X 3	DIx + 3
X 4	DIx + 4
X 5	Common earthing for the first four digital inputs.
X 6	DIx + 5
X 7	DIx + 6
X 8	DIx + 7
X 9	DIx + 8
X 10	Common earthing for the other four digital inputs.

The DI8 module is an add-on module with eight (8) galvanically isolated digital inputs. This module can be ordered directly to be installed into the device in the factory, or it can be upgraded in the field after the device's original installation when required. The properties of the inputs in this module are the same as those of the inputs in the main processor module. The current consumption of the digital inputs is 2 mA when activated, while the range of the operating voltage is from 0…265 VAC/DC. The activation and release thresholds are set in the software and the resolution is 1 V. All digital inputs are scannced in 5 ms program cycles, and their pick-up and release delays as well as their NO/NC selection can be set with software.

For the naming convention of the digital inputs provided by this module please refer to the chapter titled "Construction and installation".

For technical details please refer to the chapter titled "Digital input module" in the "Technical data" section of this document.

Setting up the activation and release delays

The settings described in the table below can be found at *Control → Device I/O → Digital input settings* in the relay settings.

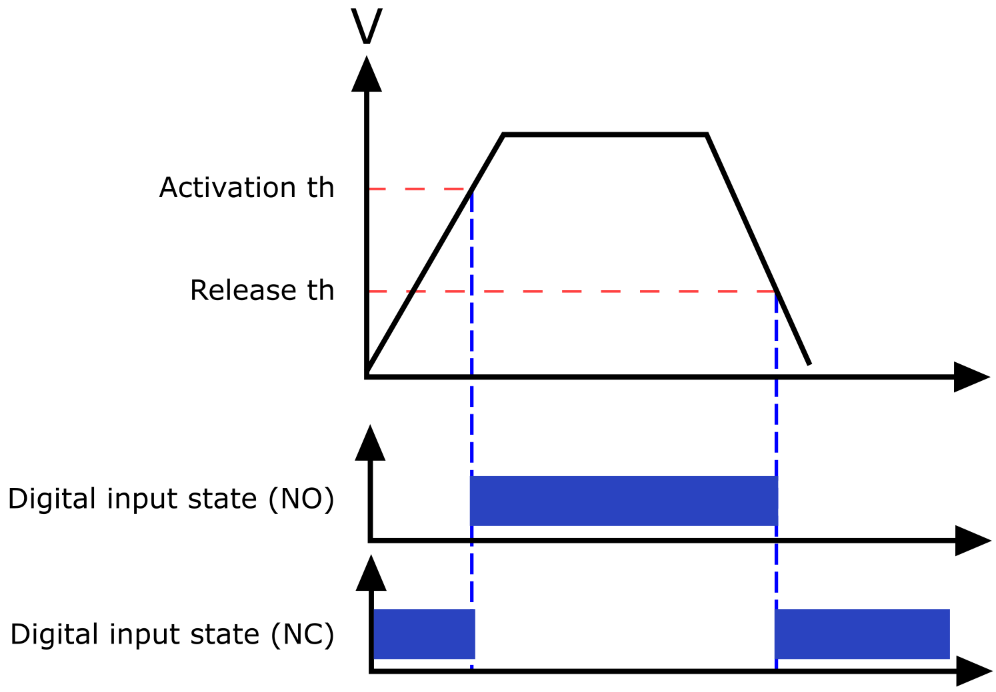
Table. 8.5. - 248. Digital input settings of DI8 module.

Name	Range	Step	Default	Description
DIx Polarity	0: NO (Normally open) 1: NC (Normally closed)	-	0: NO	Selects whether the status of the digital input is 1 or 0 when the input is energized.
DIx Activation threshold	16.0…200.0 V	0.1 V	88 V	Defines the activation threshold for the digital input. When "NO" is the selected polarity, the measured voltage exceeding this setting activates the input. When "NC" is the selected polarity, the measured voltage exceeding this setting deactivates the input.
DIx Release threshold	10.0…200.0 V	0.1 V	60V	Defines the release threshold for the digital input. When "NO" is the selected polarity, the measured voltage below this setting deactivates the input. When "NC" is the selected polarity, the measured voltage below this setting activates the input.
DIx Activation delay	0.000…1800.000 s	0.001 s	0.000 s	Defines the delay when the status changes from 0 to 1.
DIx AC drop-off time	0.000…1800.000 s	0.001 s	0.000 s	Defines the delay when the status changes from 1 to 0.
DIx AC Mode	0: Disabled 1: Enabled	-	0: Disabled	Selects whether or not a 30-ms deactivation delay is added to take the alternating current into account. The "DIx Release threshold" parameter is hidden and forced to 10 % of the set "DIx Activation threshold" parameter.
DIx Counter	0…2^{32}–1	1	0	Displays the number of times the digital input has changed its status from 0 to 1.
DIx Counter clear	0: - 1: Clear	-	0: -	Selects to clear the DIx counter.

The user can set the activation threshold individually for each digital input. When the activation and release thresholds have been set properly, they will result in the digital input states to be activated and released reliably. The selection of the normal state between normally open (NO) and normally closed (NC) defines whether or not the digital input is considered activated when the digital input channel is energized.

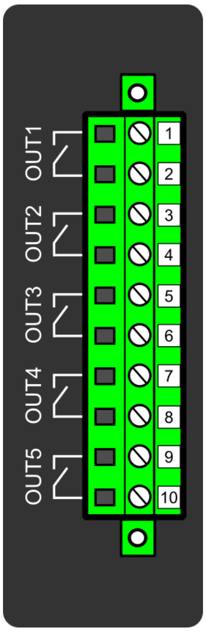
The diagram below depicts the digital input states when the input channels are energized and de-energized.

Figure. 8.5. - 187. Digital input state when energizing and de-energizing the digital input channels.



8.6. Digital output module (optional)

Figure. 8.6. - 188. Digital output module (DO5) with five add-on digital outputs.



Connector	Description
X 1–2	OUTx + 1 (1st and 2nd pole NO)
X 3–4	OUTx + 2 (1st and 2nd pole NO)
X 5–6	OUTx + 3 (1st and 2nd pole NO)
X 7–8	OUTx + 4 (1st and 2nd pole NO)

X 9–10	OUTx + 5 (1st and 2nd pole NO)

The DO5 module is an add-on module with five (5) digital outputs. This module can be ordered directly to be installed into the device in the factory, or it can be upgraded in the field after the device's original installation when required. The properties of the outputs in this module are the same as those of the outputs in the main processor module. The user can set the digital output controls with software. All digital outputs are scanned in 5 ms program cycles, and their contacts are mechanical in type. The rated voltage of the NO/NC outputs is 250 VAC/DC.

For the naming convention of the digital inputs provided by this module please refer to the chapter titled "Construction and installation".

For technical details please refer to the chapter titled "Digital output module" in the "Technical data" section of this document.

8.7. Arc protection module (optional)

Figure. 8.7. - 189. Arc protection module.

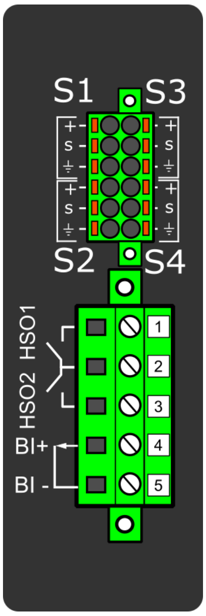


Table. 8.7. - 249. Module connections.

Connector	Description
S1	Light sensor channels 1…4 with positive ("+"), sensor ("S") and earth connectors.
S2	
S3	
S4	
X 1	HSO1 (+, NO)
X 2	Common battery positive terminal (+) for the HSOs.
X 3	HSO2 (+, NO)
X 4	Binary input 1 (+ pole)
X 5	Binary input 1 (– pole)

The arc protection module is an add-on module with four (4) light sensor channels, two (2) high-speed outputs and one (1) binary input. This module can be ordered directly to be installed into the device in the factory, or it can be upgraded in the field after the device's original installation when required. If even one of the sensor channels is connected incorrectly, the channel does not work. Each channel can have up to three (3) light sensors serially connected to it. The user can choose how many of the channels are in use.

The high-speed outputs (HSO1 and HSO2) operate only with a DC power supply. The battery's positive terminal (+) must be wired according to the drawing. The NO side of the outputs 1 or 2 must be wired through trip coil to the battery's negative terminal (–). The high-speed outputs can withstand voltages up to 250 VDC. The operation time of the high-speed outputs is less than 1 ms. For further information please refer to the chapter titled "Arc protection module" in the "Technical data" section of this manual.

The rated voltage of the binary input is 24 VDC. The threshold picks up at ≥16 VDC. The binary input can be used for external light information or for similar applications. It can also be used as a part of various ARC schemes. Please note that the binary input's delay is 5…10ms.

NOTE!

BI1, HSO1 and HSO2 are not visible in the *Binary inputs* and *Binary outputs* menus (*Control* → *Device I/O*), they can only be programmed in the arc matrix menu (*Protection* → *Arc protection* → *I/O* → *Direct output control* and *HSO control*).

8.8. RTD & mA input module (optional)

Figure. 8.8. - 190. RTD & mA module connectors.

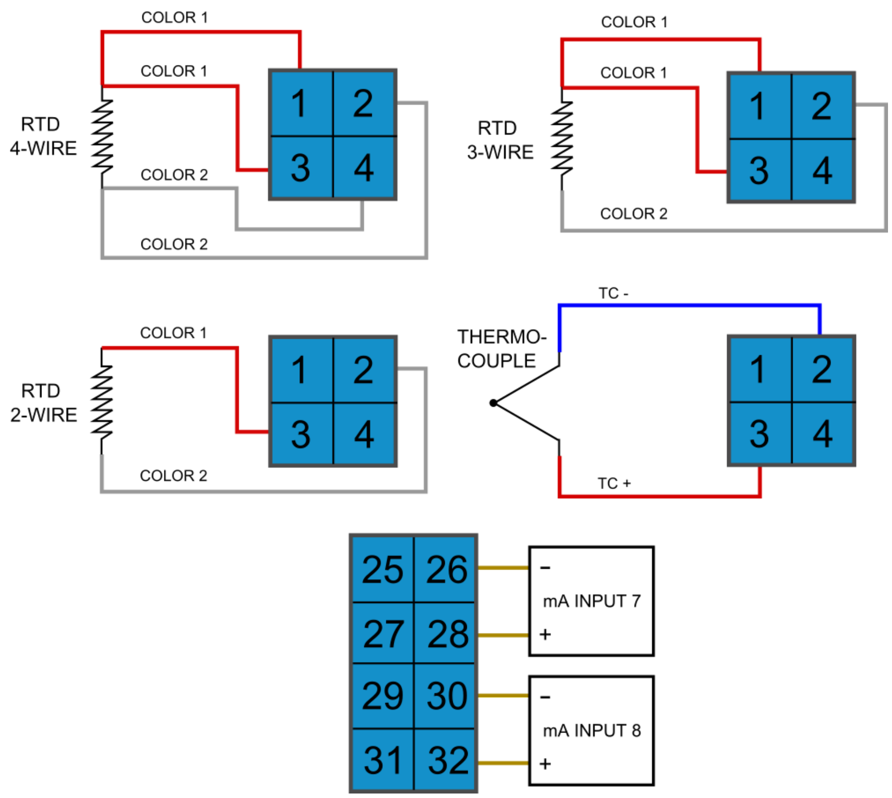
Channel	Connector			Connector
1	RTD1-1	1	2	RTD1-2/TC1-
	RTD1-3/TC1+	3	4	RTD1-4
2	RTD2-1	5	6	RTD2-2/TC2-
	RTD2-3/TC2+	7	8	RTD2-4
3	RTD3-1	9	10	RTD3-2/TC3-
	RTD3-3/TC3+	11	12	RTD3-4
4	RTD4-1	13	14	RTD4-2/TC4-
	RTD4-3/TC4+	15	16	RTD4-4
5	RTD5-1	17	18	RTD5-2/TC5-
	RTD5-3/TC5+	19	20	RTD5-4
6	RTD6-1	21	22	RTD6-2/TC6-
	RTD6-3/TC6+	23	24	RTD6-4
7	RTD7-1	25	26	RTD7-2/TC7-/mAin7-
	RTD7-3/TC7+	27	28	RTD7-4 / mAin7+
8	RTD8-1	29	30	RTD8-2/TC8/mAin8-
	RTD8-3/TC8+	31	32	RTD8-4/mAin8+

The RTD & mA module is an add-on module with eight (8) RTD input channels. Each input supports 2-wire, 3-wire and 4-wire RTD sensors as well as thermocouple (TC) sensors. The sensor type can be selected with software for two groups, four channels each. The supported sensor types are as follows:

- Supported RTD sensors: Pt100, Pt1000
- Supported thermocouple sensors: type K (NiCh/NiAl), type J (Fe/constantan), type T (Cu/constantan) and type S (Cu/CuNi compensating).

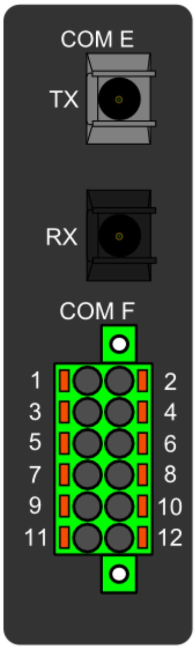
There are also two mA input channels available in the module. Please note that if the mA input channels are in use, only the first four channels are available for RTD and TC measurements.

Figure. 8.8. - 191. Different sensor types and their connections.



8.9. Serial RS-232 communication module (optional)

Figure. 8.9. - 192. Serial RS-232 module connectors.



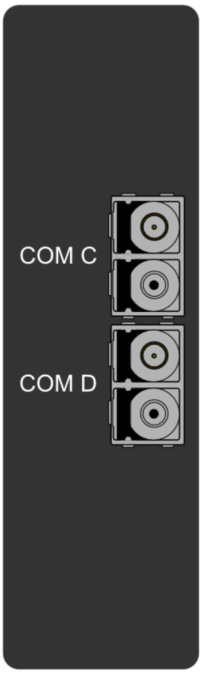
Connector	Name	Description
COM E	Serial fiber (GG/PP/GP/PG)	• Serial-based communications • Wavelength 660 nm • Compatible with 50/125 µm, 62.5/125 µm, 100/140 µm, and 200 µm Plastic-Clad Silica (PCS) fiber • Compatible with ST connectors
COM F – Pin 1	+24 V input	Optional external auxiliary voltage for serial fiber
COM F – Pin 2	GND	Optional external auxiliary voltage for serial fiber
COM F – Pin 3	-	-
COM F – Pin 4	-	-
COM F – Pin 5	RS-232 RTS	Serial based communications
COM F – Pin 6	RS-232 GND	Serial based communications
COM F – Pin 7	RS-232 TX	Serial based communications
COM F – Pin 8	RS-232 RX	Serial based communications
COM F – Pin 9	-	-
COM F – Pin 10	+3.3 V output (spare)	Spare power source for external equipment (45 mA)
COM F – Pin 11	-	-

COM F – Pin 12	-	-

The option card includes two serial communication interfaces: COM E is a serial fiber interface with glass/plastic option, COM F is an RS-232 interface.

8.10. LC 100 Mbps Ethernet communication module (optional)

Figure. 8.10. - 193. LC 100 Mbps Ethernet module connectors.

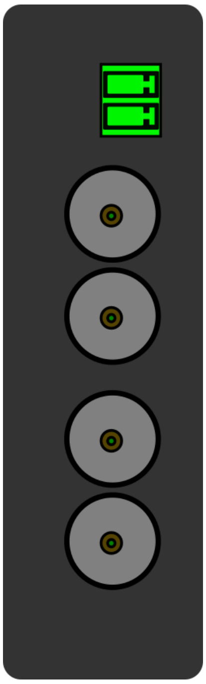


Connector	Description
COM C:	• Communication port C, LC fiber connector. • 62.5/125 µm or 50/125 µm multimode (glass). • Wavelength 1300 nm.
COM D:	• Communication port D, LC fiber connector. • 62.5/125 µm or 50/125 µm multimode (glass). • Wavelength 1300 nm.

The optional LC 100 Mbps Ethernet card supports both HSR and PRP protocols. The card has two PRP/HSR ports, which are 100 Mbps fiber ports.

8.11. Double ST 100 Mbps Ethernet communication module (optional)

Figure. 8.11. - 194. Double ST 100 Mbps Ethernet communication module connectors. Two pin connector is IRIG-B input.



Connector	Description
ST connectors:	• Duplex ST connectors • 62.5/125µm or 50/125µm multimode fiber • Transmitter wavelength 1260-1360 nm (nominal 1310 nm) • Receiver wavelength 1100-1600 nm • 100BASE-FX • Up to 2 km

This option cards supports redundant ring configuration and multidrop configurations. Redundant communication can be implemented by RSTP (Rapid Spanning Tree Protocol) supporting Ethernet switches. Each ring can only contain AQ-200 series devices. Any third party devices must be connected to separate ring.

For other redundancy options, see the 100LC option card.

Figure. 8.11. - 195. Ring connection example. Please note that third party devices should be connected in a separate ring.

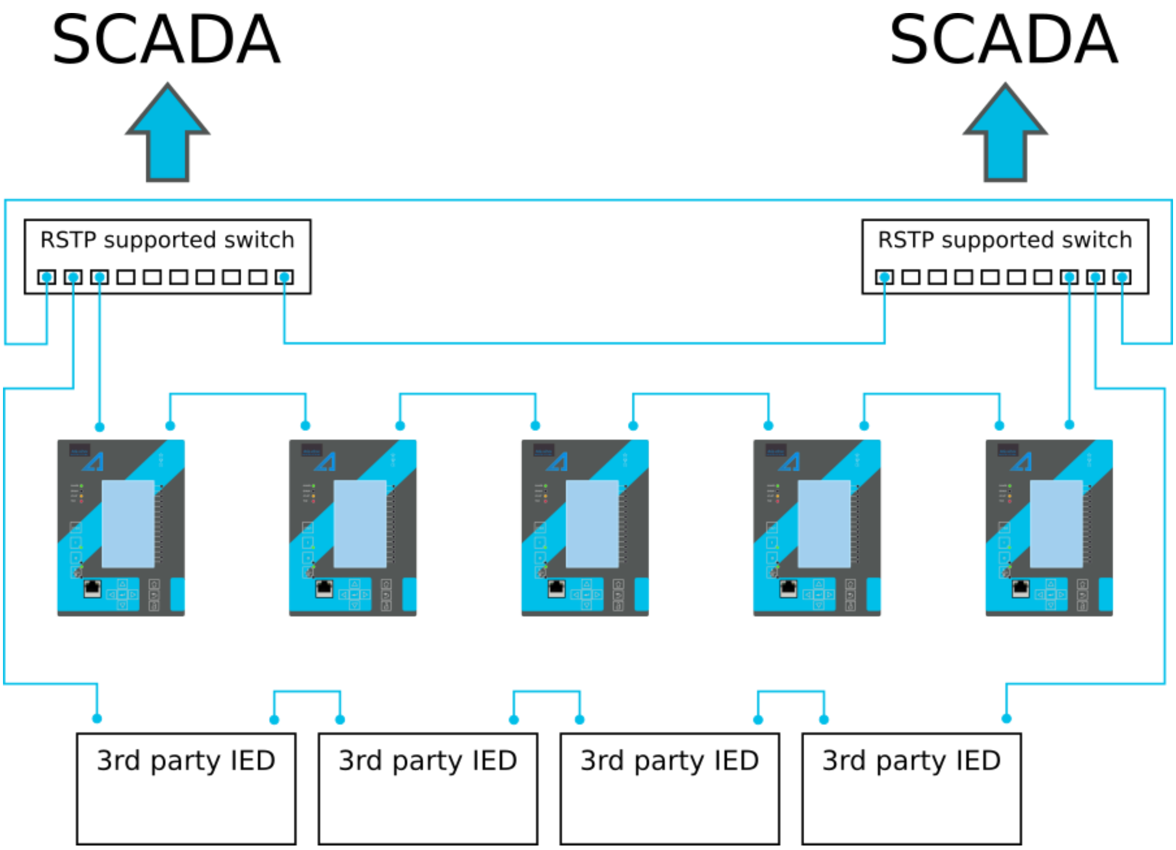
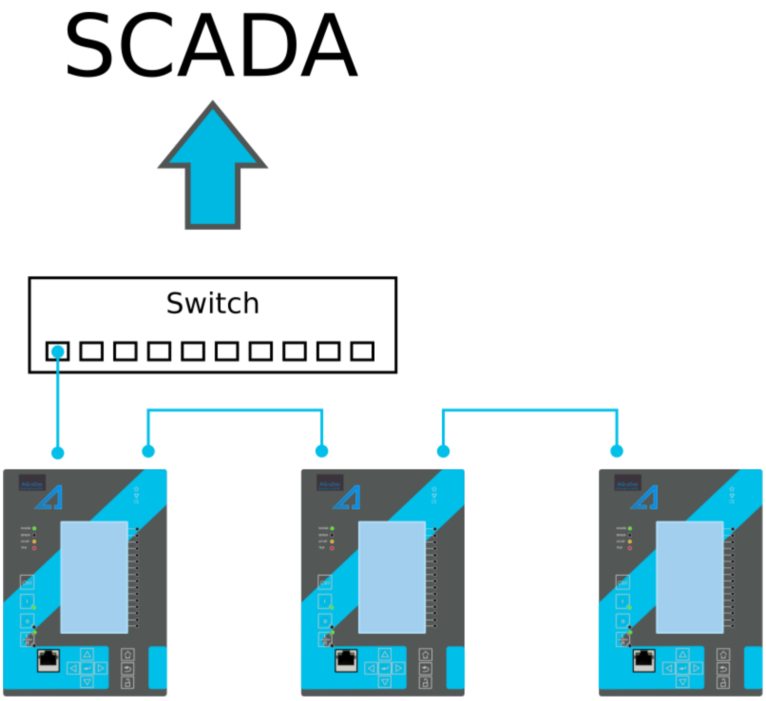
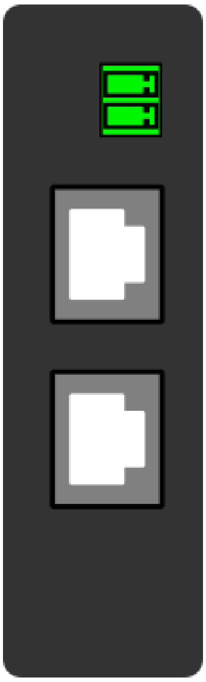


Figure. 8.11. - 196. Multidrop connection example.



8.12. Double RJ45 10/100 Mbps Ethernet communication module (optional)

Figure. 8.12. - 197. Double RJ45 10/100 Mbps Ethernet communication module (optional). Two pin connector is IRIG-B input.



Connector	Description
RJ45 connectors:	• Two Ethernet ports • RJ45 connectors • 10BASE-T and 100BASE-TX

This option cards supports redundant ring configuration and multidrop configurations. Redundant communication can be implemented by RSTP (Rapid Spanning Tree Protocol) supporting Ethernet switches. Each ring can only contain AQ-200 series devices. Any third party devices must be connected to separate ring.

For other redundancy options, see the 100LC option card.

Figure. 8.12. - 198. Ring connection example. Please note that third party devices should be connected in a separate ring.

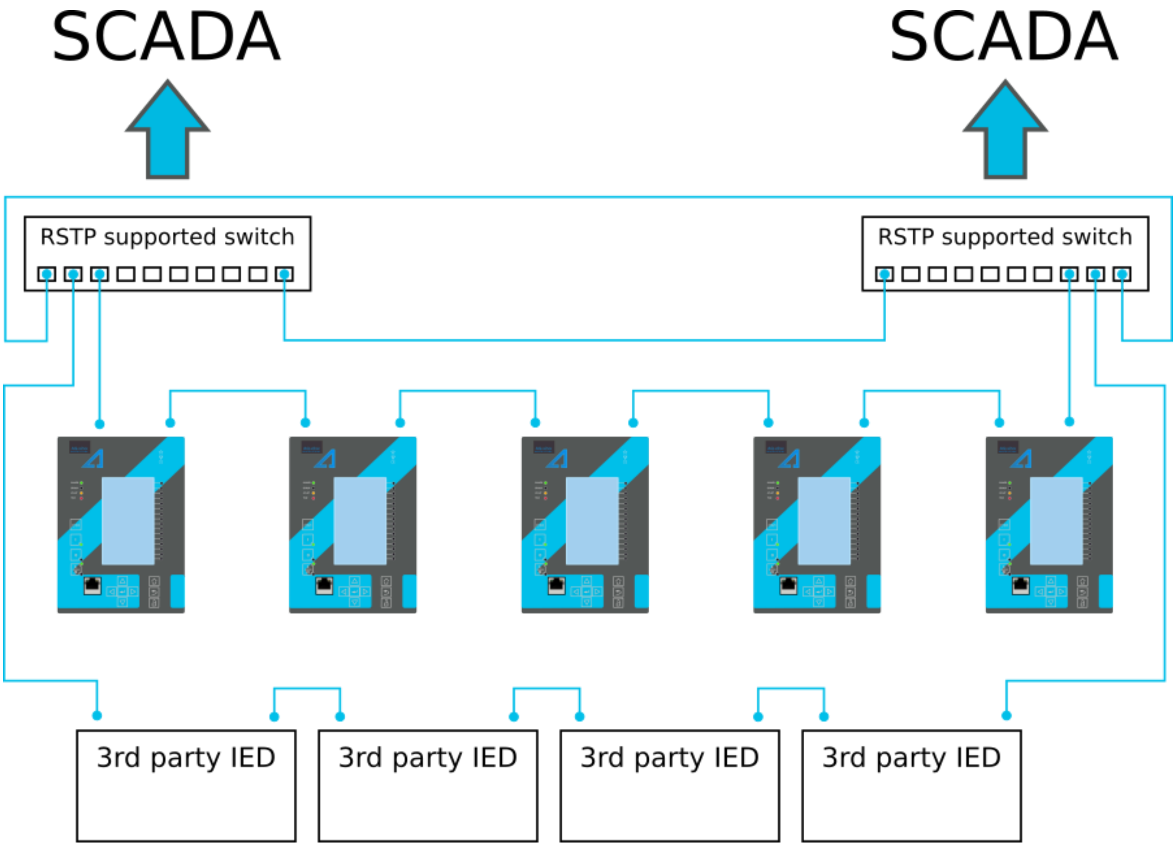
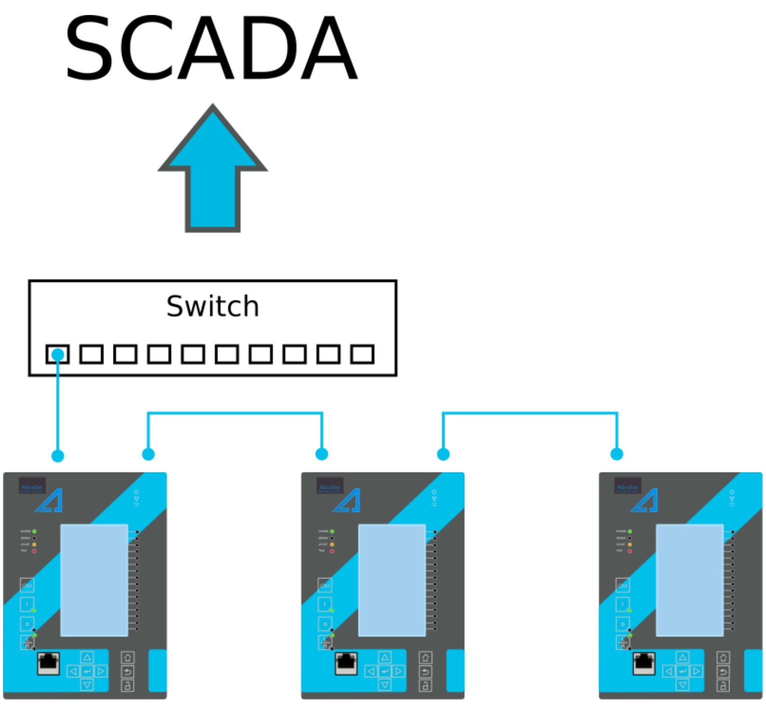
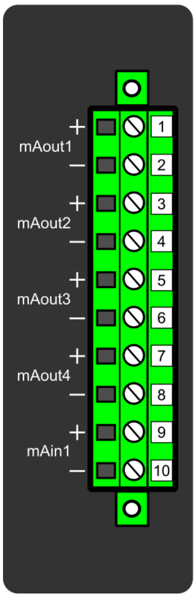


Figure. 8.12. - 199. Multidrop connection example.



8.13. Milliampere (mA) I/O module (optional)

Figure. 8.13. - 200. Milliampere (mA) I/O module connections.



Connector	Description
Pin 1	mA OUT 1 + connector (0…24 mA)
Pin 2	mA OUT 1 – connector (0…24 mA)
Pin 3	mA OUT 2 + connector (0…24 mA)
Pin 4	mA OUT 2 – connector (0…24 mA)
Pin 5	mA OUT 3 + connector (0…24 mA)
Pin 6	mA OUT 3 – connector (0…24 mA)
Pin 7	mA OUT 4 + connector (0…24 mA)
Pin 8	mA OUT 4 – connector (0…24 mA)
Pin 9	mA IN 1 + connector (0…33 mA)
Pin 10	mA IN 1 – connector (0…33 mA)

The milliampere (mA) I/O module is an add-on module with four (4) mA outputs and one (1) mA input. Both the outputs and the input are in two galvanically isolated groups, with one pin for the positive (+) connector and one pin for the negative (–) connector.

This module can be ordered directly to be installed into the device in the factory, or it can be upgraded in the field after the device's original installation when required.

The user sets the mA I/O with the mA outputs control function. This can be done at *Control → Device I/O → mA outputs* in the relay configuration settings.

8.14. Dimensions and installation

The device can be installed either to a standard 19” rack or to a switchgear panel with cutouts. The desired installation type is defined in the order code. When installing to a rack, the device takes a half (½) of the rack's width, meaning that a total of two devices can be installed to the same rack next to one another.

The figures below describe the device dimensions (first figure), the device installation (second), and the panel cutout dimensions and device spacing (third).

Figure. 8.14. - 201. Device dimensions.

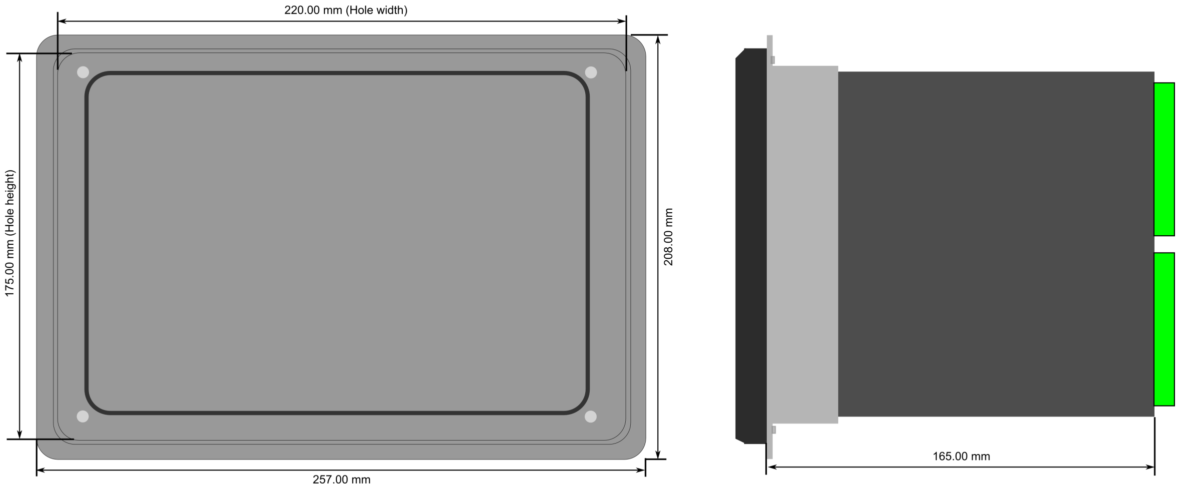


Figure. 8.14. - 202. Device installation.

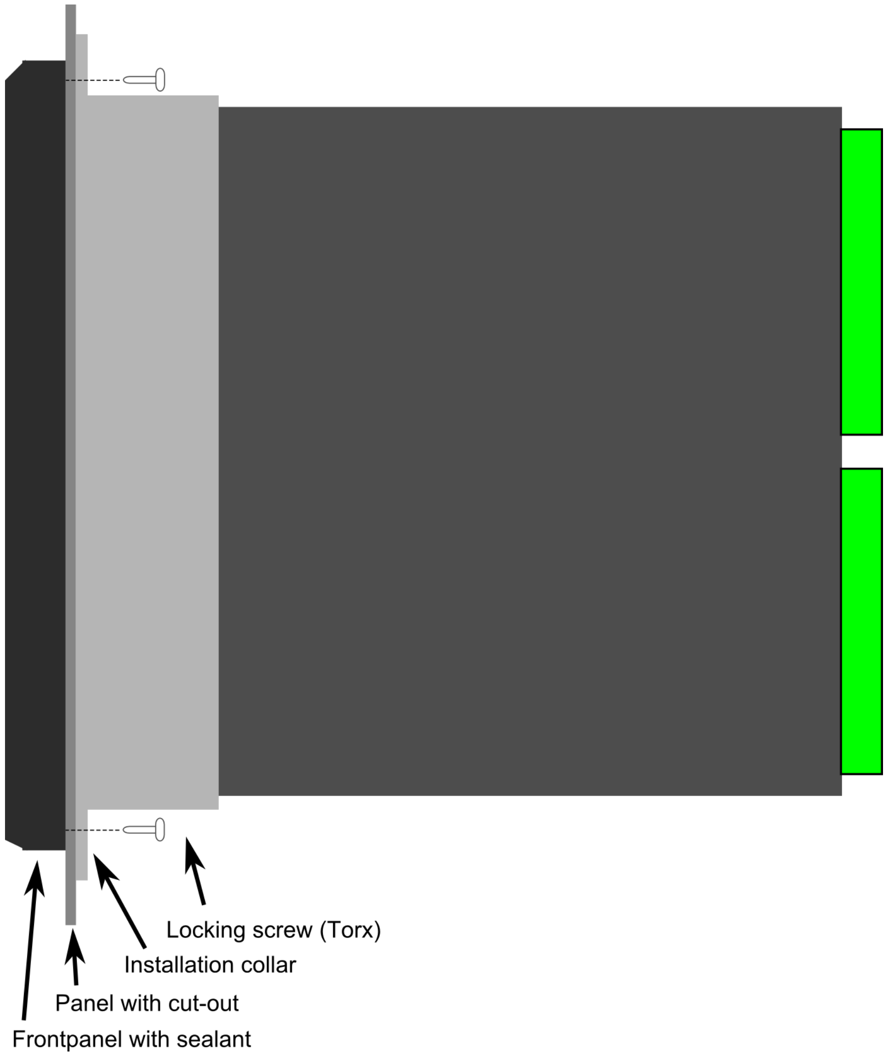
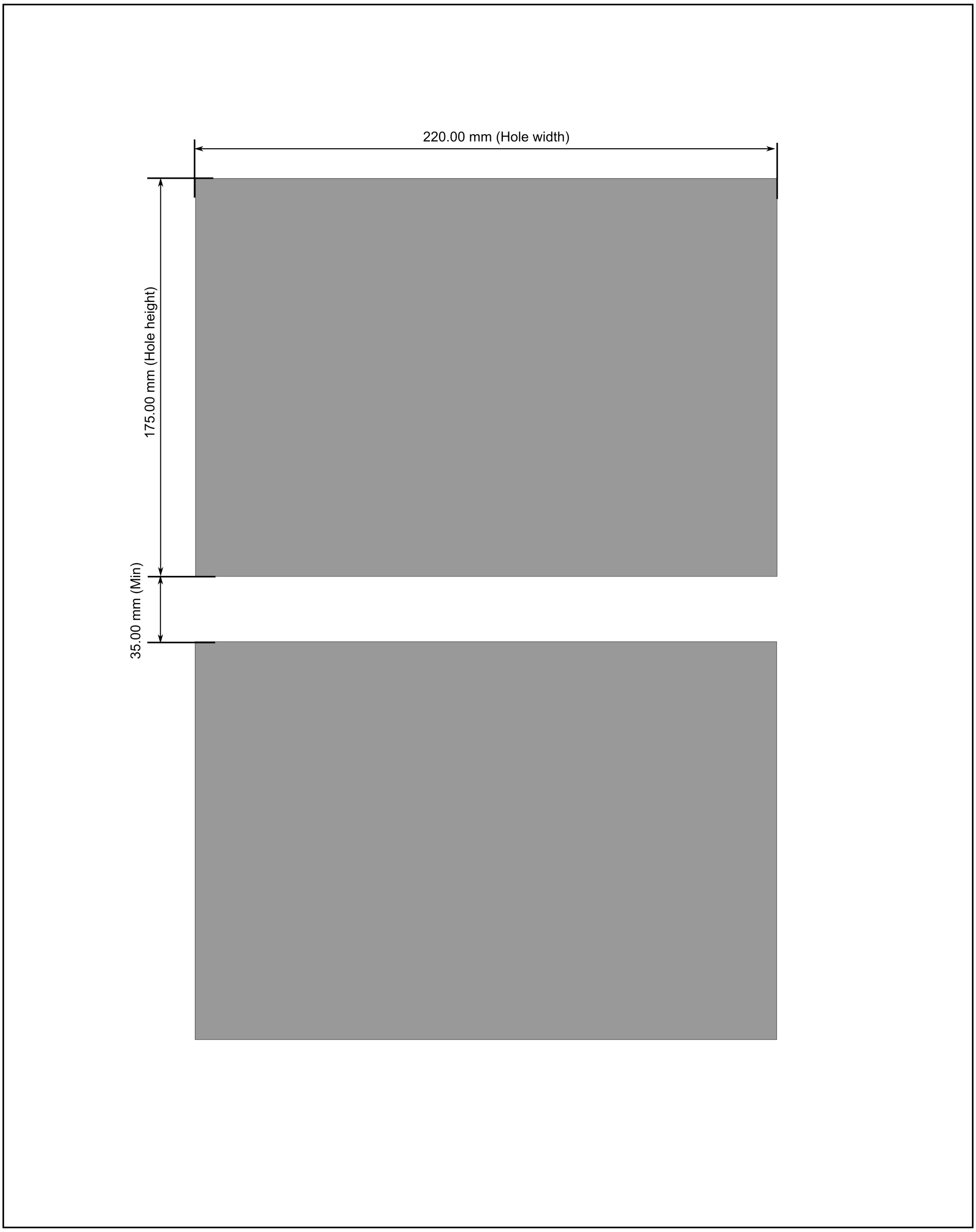


Figure. 8.14. - 203. Panel cut-out and spacing of the IED.



9. Technical data

9.1. Hardware

9.1.1. Measurements

9.1.1.1. Current measurement

Table. 9.1.1.1. - 250. Technical data for the current measurement module.

Phase current inputs (A, B, C)	
Rated current I_N	5 A (configurable 0.2…10 A)
Thermal withstand	30 A (continuous) 100 A (for 10 s) 500 A (for 1 s) 1250 A (for 0.01 s)
Frequency measurement range	From 6…75Hz fundamental, up to the 31^{st} harmonic current
Current measurement range	25 mA…250 A (RMS)
Current measurement inaccuracy	0.005…4.000 × I_N < ±0.5 % or < ±15 mA 4…20 × I_N < ±0.5 % 20…50 × I_N < ±1.0 %
Angle measurement inaccuracy	< ±0.2° (I> 0.1 A) < ±1.0° (I≤ 0.1 A)
Burden (50/60 Hz)	<0.1 VA
Transient overreach	<8 %
Coarse residual current input (I01)	
Rated current I_N	1 A (configurable 0.2…10 A)
Thermal withstand	25 A (continuous) 100 A (for 10 s) 500 A (for 1 s) 1250 A (for 0.01 s)
Frequency measurement range	From 6…75 Hz fundamental, up to the 31^{st} harmonic current
Current measurement range	5 mA…150 A (RMS)
Current measurement inaccuracy	0.002…10.000 × I_N < ±0.5 % or < ±3 mA 10…150 × I_N < ±0.5 %
Angle measurement inaccuracy	< ±0.2° (I> 0.05 A) < ±1.0° (I≤ 0.05 A)
Burden (50/60Hz)	<0.1 VA
Transient overreach	<5 %
Fine residual current input (I02)	
Rated current I_N	0.2 A (configurable 0.2…10 A)

Thermal withstand	25 A (continuous) 100 A (for 10 s) 500 A (for 1 s) 1250 A (for 0.01 s)
Frequency measurement range	From 6…75 Hz fundamental, up to the 31st harmonic current
Current measurement range	1 mA…75 A (RMS)
Current measurement inaccuracy	0.002…25.000 × I_N < ±0.5 % or < ±0.6 mA 25…375 × I_N < ±1.0 %
Angle measurement inaccuracy	< ±0.2° (I> 0.01 A) < ±1.0° (I≤ 0.01 A)
Burden (50/60Hz)	<0.1 VA
Transient overreach	<5 %
Terminal block connection	
Terminal block	Phoenix Contact FRONT 4-H-6,35
Solid or stranded wire Maximum wire diameter	4 mm^2

NOTE!

Current measurement accuracy has been verified with 50/60 Hz.

The amplitude difference is 0.2 % and the angle difference is 0.5 degrees higher at 16.67 Hz and other frequencies.

9.1.1.2. Voltage measurement

Table. 9.1.1.2. - 251. Technical data for the voltage measurement module.

Connection	
Measurement channels/VT inputs	4 independent VT inputs (Ua, Ub, Uc and Ud)
Measurement	
Voltage measuring range	0.50…480.00 V (RMS)
Voltage measurement inaccuracy	1…2 V ±1.5 % 2…10 V ±0.5 % 10…480 V ±0.35 %
Angle measurement inaccuracy	±0.2 degrees (15…300 V) ±1.5 degrees (1…15 V)
Voltage measurement bandwidth (freq.)	7…75 Hz fundamental, up to the 31st harmonic voltage
Terminal block connection	
Terminal block	Phoenix Contact PC 5/8-STCL1-7.62
Solid or stranded wire Maximum wire diameter	6 mm^2
Input impedance	24.5…24.6 Ω
Burder (50/60 Hz)	<0.02 VA

Thermal withstand	630 V_{RMS} (continuous)

NOTE!

Voltage measurement accuracy has been verified with 50/60 Hz.

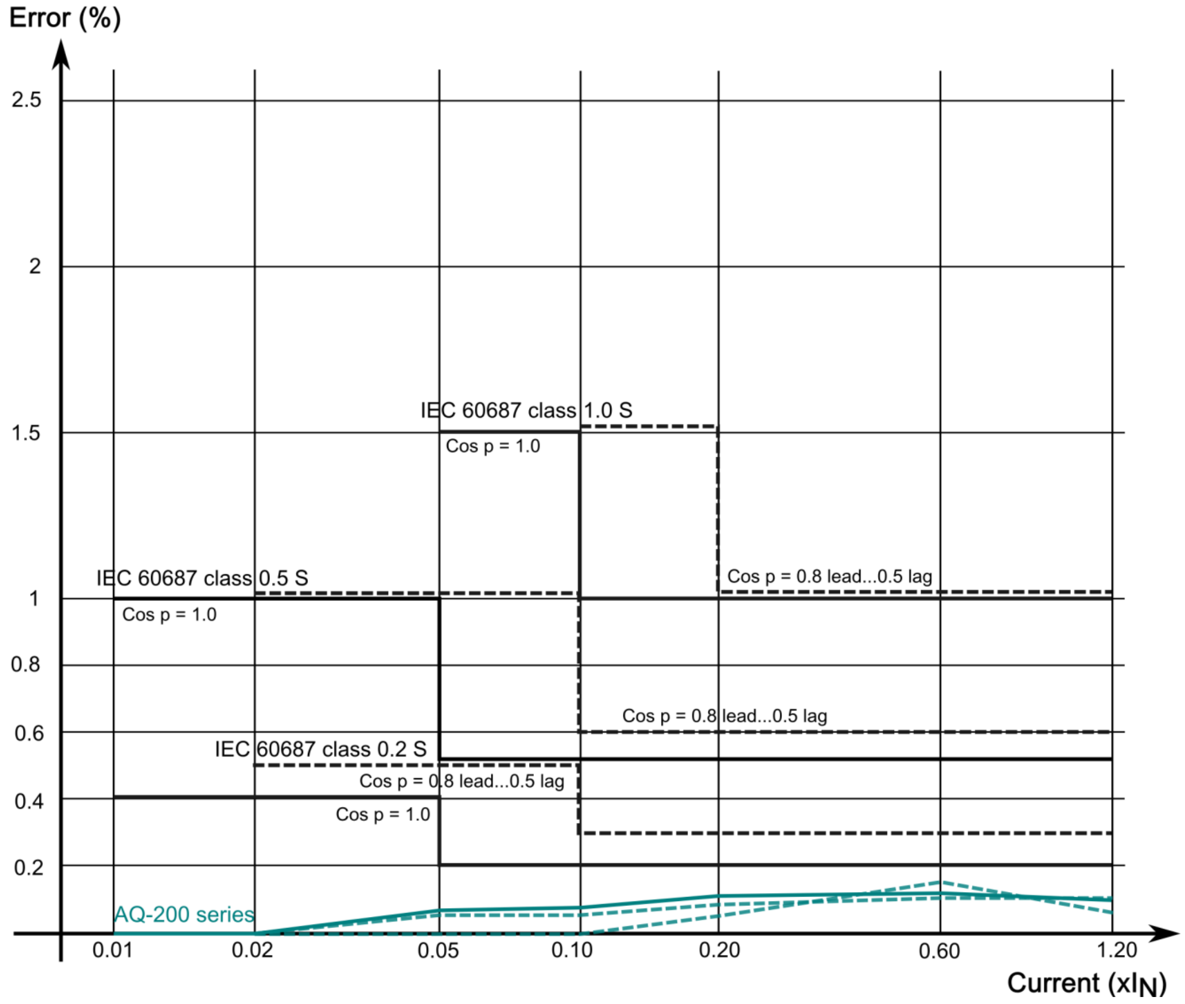
The amplitude difference is 0.2 % and the angle difference is 0.5 degrees higher at 16.67 Hz and other frequencies.

9.1.1.3. Power and energy measurement

Table. 9.1.1.3. - 252. Power and energy measurement accuracy

Power measurement P, Q, S	Frequency range 6…75 Hz
Inaccuracy	0.3 % <1.2 × I_N or 3 VA secondary 1.0 % >1.2 × I_N or 3 VA secondary
Energy measurement	**Frequency range 6…75 Hz**
Energy and power metering inaccuracy	IEC 62053-22 class 0.5 S (50/60Hz) as standard IEC 62053-22 class 0.2 S (50/60Hz) option available (see the order code for details)

Figure. 9.1.1.3. - 204. Energy and power metering accuracy in the optional 0.2 S accuracy model.



9.1.1.4. Frequency measurement

Table. 9.1.1.4. - 253. Frequency measurement accuracy.

Frequency measurement performance	
Frequency measuring range	6…75 Hz fundamental, up to the 31^{st} harmonic current or voltage
Inaccuracy	10 mHz

9.1.2. CPU & Power supply

9.1.2.1. Auxiliary voltage

Table. 9.1.2.1. - 254. Power supply model A

Rated values	
Rated auxiliary voltage	85…265 V (AC/DC)
Power consumption	< 20 W < 40 W
Maximum permitted interrupt time	< 40 ms with 110 VDC
DC ripple	< 15 %
Terminal block connection	
Terminal block	Phoenix Contact MSTB 2,5/5-ST-5,08
Solid or stranded wire Maximum wire diameter	2.5 mm^2

Table. 9.1.2.1. - 255. Power supply model B

Rated values	
Rated auxiliary voltage	18…72 VDC
Power consumption	< 20 W < 40 W
Maximum permitted interrupt time	< 40 ms with 24 VDC
DC ripple	< 15 %
Terminal block connection	
Terminal block	Phoenix Contact MSTB 2,5/5-ST-5,08
Solid or stranded wire Maximum wire diameter	2.5 mm^2

9.1.2.2. CPU communication ports

Table. 9.1.2.2. - 256. Front panel local communication port.

Port	
Port media	Copper Ethernet RJ-45
Number of ports	1

Port protocols	PC-protocols FTP Telnet
Features	
Data transfer rate	100 MB
System integration	Cannot be used for system protocols, only for local programming

Table. 9.1.2.2. - 257. Rear panel system communication port A.

Port	
Port media	Copper Ethernet RJ-45
Number of ports	1
Features	
Port protocols	IEC 61850 IEC 104 Modbus/TCP DNP3 FTP Telnet
Data transfer rate	100 MB
System integration	Can be used for system protocols and for local programming

Table. 9.1.2.2. - 258. Rear panel system communication port B.

Port	
Port media	Copper RS-485
Number of ports	1
Features	
Port protocols	Modbus/RTU IEC 103 IEC 101 DNP3 SPA
Data transfer rate	65 580 kB/s
System integration	Can be used for system protocols

9.1.2.3. CPU digital inputs

Table. 9.1.2.3. - 259. CPU model-isolated digital inputs, with thresholds defined by order code.

Rated values	
Rated auxiliary voltage	24, 110, 220 V (AC/DC)
Pick-up threshold Release threshold	Order code defined: 19, 90,170 V Order code defined: 14, 65, 132 V
Scanning rate	5 ms
Settings	

Pick-up delay	Software settable: 0…1800 s
Polarity	Software settable: Normally On/Normally Off
Current drain	2 mA
Terminal block connection	
Terminal block	Phoenix Contact MSTB 2,5/5-ST-5,08
Solid or stranded wire Maximum wire diameter	2.5 mm^2

9.1.2.4. CPU digital outputs

Table. 9.1.2.4. - 260. Digital outputs (Normal Open)

Rated values	
Rated auxiliary voltage	265 V (AC/DC)
Continuous carry	5 A
Make and carry 0.5 s Make and carry 3 s	30 A 15 A
Breaking capacity, DC (L/R = 40 ms) at 48 VDC at 110 VDC at 220 VDC	 1 A 0.4 A 0.2 A
Control rate	5 ms
Settings	
Polarity	Software settable: Normally On/Normally Off
Terminal block connection	
Terminal block	Phoenix Contact MSTB 2,5/5-ST-5,08
Solid or stranded wire Maximum wire diameter	2.5 mm^2

Table. 9.1.2.4. - 261. Digital outputs (Change-Over)

Rated values	
Rated auxiliary voltage	265 V (AC/DC)
Continuous carry	5 A
Make and carry 0.5 s Make and carry 3 s	30 A 15 A
Breaking capacity, DC (L/R = 40 ms) at 48 VDC at 110 VDC at 220 VDC	 1 A 0.4 A 0.2 A
Control rate	5 ms
Settings	
Polarity	Software settable: Normally On/Normally Off
Terminal block connection	
Terminal block	Phoenix Contact MSTB 2,5/5-ST-5,08
Solid or stranded wire Maximum wire diameter	2.5 mm^2

9.1.3. Option cards

9.1.3.1. Digital input module

Table. 9.1.3.1. - 262. Technical data for the digital input module.

Rated values	
Rated auxiliary voltage	5…265 V (AC/DC)
Current drain	2 mA
Scanning rate Activation/release delay	5 ms 5...11 ms
Settings	
Pick-up threshold Release threshold	Software settable: 16…200 V, setting step 1 V Software settable: 10…200 V, setting step 1 V
Pick-up delay	Software settable: 0…1800 s
Drop-off delay	Software settable: 0…1800 s
Polarity	Software settable: Normally On/Normally Off
Terminal block connection	
Terminal block	Phoenix Contact MSTB 2,5/5-ST-5,08
Solid or stranded wire Maximum wire diameter	2.5 mm^2

9.1.3.2. Digital output module

Table. 9.1.3.2. - 263. Technical data for the digital output module.

Rated values	
Rated auxiliary voltage	265 V (AC/DC)
Continuous carry	5 A
Make and carry 0.5 s Make and carry 3 s	30 A 15 A
Breaking capacity, DC (L/R = 40 ms) at 48 VDC at 110 VDC at 220 VDC	 1 A 0.4 A 0.2 A
Control rate	5 ms
Settings	
Polarity	Software settable: Normally On/Normally Off
Terminal block connection	
Terminal block	Phoenix Contact MSTB 2,5/5-ST-5,08
Solid or stranded wire Maximum wire diameter	2.5 mm^2

9.1.3.3. Arc protection module

Table. 9.1.3.3. - 264. Technical data for the arc protection module.

Connections

Input arc point sensor	S1, S2, S3, S4 (pressure and light, or light only)
Performance	
Pick-up light intensity	8, 25 or 50 kLx (the sensor is selectable in the order code)
Inaccuracy: - Point sensor detection radius	180 degrees
Start and instant operating time (light only)	Typically <5 ms (dedicated semiconductor outputs) Typically <10 ms (regular output relays)

Table. 9.1.3.3. - 265. High Speed Outputs (HSO1…2)

Rated values	
Rated auxiliary voltage	250 VDC
Continuous carry	2 A
Make and carry 0.5 s Make and carry 3 s	15 A 6 A
Breaking capacity, DC (L/R = 40 ms)	1 A/110 W
Control rate	5 ms
Operation delay	<1 ms
Polarity	Normally Off
Contact material	Semiconductor
Terminal block connection	
Terminal block	Phoenix Contact MSTB 2,5/5-ST-5,08
Solid or stranded wire Maximum wire diameter	2.5 mm^2

Table. 9.1.3.3. - 266. Binary input channel

Rated values	
Voltage withstand	265 VDC
Rated auxiliary voltage Pick-up threshold Release threshold	24 VDC ≥16 VDC ≤15 VDC
Scanning rate	5 ms
Polarity	Normally Off
Current drain	3 mA
Terminal block connection	
Terminal block	Phoenix Contact MSTB 2,5/5-ST-5,08
Solid or stranded wire Maximum wire diameter	2.5 mm^2

NOTE! Polarity has to be correct.

9.1.3.4. Milliampere module (mA out & mA in)

Table. 9.1.3.4. - 267. Technical data for the milliampere module.

Signals

Output magnitudes Input magnitudes	4 × mA output signal (DC) 1 × mA input signal (DC)
mA input	
Range (hardware) Range (measurement) Inaccuracy	0...33 mA 0...24 mA ±0.1 mA
Update cycle Response time @ 5 ms cycle Update cycle time inaccuracy	5...10 000 ms, setting step 5 ms ~ 15 ms (13...18 ms) Max. +20 ms above the set cycle
mA input scaling range Output scaling range	0...4000 mA -1 000 000.0000…1 000 000.0000, setting step 0.0001
mA output	
Inaccuracy @ 0...24 mA	±0.01 mA
Response time @ 5 ms cycle [fixed]	< 5 ms
mA output scaling range Source signal scaling range	0...24 mA, setting step 0.001 mA -1 000 000.000…1 000 000.0000, setting step 0.0001

9.1.3.5. RTD & mA input module

Table. 9.1.3.5. - 268. Technical data for the RTD & mA input module.

Channels 1-8	
2/3/4-wire RTD and thermocouple sensors	
Pt100 or Pt1000	
Type K, Type J, Type T and Type S	
Channels 7 & 8 support mA measurement	
Measurement range	
mA input range	0…33 mA

9.1.3.6. RS-232 & serial fiber communication module

Table. 9.1.3.6. - 269. Technical data for the RS-232 & serial fiber communication module.

Ports
RS-232
Serial fiber (GG/PP/GP/PG)
Serial port wavelength
660 nm
Cable type
1 mm plastic fiber

9.1.3.7. Double LC 100 Mbps Ethernet communication module

Table. 9.1.3.7. - 270. Technical data for the double LC 100 Mbps Ethernet communication module.

Protocols

Protocols	HSR and PRP
Ports	
Quantity of fiber ports	2
Communication port C & D	LC fiber connector Wavelength 1300 nm
Fiber cable	50/125 µm or 62.5/125 µm multimode (glass)

9.1.4. Display

Table. 9.1.4. - 271. Technical data for the HMI TFT display.

Dimensions and resolution	
Number of dots/resolution	800 x 480
Size	84.78 × 49.90 mm (3.34 × 1.96 in)
Display	
Type of display	TFT
Color	RGB color

9.2. Functions

9.2.1. Protection functions

9.2.1.1. Non-directional overcurrent (I>; 50/51)

Table. 9.2.1.1. - 272. Technical data for the non-directional overcurrent function.

Input signals	
Current input magnitudes	Phase current fundamental frequency RMS Phase current TRMS Phase current peak-to-peak
Pick-up	
Pick-up current setting	0.10…50.00 × I_n, setting step 0.0001 × I_n 0.10…50.00 %I_{fund}, setting step 0.01 %I_{fund}
Inaccuracy: - Current - 2^{nd} harmonic blocking	±0.5 %I_{set} or ±15 mA (0.10…4.0 × I_{set}) ±1.0 %-unit of the 2^{nd} harmonic setting
Operation time	
Definite time function operating time setting	0.00…1800.00 s, setting step 0.005 s
Inaccuracy: - Definite time: I_m/I_{set} ratio > 3 - Definite time: I_m/I_{set} ratio = 1.05…3	±1.0 % or ±20 ms ±1.0 % or ±30 ms
IDMT operating time setting (ANSI/IEC)	0.02…1800.00 s, setting step 0.001 × parameter
IDMT setting parameters: - k Time dial setting for IDMT - A IDMT constant - B IDMT constant - C IDMT constant	0.01…25.00, step 0.01 0…250.0000, step 0.0001 0…5.0000, step 0.0001 0…250.0000, step 0.0001
Inaccuracy: - IDMT operating time - IDMT minimum operating time	±1.5 % or ±20 ms ±20 ms
Retardation time (overshoot)	<25 ms

Instant operation time	
Start time and instant operation time (trip): - I_m/I_{set} ratio > 3 - I_m/I_{set} ratio = 1.05…3	<35 ms (typically 25 ms) <50 ms
Reset	
Reset ratio	97 % of the pick-up current setting
Reset time setting Inaccuracy: Reset time	0.010…10.000 s, step 0.005 s ±1.0 % or ±50 ms
Instant reset time and start-up reset	<50 ms

Note!

- The release delay does not apply to phase-specific tripping.

9.2.1.2. Non-directional earth fault (I0>; 50N/51N)

Table. 9.2.1.2. - 273. Technical data for the non-directional earth fault function.

Input signals	
Current input magnitudes	Phase current fundamental frequency RMS Phase current TRMS Phase current peak-to-peak Residual current fundamental frequency RMS Residual current TRMS Residual current peak-to-peak
Pick-up	
Used magnitude	Measured residual current I01 (1 A) Measured residual current I02 (0.2 A) Calculated residual current I0Calc (5 A)
Pick-up current setting	0.0001…40.00 × I_n, setting step 0.0001 × I_n
Inaccuracy: - Starting I01 (1 A) - Starting I02 (0.2 A) - Starting I0Calc (5 A)	±0.5 %$I0_{set}$ or ±3 mA (0.005…10.0 × I_{set}) ±1.5 %$I0_{set}$ or ±1.0 mA (0.005…25.0 × I_{set}) ±1.0 %$I0_{set}$ or ±15 mA (0.005…4.0 × I_{set})
Operating time	
Definite time function operating time setting	0.00…1800.00 s, setting step 0.005 s
Inaccuracy: - Definite time: I_m/I_{set} ratio > 3 - Definite time: I_m/I_{set} ratio = 1.05…3	±1.0 % or ±20 ms ±1.0 % or ±30 ms
IDMT operating time setting (ANSI/IEC)	0.02…1800.00 s, setting step 0.001 × parameter
IDMT setting parameters: - k Time dial setting for IDMT - A IDMT constant - B IDMT constant - C IDMT constant	0.01…25.00, step 0.01 0…250.0000, step 0.0001 0…5.0000, step 0.0001 0…250.0000, step 0.0001
Inaccuracy: - IDMT operating time - IDMT minimum operating time	±1.5 % or ±20 ms ±20 ms
Retardation time (overshoot)	<25 ms
Instant operation time	
Start time and instant operation time (trip): - I_m/I_{set} ratio > 3.5 - I_m/I_{set} ratio = 1.05…3.5	<50 ms (typical 35 ms) <55 ms

Reset	
Reset ratio	97 % of the pick-up current setting
Reset time setting Inaccuracy: Reset time	0.010…10.000 s, step 0.005 s ±1.0 % or ±50 ms
Instant reset time and start-up reset	<50 ms

Note!

- The operation and reset time accuracy does not apply when the measured primary current in I02 is 1…20 mA. The pick-up is tuned to be more sensitive and the operation times vary because of this.

9.2.1.3. Directional overcurrent (Idir>; 67)

Table. 9.2.1.3. - 274. Technical data for the directional overcurrent function.

Input signals	
Current input magnitudes	Phase current fundamental frequency RMS Phase current TRMS Phase current peak-to-peak
Voltage input magnitudes	P-P +U_0 voltage fundamental frequency RMS P-E voltage fundamental frequency RMS
Pick-up	
Characteristic direction	Directional, non-directional
Operating sector center	-180.0…180.0 deg, setting step 0.1 deg
Operating sector size (+/-)	1.00…170.00 deg, setting step 0.10 deg
Pick-up current setting	0.10…40.00 × I_n, setting step 0.01 × I_n
Inaccuracy: - Current - U1/I1 angle (U > 15 V) - U1/I1 angle (U = 1…15 V)	±0.5 %I_{set} or ±15 mA (0.10…4.0 × I_{set}) ±0.20° ±1.5°
Operation time	
Definite time function operating time setting	0.00…1800.00 s, setting step 0.005 s
Inaccuracy: - Definite time: I_m/I_{set} ratio > 3 - Definite time: I_m/I_{set} ratio = 1.05…3	±1.0 % or ±20 ms ±1.0 % or ±35 ms
IDMT operating time setting (ANSI/IEC)	0.02…1800.00 s, setting step 0.001 × parameter
IDMT setting parameters: - k Time dial setting for IDMT - A IDMT constant - B IDMT constant - C IDMT constant	0.01…25.00, step 0.01 0…250.0000, step 0.0001 0…5.0000, step 0.0001 0…250.0000, step 0.0001
Inaccuracy: - IDMT operating time - IDMT minimum operating time	±1.5 % or ±20 ms ±20 ms
Instant operation time	
Start time and instant operation time (trip): - I_m/I_{set} ratio > 3 - I_m/I_{set} ratio = 1.05…3	<40 ms (typical 30 ms) <50 ms
Reset	
Reset ratio: - Current - U1/I1 angle	97 % of the pick-up current setting 2.0°

Reset time setting Inaccuracy: Reset time	0.010…10.000 s, step 0.005 s ±1.0 % or ±50 ms
Instant reset time and start-up reset	<50 ms

Note!

- The minimum voltage for direction solving is 1.0 V secondary. During three-phase short-circuits the angle memory is active for 0.5 seconds in case the voltage drops below 1.0 V.

9.2.1.4. Directional earth fault (I0dir>; 67N)

Table. 9.2.1.4. - 275. Technical data for the directional earth fault function.

Input signals	
Current input magnitudes	Phase current fundamental frequency RMS (I0calc) Phase current TRMS (I0Calc) Phase current peak-to-peak (I0Calc) Residual current fundamental frequency RMS Residual current TRMS Residual current peak-to-peak
Voltage input magnitudes	P-E voltage fundamental frequency RMS (U0Calc) Zero sequence voltage fundamental frequency RMS
Pick-up	
Used current magnitude	Measured residual current I01 (1 A) Measured residual current I02 (0.2 A) Calculated residual current I0Calc (5 A)
Used voltage magnitude	Measured zero sequence voltage U0 Calculated zero sequence voltage U0Calc
Characteristic direction	Unearthed (Varmetric 90°) Petersen coil GND (Wattmetric 180°) *Earthed* (Adjustable sector)
When the *earthed* mode is active: - Trip area center - Trip area size (+/-)	 0.00…360.00 deg, setting step 0.10 deg 45.00…135.00 deg, setting step 0.10 deg
Pick-up current setting Pick-up voltage setting	0.005…40.00 × I_n, setting step 0.001 × I_n 1.00…50.00 %$U0_n$, setting step 0.01 %$U0_n$
Inaccuracy: - Starting I01 (1 A) - Starting I02 (0.2 A) - Starting I0Calc (5 A) - Voltage U0 and U0Calc - U0/I0 angle (U > 15 V) - U0/I0 angle (U = 1…15 V)	 ±0.5 %$I0_{set}$ or ±3 mA (0.005…10.0 × I_{set}) ±1.5 %$I0_{set}$ or ±1.0 mA (0.005…25.0 × I_{set}) ±1.5 %$I0_{set}$ or ±15 mA (0.005…4.0 × I_{set}) ±2.5 %$U0_{set}$ ±0.1° (I0Calc ±1.0°) ±1.0°
Operation time	
Definite time function operating time setting	0.00…1800.00 s, setting step 0.005 s
Inaccuracy: - Definite time (I_m/I_{set} ratio 1.05→)	±1.0 % or ±45 ms
IDMT operating time setting (ANSI/IEC)	0.02…1800.00 s, setting step 0.001 × parameter
IDMT setting parameters: - k Time dial setting for IDMT - A IDMT constant - B IDMT constant - C IDMT constant	 0.01…25.00, step 0.01 0…250.0000, step 0.0001 0…5.0000, step 0.0001 0…250.0000, step 0.0001

Inaccuracy: - IDMT operating time - IDMT minimum operating time	±1.5 % or ±20 ms ±20 ms
Instant operation time	
Start time and instant operation time (trip): - I_m/I_{set} ratio > 3 - I_m/I_{set} ratio = 1.05…3	<50 ms (typical 40 ms) <65 ms
Reset	
Current and voltage reset U0/I0 angle	97 % of the pick-up current and voltage setting 2.0°
Reset time setting Inaccuracy: Reset time	0.000…150.000 s, step 0.005 s ±1.0 % or ±45 ms
Instant reset time and start-up reset	<50 ms

9.2.1.5. Current unbalance (I2>; 46/46R/46L)

Table. 9.2.1.5. - 276. Technical data for the current unbalance function.

Input signals	
Current input magnitudes	Phase current fundamental frequency RMS
Pick-up	
Used magnitude	Negative sequence component I2pu Relative unbalance I2/I1
Pick-up setting	0.01…40.00 × I_n, setting step 0.01 × I_n (I2pu) 1.00…200.00 %, setting step 0.01 % (I2/I1)
Minimum phase current (at least one phase above)	0.01…2.00 × I_n, setting step 0.01 × I_n
Inaccuracy: - Starting I2pu - Starting I2/I1	±1.0 %-unit or ±100 mA (0.10…4.0 × I_n) ±1.0 %-unit or ±100 mA (0.10…4.0 × I_n)
Operating time	
Definite time function operating time setting	0.00…1800.00 s, setting step 0.005 s
Inaccuracy: - Definite time (I_m/I_{set} ratio > 1.05)	±1.5 % or ±60 ms
IDMT operating time setting (ANSI/IEC)	0.02…1800.00 s, setting step 0.001 × parameter
IDMT setting parameters: - k Time dial setting for IDMT - A IDMT Constant - B IDMT Constant - C IDMT Constant	0.01…25.00, step 0.01 0…250.0000, step 0.0001 0…5.0000, step 0.0001 0…250.0000, step 0.0001
Inaccuracy: - IDMT operating time - IDMT minimum operating time	±1.5 % or ±20 ms ±20 ms
Retardation time (overshoot)	<5 ms
Instant operation time	
Start time and instant operation time (trip): - I_m/I_{set} ratio > 1.05	<70 ms
Reset	
Reset ratio	97 % of the pick-up setting
Reset time setting Inaccuracy: Reset time	0.010…10.000 s, step 0.005 s ±1.5 % or ±60 ms

Instant reset time and start-up reset	<55 ms

9.2.1.6. Harmonic overcurrent (Ih>; 50H/51H, 68)

Table. 9.2.1.6. - 277. Technical data for the harmonic overcurrent function.

Input signals	
Current input magnitudes	Phase current IL1/IL2/IL3 TRMS Residual current I01 TRMS Residual current I02 TRMS
Pick-up	
Harmonic selection	2^{nd}, 3^{rd}, 4^{th}, 5^{th}, 7^{th}, 9^{th}, 11^{th}, 13^{th}, 15^{th}, 17^{th} or 19^{th}
Used magnitude	Harmonic per unit (× I_N) Harmonic relative (Ih/IL)
Pick-up setting	0.05…2.00 × I_N, setting step 0.01 × I_N (× I_N) 5.00…200.00 %, setting step 0.01 % (Ih/IL)
Inaccuracy: - Starting × I_N - Starting × Ih/IL	<0.03 × I_N (2^{nd}, 3^{rd}, 5^{th}) <0.03 × I_N tolerance to Ih (2^{nd}, 3^{rd}, 5^{th})
Operation time	
Definite time function operating time setting	0.00…1800.00 s, setting step 0.005 s
Inaccuracy: - Definite time (I_M/I_{SET} ratio >1.05)	±1.0 % or ±35 ms
IDMT operating time setting (ANSI/IEC)	0.02…1800.00 s, setting step 0.001 × parameter
IDMT setting parameters: k Time dial setting for IDMT A IDMT constant B IDMT constant C IDMT constant	0.01…25.00, step 0.01 0…250.0000, step 0.0001 0…5.0000, step 0.0001 0…250.0000, step 0.0001
Inaccuracy: - IDMT operating time - IDMT minimum operating time	±1.5 % or ±20 ms ±20 ms
Instant operation time	
Start time and instant operation time (trip): I_M/I_{SET} ratio >1.05	<50 ms
Reset	
Reset ratio	95 % of the pick-up setting
Reset time setting Inaccuracy: Reset time	0.010…10.000 s, step 0.005 s ±1.0 % or ±35 ms
Instant reset time and start-up reset	<50 ms

Note!

- Harmonics generally: The amplitude of the harmonic content has to be least 0.02 × I_N when the relative mode (Ih/IL) is used.
- Blocking: To achieve fast activation for blocking purposes with the harmonic overcurrent stage, note that the harmonic stage may be activated by a rapid load change or fault situation. An intentional activation lasts for approximately 20 ms if a harmonic component is not present. The harmonic stage stays active if the harmonic content is above the pick-up limit.
- Tripping: When using the harmonic overcurrent stage for tripping, please ensure that the operation time is set to 20 ms (DT) or longer to avoid nuisance tripping caused by the above-mentioned reasons.

9.2.1.7. Circuit breaker failure protection (CBFP; 50BF/52BF)

Table. 9.2.1.7. - 278. Technical data for the circuit breaker failure protection function.

Input signals	
Current input magnitudes	Phase currents, I01, I02 I0Calc fundamental frequency RMS
Monitored signals	Digital input status, digital output status
Pick-up	
Pick-up current setting: - IL1…IL3 - I01, I02, I0Calc	0.10…40.00 × I_N, setting step 0.01 × I_N 0.005…40.00 × I_N, setting step 0.005 × I_N
Inaccuracy: - Starting phase current (5A) - Starting I01 (1 A) - Starting I02 (0.2 A) - Starting I0Calc (5 A)	±0.5 %I_{SET} or ±15 mA (0.10…4.0 × I_{SET}) ±0.5 %$I0_{SET}$ or ±3 mA (0.005…10.0 × I_{SET}) ±1.5 %$I0_{SET}$ or ±1.0 mA (0.005…25.0 × I_{SET}) ±1.0 %$I0_{SET}$ or ±15 mA (0.005…4.0 × I_{SET})
Operation time	
Definite time function operating time setting	0.050…1800.000 s, setting step 0.005 s
Inaccuracy: - Current criteria (I_M/I_{SET} ratio 1.05→) - DO or DI only	±1.0 % or ±55 ms ±15 ms
Reset	
Reset ratio	97 % of the pick-up current setting
Reset time	<50 ms

9.2.1.8. Restricted earth fault/Cable end differential (I0d; 87N)

Table. 9.2.1.8. - 279. Technical data for the restricted earth fault/cable end differential function.

Input signals	
Current input magnitudes	Phase currents, I01, I02 fundamental frequency RMS Calculated bias and residual differential currents
Pick-up	
Operating modes	Restricted earth fault Cable end differential
Characteristics	Biased differential with 3 settable sections and 2 slopes
Pick-up current sensitivity setting Slope 1 Slope 2 Bias (Turnpoint 1 & 2)	0.01…50.00 % (I_N), setting step 0.01 % 0.00…150.00 %, setting step 0.01 % 0.00…250.00 %, setting step 0.01 % 0.01…50.00 × I_N, setting step 0.01 × I_N
Inaccuracy - Starting	±3% of the set pick-up value > 0.5 × I_N setting. ±5 mA < 0.5 × I_N setting
Operation time	
Instant operation time 1.05 x I_{SET}	<30 ms
Reset	
Reset ratio	No hysteresis
Reset time	<40 ms

9.2.1.9. Overvoltage (U>; 59)

Table. 9.2.1.9. - 280. Technical data for the overvoltage function.

Input signals	
Voltage input magnitudes	P-P voltage fundamental frequency RMS P-E voltage fundamental frequency RMS
Pick-up	
Pick-up terms	1 voltage 2 voltages 3 voltages
Pick-up setting	50.00…150.00 $\%U_N$, setting step 0.01 $\%U_N$
Inaccuracy: - Voltage	±1.5 $\%U_{SET}$
Operating time	
Definite time function operating time setting	0.00…1800.00 s, setting step 0.005 s
Inaccuracy: - Definite time (U_M/U_{SET} ratio 1.05→)	±1.0 % or ±35 ms
IDMT operating time setting (ANSI/IEC)	0.02…1800.00 s, setting step 0.001 × parameter
IDMT setting parameters: k Time dial setting for IDMT A IDMT constant B IDMT constant C IDMT constant	 0.01…25.00, step 0.01 0…250.0000, step 0.0001 0…5.0000, step 0.0001 0…250.0000, step 0.0001
Inaccuracy: - IDMT operating time - IDMT minimum operating time	 ±1.5 % or ±20 ms ±20 ms
Instant operation time	
Start time and instant operation time (trip): - U_M/U_{SET} ratio 1.05→	<50 ms
Reset	
Reset ratio	97 % of the pick-up voltage setting
Reset time setting Inaccuracy: Reset time	0.010…10.000 s, step 0.005 s ±1.0 % or ±45 ms
Instant reset time and start-up reset	<50 ms

9.2.1.10. Undervoltage (U<; 27)

Table. 9.2.1.10. - 281. Technical data for the undervoltage function.

Input signals	
Voltage input magnitudes	P-P voltage fundamental frequency RMS P-E voltage fundamental frequency RMS
Pick-up	
Pick-up terms	1 voltage 2 voltages 3 voltages
Pick-up setting	0.00…120.00 $\%U_N$, setting step 0.01 $\%U_N$
Inaccuracy: - Voltage	±1.5 $\%U_{SET}$ or ±30 mV
Low voltage block	

Pick-up setting	0.00…80.00 %U_N, setting step 0.01 %U_N
Inaccuracy: - Voltage	±1.5 %U_{SET} or ±30 mV
Operation time	
Definite time function operating time setting	0.00…1800.00 s, setting step 0.005 s
Inaccuracy: - Definite time (U_M/U_{SET} ratio 1.05→)	±1.0 % or ±35 ms
IDMT operating time setting (ANSI/IEC)	0.02…1800.00 s, setting step 0.001 × parameter
IDMT setting parameters: k Time dial setting for IDMT A IDMT constant B IDMT constant C IDMT constant	0.01…25.00, step 0.01 0…250.0000, step 0.0001 0…5.0000, step 0.0001 0…250.0000, step 0.0001
Inaccuracy: - IDMT operating time - IDMT minimum operating time	±1.5 % or ±20 ms ±20 ms
Instant operation time	
Start time and instant operation time (trip): - U_M/U_{SET} ratio 1.05→	<65 ms
Retardation time (overshoot)	<30 ms
Reset	
Reset ratio	103 % of the pick-up voltage setting
Reset time setting Inaccuracy: Reset time	0.010…10.000 s, step 0.005 s ±1.0 % or ±45 ms
Instant reset time and start-up reset	<50 ms

Note!

- The low-voltage block is not in use when its pick-up setting is set to 0 %. The undervoltage function is in trip stage when the LV block is disabled and the device has no voltage injection.
- After the blocking condition, the undervoltage stage does not trip unless the voltage exceeds the pick-up setting first.

9.2.1.11. Neutral overvoltage (U0>; 59N)

Table. 9.2.1.11. - 282. Technical data for the neutral overvoltage function.

Input signals	
Voltage input magnitudes	U0 voltage fundamental frequency RMS
Pick-up	
Pick-up voltage setting	1.00…50.00 % $U0_N$, setting step 0.01 × I_N
Inaccuracy: - Voltage U0 - Voltage U0Calc	±1.5 %$U0_{SET}$ or ±30 mV ±150 mV
Operation time	
Definite time function operating time setting	0.00…1800.00 s, setting step 0.005 s
Inaccuracy: - Definite time ($U0_M/U0_{SET}$ ratio 1.05→)	±1.0 % or ±45 ms
IDMT operating time setting (ANSI/IEC)	0.02…1800.00 s, setting step 0.001 × parameter

IDMT setting parameters: k Time dial setting for IDMT A IDMT constant B IDMT constant C IDMT constant	0.01…25.00, step 0.01 0…250.0000, step 0.0001 0…5.0000, step 0.0001 0…250.0000, step 0.0001
Inaccuracy: - IDMT operating time - IDMT minimum operating time	±1.5 % or ±20 ms ±20 ms
Instant operation time	
Start time and instant operation time (trip): - $U0_M/U0_{SET}$ ratio 1.05→	<50 ms
Reset	
Reset ratio	97 % of the pick-up voltage setting
Reset time setting Inaccuracy: Reset time	0.000 … 150.000 s, step 0.005 s ±1.0 % or ±50 ms
Instant reset time and start-up reset	<50 ms

9.2.1.12. Sequence voltage (U1/2>/<; 47/27P/59NP)

Table. 9.2.1.12. - 283. Technical data for the sequence voltage function.

Input signals	
Voltage input magnitudes	P-E voltage fundamental frequency RMS P-P voltage fundamental frequency RMS + U0
Pick-up	
Pick-up setting	5.00…150.00 $\%U_N$, setting step 0.01 $\%U_N$
Inaccuracy: - Voltage	±1.5 $\%U_{SET}$ or ±30 mV
Low voltage block	
Pick-up setting	1.00…80.00 $\%U_N$, setting step 0.01 $\%U_N$
Inaccuracy: -Voltage	±1.5 $\%U_{SET}$ or ±30 mV
Operation time	
Definite time function operating time setting	0.00…1800.00 s, setting step 0.005 s
Inaccuracy -Definite Time (U_M/U_{SET} ratio 1.05→)	±1.0 % or ±35 ms
IDMT operating time setting (ANSI/IEC)	0.02…1800.00 s, setting step 0.001 × parameter
IDMT setting parameters: k Time dial setting for IDMT A IDMT constant B IDMT constant C IDMT constant	0.01…25.00, step 0.01 0…250.0000, step 0.0001 0…5.0000, step 0.0001 0…250.0000, step 0.0001
Inaccuracy: - IDMT operating time - IDMT minimum operating time	±1.5 % or ±20 ms ±20 ms
Instant operation time	
Start time and instant operation time (trip): - U_M/U_{SET} ratio <0.95/1.05→	<65 ms
Reset	
Reset ratio	97 or 103 % of the pick-up voltage setting

Reset time setting Inaccuracy: Reset time	0.010…10.000 s, step 0.005 s ±1.0 % or ±35 ms
Instant reset time and start-up reset	<50 ms

9.2.1.13. Overfrequency and underfrequency (f>/<; 81O/81U)

Table. 9.2.1.13. - 284. Technical data for the overfrequency and underfrequency function.

Input signals	
Sampling mode	Fixed Tracking
Frequency reference 1 Frequency reference 2 Frequency reference 3	CT1IL1, CT2IL1, VT1U1, VT2U1 CT1IL2, CT2IL2, VT1U2, VT2U2 CT1IL3, CT2IL3, VT1U3, VT2U3
Pick-up	
f> pick-up setting f< pick-up setting	10.00…70.00 Hz, setting step 0.01 Hz 7.00…65.00 Hz, setting step 0.01 Hz
Inaccuracy (sampling mode): - Fixed - Tracking	±15 mHz (50/60 Hz fixed frequency) ±20 mHz (U > 30 V secondary) ±20 mHz (I > 30 % of rated secondary)
Operation time	
Definite time function operating time setting	0.00…1800.00 s, setting step 0.005 s
Inaccuracy: - Definite time (I_M/I_{SET} ratio +/- 50 mHz)	±1.5 % or ±50 ms (max. step size: 100 mHz)
Instant operation time	
Start time and instant operation time (trip): - I_M/I_{SET} ratio +/- 50 mHz (Fixed) - I_M/I_{SET} ratio +/- 50 mHz (Tracking)	<70 ms (max. step size: 100 mHz) <3 cycles or <60 ms (max. step size: 100 mHz)
Reset	
Reset ratio	0.020 Hz
Instant reset time and start-up reset: - I_M/I_{SET} ratio +/- 50 mHz (Fixed) - I_M/I_{SET} ratio +/- 50 mHz (Tracking)	<110 ms (max. step size: 100 mHz) <3 cycles or <70 ms (max. step size: 100 mHz)

Note!

- The secondary voltage must exceed 2 volts or the current must exceed 0.25 amperes (peak-to peak) in order for the function to measure frequency.
- The frequency is measured two seconds after a signal is received.
- The fixed frequency mode: When the fixed mode is used, the system's nominal frequency should be set to 50 or 60 Hz.
- The tracked frequency mode: When tracked mode is used, the system's nominal frequency can be anything between 7...75 Hz.

9.2.1.14. Rate of change of frequency (df/dt >/<; 81R)

Table. 9.2.1.14. - 285. Technical data for the rate of change of frequency function.

Input signals	
Sampling mode	Fixed Tracking

Frequency reference 1 Frequency reference 2 Frequency reference 3	CT1IL1, CT2IL1, VT1U1, VT2U1 CT1IL2, CT2IL2, VT1U2, VT2U2 CT1IL3, CT2IL3, VT1U3, VT2U3
Pick-up	
Df/dt >/< pick-up setting f> limit f< limit	0.15…1.00 Hz/s, setting step 0.01 Hz 10.00…70.00 Hz, setting step 0.01 Hz 7.00…65.00 Hz, setting step 0.01 Hz
Inaccuracy: - df/dt - frequency	±5.0 %I_{SET} or ±20 mHz/s ±15 mHz (U > 30 V secondary) ±20 mHz (I > 30 % of rated secondary)
Operation time	
Definite time function operating time setting	0.00…1800.00 s, setting step 0.005 s
Inaccuracy: - Definite time (I_M/I_{SET} ratio +/- 50 mHz)	±1.5 % or ±110 ms (max. step size: 100 mHz)
Instant operation time	
Start time and instant operation time (trip): - f_M/f_{SET} ratio +/- 20 mHz (overreach) - f_M/f_{SET} ratio +/- 200 mHz (overreach)	<200 ms <90 ms
Reset	
Reset ratio (frequency limit) df/dt	0.020 Hz 0.100 Hz/s of the pick-up setting or 0.100 Hz/s absolute at the low end
Instant reset time and start-up reset: - f_M/f_{SET} ratio +/- 50 mHz	<325 ms (max. step size: 100 mHz)

Note!

- Frequency is measured 2 seconds after a signal is received.

9.2.1.15. Transformer thermal overload protection (TT>; 49T)

Table. 9.2.1.15. - 286. Technical data for the transformer thermal overload protection function.

Input signals	
Current input magnitude	Phase current TRMS (up to the 31st harmonic)
Setting specifications	
Time constants τ	1 heating, 1 cooling
Time constant value	0.0…500.00 min, step 0.1 min
Service factor (maximum overloading)	0.01…5.00 × I_N, step 0.01 × I_N
Thermal model biasing	- Ambient temperature (Set –60.0…500.0 deg, step 0.1 deg, and RTD) - Negative sequence current
Thermal replica temperature estimates	Selectable between °C and °F
Outputs	
- Alarm 1 - Alarm 2 - Thermal trip - Trip delay - Restart inhibit	0…150 %, step 1 % 0…150 %, step 1 % 0…150 %, step 1 % 0.000…3600.000 s, step 0.005 s 0…150 %, step 1 %
Inaccuracy	

- Starting - Operating time	±0.5 % of the set pick-up value ±5 % or ± 500 ms

9.2.1.16. Active, reactive and apparent power protection (P, Q, S >/<; 32/37)

Table. 9.2.1.16. - 287. Technical data for the active, reactive and apparent power protection function.

Input signals	
Current input magnitudes	Phase current fundamental frequency RMS
Voltage input magnitudes	Phase voltage fundamental frequency RMS
Magnitude selection	P, Q or S value based on the chosen or set nominal amplitude
Comparator selection	> or <
Pick-up	
> or <	-500.000...500.000 %/MVA_N, setting step 0.005 %/MVA_N
Inaccuracy: - Active, reactive, or apparent power	Typically <1.0 %P_{SET}
Operation time	
Definite time function operating time setting	0.00…1800.00 s, setting step 0.005 s
Inaccuracy: - Definite time (P_M/P_{SET} ratio 1.05→)	±1.0 % or ±35 ms
Instant operation time	
Start time and instant operation time (trip): - PQS_M/PQS_{SET} ratio 1.05→	<40 ms
Reset	
Reset ratio	97 or 103 %P_{SET}
Instant reset time and start-up reset	<40 ms

Note!

- The voltage measurement starts from 0.5 V and the current measurement from 25 mA. In case either or both are missing, the measured magnitude is forced to 0 MW/MVar/MVA. Please avoid using settings that should operate below the relay's current squelch limit (25 mA on the relay terminal).

9.2.1.17. Resistance temperature detectors

Table. 9.2.1.17. - 288. Technical data of the resistance temperature detectors.

Inputs	
Resistance input magnitudes	Measured temperatures measured by RTD sensors
Alarm channels	12 individual alarm channels
Settable alarms	24 alarms available (two per each alarm channel)
Pick-up	
Alarm setting range Inaccuracy Reset ratio	101.00…2000.00 deg, setting step 0.1 deg (either < or > setting) ±3 % of the set pick-up value 97 % of the pick-up setting
Operation	
Operating time	Typically <500 ms

9.2.1.18. Transformer status monitoring

Table. 9.2.1.18. - 289. Technical data for the transformer status monitoring function.

Features	
Control scale	Common transformer data settings for all functions in the transformer module, the protection logic, the HMI and the I/O.
Settings	Transformer application nominal data
Other features	Status hours counters (normal load, overload, high overload) Transformer status signals Transformer data for functions
Outputs	
Light/no load	$I_M < 0.2 \times I_N$
Inrush HV side detected	$I_M < 0.2 \times I_N \rightarrow I_M > 1.3 \times I_N$
Inrush LV side detected	$I_M < 0.2 \times I_N \rightarrow I_M > 1.3 \times I_N$
Load normal	$I_M > 0.2 \times I_N \ldots I_M < 1.0 \times I_N$
Overloading	$I_M > 1.0 \times I_N \ldots I_M < 1.3 \times I_N$
High overload	$I_M > 1.3 \times I_N$
Inaccuracy	
Current detection	±3 % of the set pick-up value > 0.5 × I_N setting. 5 mA < 0.5 × I_N setting
Detection time	±0.5 % or ±10 ms

9.2.1.19. Transformer differential protection (Idb>/Idi>/I0dHV>/I0dLV>; 87T/87R)

Table. 9.2.1.19. - 290. Technical data for the transformer differential protection function.

Input signals	
Current input magnitudes	The phase currents of the high-voltage and the low-voltage sides. Fundamental residual current measurement for HV/LV REF protection. Phase currents 2nd and 5th harmonic measurement.
Characteristics (differential and REF)	
Differential calculation mode Bias calculation mode	Add or subtract (CT direction) Average or maximum (sensitivity)
Idb> pick-up Turnpoint 1 Slope 1 Turnpoint 2 Slope 2	0.01…100.00 %, step 0.01 %, default 10.00 % 0.01…50.00 × I_N, step 0.01× I_N, default 1.00 × I_N 0.01…250.00 %, step 0.01 %, default 10.00 % 0.01…50.00 × I_N, step 0.01 × I_N, default 3.00 × I_N 0.01…250.00 % by step 0.01 %, default 200.00 %
Idi> pick-up	200.00...1500.00 %, step 0.01 %, default 600.00 %
Internal harmonic blocking selection	None, 2nd harmonic, 5th harmonic, both 2nd and 5th harmonic.
2nd harmonic blocking pick-up	0.01…50.00 %, step 0.01 %, default 15.00 %
5th harmonic blocking pick-up	0.01…50.00 %, step 0.01 %, default 35.00 %

Inaccuracy: - Differential current - 2^{nd} harmonic	$\pm$2.5 %I_{SET} or $\pm$50 mA (0.10…4.0 × ISET) $\pm$1.5 %I_{SIDE1}
Instant operation time	
Instant operation time >1.05 × I_{SET}	<40 ms (Harmonic blocking active)
Instant operation time >3.00 × I_{SET}	<30 ms (Harmonic blocking active)
Instant operation time >3.00 × I_{SET}	~15 ms (No harmonic blocking)
Reset	
Reset ratio: differential current	97 % of the differential current setting (typically)
Reset time	<45 ms

Note!

- The harmonic current is set and calculated according to the highest amplitude of side 1, 2 or 3 currents (Ih%/$I_{SIDE1/2/3}$). The harmonic current is calculated individually for each phase.
- The restricted earth fault stage must be used with at least a 20 ms delay blocking to avoid false operation.

9.2.1.20. Arc fault protection (IArc>/I0Arc>; 50Arc/50NArc) (optional)

Table. 9.2.1.20. - 291. Technical data for the arc fault protection function.

Input signals	
Current input magnitudes	Sample-based phase current measurement Sample-based residual current measurement
Arc point sensor inputs	Channels S1, S2, S3, S4 (pressure and light sensor, or light only sensor) Up to four (4) sensors per channel
System frequency operating range	6.00…75.00 Hz
Pick-up	
Pick-up current setting (phase current) Pick-up current setting (residual current) Pick-up light intensity	0.50…40.00 × I_N, setting step 0.01 × I_N 0.10…40.00 × I_N, setting step 0.01 × I_N 8, 25 or 50 kLx (the sensor is selected in the order code)
Starting inaccuracy (IArc> and I0Arc>)	$\pm$3 % of the set pick-up value > 0.5 × I_N setting. 5 mA < 0.5 × I_N setting.
Point sensor detection radius	180 degrees
Operation time	
Light only: - Semiconductor outputs HSO1 and HSO2 - Regular relay outputs	Typically 7 ms (3…12 ms) Typically 10 ms (6.5…15 ms)
Light + current criteria (zone 1…4): - Semiconductor outputs HSO1 and HSO2 - Regular relay outputs	Typically 10 ms (6.5…14 ms) Typically 14 ms (10…18 ms)
Arc BI only: - Semiconductor outputs HSO1 and HSO2 - Regular relay outputs	Typically 7 ms (2…12 ms) Typically 10 ms (6.5…15 ms)
Reset	
Reset ratio for current	97 % of the pick-up setting
Reset time	<35 ms

Note!

- The maximum length of the arc sensor cable is 200 meters.

9.2.2. Control functions

9.2.2.1. Automatic voltage regulator (90)

Table. 9.2.2.1. - 292. Technical data for the automatic voltage regulator function.

Input signals	
Voltage input magnitudes	U12, U23, U31 or U4 channel
Current input magnitudes	IL1, IL2, IL3 (I> blocking)
Pick-up	
Pick-up area (U>/<, U>>/<<, U>>>/<<<) Tap step effect (1…70 steps) I> blocking	0.10…30.00 %U_N, setting step 0.01 %U_N 0.01…10.00 %U_N, setting step 0.01 %U_N 0.00…40.00 × I_N, setting step 0.01 × I_N
Inaccuracy: - Voltage - Current	±1.5 %U_{SET} ±0.5 %I_{SET} or ±15 mA (0.10…4.0 × I_{SET})
Operating time	
Control pulse min/max and time between Definite time function operating time setting	0.00…1800.00 s, setting step 0.005 s 0.00…1800.00 s, setting step 0.005 s
Inaccuracy: - Definite time (U_M/U_{SET} ratio 1.05→)	±1.5 % or ±50 ms
Integrated operating time setting: - Multiplier (k)	0.000…1800.00, setting step 0.005
Inaccuracy: - IDMT operating time - IDMT minimum operating time	±1.5 % or ±35 ms ±20 ms
Instant operation time	
Start time and instant operation time (trip): - U_M/U_{SET} ratio 1.05→	<50 ms
Reset	
Reset ratio: - Voltage - Current	95/105 % of the pick-up voltage setting 97 % of the pick-up current setting
Reset time setting Inaccuracy: Reset time	0.010…10.000 s, step 0.005 s ±1.0 % or ±35 ms
Instant reset time and start-up reset	<50 ms

9.2.2.2. Setting group selection

Table. 9.2.2.2. - 293. Technical data for the setting group selection function.

Settings and control modes	
Setting groups	8 independent, control-prioritized setting groups
Control scale	Common for all installed functions which support setting groups
Control mode	
Local	Any digital signal available in the device
Remote	Force change overrule of local controls either from the setting tool, HMI or SCADA

Operation time	
Reaction time	<5 ms from receiving the control signal

9.2.2.3. Object control and monitoring

Table. 9.2.2.3. - 294. Technical data for the object control and monitoring function.

Signals	
Input signals	Digital inputs Software signals
Output signals	Close command output Open command output
Operation time	
Breaker traverse time setting	0.02…500.00 s, setting step 0.02 s
Max. close/open command pulse length	0.02…500.00 s, setting step 0.02 s
Control termination time out setting	0.02…500.00 s, setting step 0.02 s
Inaccuracy: - Definite time operating time	±0.5 % or ±10 ms
Breaker control operation time	
External object control time	<75 ms
Object control during auto-reclosing	See the technical sheet for the auto-reclosing function.

9.2.2.4. Synchrocheck (ΔV/Δa/Δf; 25)

Table. 9.2.2.4. - 295. Technical data for the synchrocheck function.

Input signals	
Voltage input magnitudes	P-P voltage fundamental frequency RMS P-E voltage fundamental frequency RMS
Pick-up	
U diff < setting	2.00…50.00 $\%U_N$, setting step 0.01 $\%U_N$
Angle diff < setting	3.0…90.0 deg, setting step 0.10 deg
Freq diff < setting	0.05…0.50 Hz, setting step 0.01 Hz
Inaccuracy: - Voltage - Frequency - Angle	±3.0 $\%U_{SET}$ or ±0.3 $\%U_N$ ±25 mHz (U> 30 V secondary) ±1.5° (U> 30 V secondary)
Reset	
Reset ratio: - Voltage - Frequency - Angle	99 % of the pick-up voltage setting 20 mHz ±2.0°
Activation time	
Activation (to LD/DL/DD) Activation (to Live Live)	<35 ms <60 ms
Reset	<40 ms
Bypass modes	
Voltage check mode (excluding LL)	LL+LD, LL+DL, LL+DD, LL+LD+DL, LL+LD+DD, LL+DL+DD, bypass
U live > limit U dead < limit	0.10…100.00 $\%U_N$, setting step 0.01 $\%U_N$ 0.00…100.00 $\%U_N$, setting step 0.01 $\%U_N$

Note!

- Voltage is scaled to the primary amplitude; therefore, the different sized PT secondaries are possible.
- The minimum voltage for direction and frequency solving is 20.0 %U_N.
- U< dead limit is not in use when set to 0 %U_N.
- When SYN3 is used, SYN1 and SYN2 must have the same reference voltage.
- In 3LN mode the synchronization to the L-N and L-L voltages is possible. In 3LL/2LL modes the synchronization is only supported to the L-L voltage.

9.2.3. Monitoring functions

9.2.3.1. Current transformer supervision

Table. 9.2.3.1. - 296. Technical data for the current transformer supervision function.

Input signals	
Current input magnitudes	Phase current fundamental frequency RMS Residual current fundamental frequency RMS (optional)
Pick-up	
Pick-up current settings: - I_{SET} high limit - I_{SET} low limit - I_{SUM} difference - I_{SET} ratio - I2/I1 ratio	0.10…40.00 × I_N, setting step 0.01 × I_N 0.10…40.00 × I_N, setting step 0.01 × I_N 0.10…40.00 × I_N, setting step 0.01 × I_N 0.01…100.00 %, setting step 0.01 % 0.01…100.00 %, setting step 0.01 %
Inaccuracy: - Starting IL1, IL2, IL3 - Starting I2/I1 - Starting I01 (1 A) - Starting I02 (0.2 A)	±0.5 %I_{SET} or ±15 mA (0.10…4.0 × I_{SET}) ±1.0 %$I2_{SET}$ / $I1_{SET}$ or ±100 mA (0.10…4.0 × I_N) ±0.5 %$I0_{SET}$ or ±3 mA (0.005…10.0 × I_{SET}) ±1.5 %$I0_{SET}$ or ±1.0 mA (0.005…25.0 × I_{SET})
Time delay for alarm	
Definite time function operating time setting	0.00…1800.00 s, setting step 0.005 s
Inaccuracy_ - Definite time (I_M/I_{SET} ratio > 1.05)	±2.0 % or ±80 ms
Instant operation time (alarm): - I_M/I_{SET} ratio > 1.05	<80 ms (<50 ms in differential protection relays)
Reset	
Reset ratio	97/103 % of the pick-up current setting
Instant reset time and start-up reset	<80 ms (<50 ms in differential protection relays)

9.2.3.2. Voltage transformer supervision (60)

Table. 9.2.3.2. - 297. Technical data for the voltage transformer supervision function.

Input signals	
Voltage input magnitudes	P-P voltage fundamental frequency RMS P-E voltage fundamental frequency RMS
Pickup	
Pickup settings: - Voltage (low pick-up) - Voltage (high pick-up) - Angle shift limit	0.05…0.50 × U_N, setting step 0.01 × U_N 0.50…1.10 × U_N, setting step 0.01 × U_N 2.00…90.00 deg, setting step 0.10 deg

Inaccuracy: - Voltage - U angle (U> 1 V)	±1.5 %U_{SET} ±1.5°
External line/bus side pick-up (optional)	0 → 1
Time delay for alarm	
Definite time function operating time setting	0.00…1800.00 s, setting step 0.005 s
Inaccuracy: - Definite time (U_M/U_{SET} ratio > 1.05/0.95)	±1.0 % or ±35 ms
Instant operation time (alarm): - U_M/U_{SET} ratio > 1.05/0.95	<80 ms
VTS MCB trip bus/line (external input)	<50 ms
Reset	
Reset ratio	97/103 % of the pick-up voltage setting
Reset time setting Inaccuracy: Reset time	0.010…10.000 s, step 0.005 s ±2.0 % or ±80 ms
Instant reset time and start-up reset	<50 ms
VTS MCB trip bus/line (external input)	<50 ms

Note!

- When turning on the auxiliary power of an IED, the normal condition of a stage has to be fulfilled before tripping.

9.2.3.3. Disturbance recorder

Table. 9.2.3.3. - 298. Technical data for the disturbance recorder function.

Recorded values	
Recorder analogue channels	0…20 channels Freely selectable
Recorder digital channels	0…95 channels Freely selectable analogue and binary signals 5 ms sample rate (FFT)
Performance	
Sample rate	8, 16, 32 or 64 samples/cycle
Recording length	0.000…1800.000 s, setting step 0.001 s The maximum length is determined by the chosen signals.
Number of recordings	0…100, 60 MB of shared flash memory reserved The maximum number of recordings according to the chosen signals and operation time setting combined

9.2.3.4. Circuit breaker wear monitor

Table. 9.2.3.4. - 299. Technical data for the circuit breaker wear monitor function.

Pick-up	
Breaker characteristics settings: - Nominal breaking current - Maximum breaking current - Operations with nominal current - Operations with maximum breaking current	0.00…100.00 kA, setting step 0.001 kA 0.00…100.00 kA, setting step 0.001 kA 0…200 000 operations, setting step 1 operation 0…200 000 operations, setting step 1 operation
Pick-up setting for Alarm 1 and Alarm 2	0…200 000 operations, setting step 1 operation
Inaccuracy	

Inaccuracy for current/operations counter: - Current measurement element - Operation counter	$0.1\times I_N > I < 2 \times I_N$ ±0.2 % of the measured current, rest 0.5 % ±0.5 % of operations deducted

9.2.3.5. Total harmonic distortion (THD)

Table. 9.2.3.5. - 300. Technical data for the total harmonic distortion function.

Input signals	
Current input magnitudes	Current measurement channels (FFT result) up to the 31st harmonic component.
Pick-up	
Operating modes	Power THD Amplitude THD
Pick-up setting for all comparators	0.10…200.00 % , setting step 0.01 %
Inaccuracy	±3 % of the set pick-up value > $0.5 \times I_N$ setting; 5 mA < $0.5 \times I_N$ setting.
Time delay	
Definite time function operating time setting for all timers	0.00…1800.00 s, setting step 0.005 s
Inaccuracy: - Definite time operating time - Instant operating time, when I_M/I_{SET} ratio > 3 - Instant operating time, when I_M/I_{SET} ratio 1.05 < I_M/I_{SET} < 3	±0.5 % or ±10 ms Typically <20ms Typically <25 ms
Reset	
Reset time	Typically <10 ms
Reset ratio	97 %

9.2.3.6. Voltage memory

Table. 9.2.3.6. - 301. Technical data for the voltage memory function.

Input signals	
Input magnitudes	P-P voltage fundamental frequency RMS P-E voltage fundamental frequency RMS Phase current fundamental frequency RMS (back-up frequency)
Pick-up	
Pick-up voltage setting Pick-up current setting (optional)	2.00…50.00 $\%U_N$, setting step 0.01 x $\%U_N$ 0.01…50.00 × I_N, setting step 0.01 × I_N
Inaccuracy: - Voltage - Current	±1.5 $\%U_{SET}$ or ±30 mV ±0.5 $\%I_{SET}$ or ±15 mA (0.10…4.0 × I_{SET})
Operation time	
Angle memory activation delay	<20 ms (typically 5 ms)
Maximum active time	0.020…50.000 s, setting step 0.005 s
Inaccuracy: - Definite time (U_M/U_{SET} ratio >1.05)	±1.0 % or ±35 ms
Angle memory	
Angle drift while voltage is absent	±1.0° per 1 second

Reset	
Reset ratio: - Voltage memory (voltage) - Voltage memory (current)	103 % of the pick-up voltage setting 97 % of the pick-up current setting
Reset time	<50 ms

Note!

- This function is integrated into the directional overcurrent (ANSI: 67) and x (ANSI: 21G) functions.

9.3. Tests and environmental

Electrical environment compatibility

Table. 9.3. - 302. Disturbance tests.

All tests	CE-approved and tested according to EN 60255-26
Emissions	
Conducted emissions: EN 60255-26 Ch. 5.2, CISPR 22	150 kHz…30 MHz
Radiated emissions: EN 60255-26 Ch. 5.1, CISPR 11	30…1 000 MHz
Immunity	
Electrostatic discharge (ESD): EN 60255-26, IEC 61000-4-2	Air discharge 15 kV Contact discharge 8 kV
Electrical fast transients (EFT): EN 60255-26, IEC 61000-4-4	Power supply input 4 kV, 5/50 ns, 5 kHz Other inputs and outputs 4 kV, 5/50 ns, 5 kHz
Surge: EN 60255-26, IEC 61000-4-5	Between wires: 2 kV, 1.2/50 μs Between wire and earth: 4 kV, 1.2/50 μs
Radiated RF electromagnetic field: EN 60255-26, IEC 61000-4-3	f = 80…1 000 MHz, 10 V/m
Conducted RF field: EN 60255-26, IEC 61000-4-6	f = 150 kHz…80 MHz, 10 V (RMS)

Table. 9.3. - 303. Voltage tests.

Dielectric voltage test	
EN 60255-27, IEC 60255-5, EN 60255-1	2 kV, 50 Hz, 1 min
Impulse voltage test	
EN 60255-27, IEC 60255-5	5 kV, 1.2/50 μs, 0.5 J

Physical environment compatibility

Table. 9.3. - 304. Mechanical tests.

Vibration test

EN 60255-1, EN 60255-27, IEC 60255-21-1	2…13.2 Hz, ± 3.5 mm 13.2…100 Hz, ± 1.0 g
Shock and bump test	
EN 60255-1, EN 60255-27, IEC 60255-21-2	20 g, 1 000 bumps/dir.

Table. 9.3. - 305. Environmental tests.

Damp heat (cyclic)	
EN 60255-1, IEC 60068-2-30	Operational: +25…+55 °C, 93…97 % (RH), 12+12h
Dry heat	
EN 60255-1, IEC 60068-2-2	Storage: +70 °C, 16 h Operational: +55 °C, 16 h
Cold test	
EN 60255-1, IEC 60068-2-1	Storage: –40 °C, 16 h Operational: –20 °C, 16 h

Table. 9.3. - 306. Environmental conditions.

IP classes	
Casing protection class	IP54 (front) IP21 (rear)
Temperature ranges	
Ambient service temperature range	–35…+70 °C
Transport and storage temperature range	–40…+70 °C
Other	
Altitude	<2000 m
Overvoltage category	III
Pollution degree	2

Casing and package

Table. 9.3. - 307. Dimensions and weight.

Without packaging (net)	
Dimensions	Height: 208 mm Width: 257 mm (½ rack) Depth: 165 mm (no cards or connectors)
Weight	1.5 kg
With packaging (gross)	
Dimensions	Height: 250 mm Width: 343 mm Depth: 256 mm
Weight	2.0 kg

10. Ordering information

AQ - T 2 5 7 X - P X X X A X A - X X X X X X X X X

Model
- T Transformer protection

Device size
- 5 1/2 of 19" rack

Analog measurement
- 7 10 Current and 4 voltage measurement channels

Function package
- A Standard
- B Standard + Automatic Voltage Regulator function

Mounting
- P Panel mounted

Auxiliary voltage
- H 80...265 VAC/DC
- L 18...72 VDC

Measurement accuracy
- 0 Power/Energy measurement accuracy class 0.5
- 2 Power/Energy measurement accuracy class 0.2S

Terminals
- A Standard
- B Ring lug terminals

Reserved for future use
- A N/A

Binary inputs on power supply module
- A 3 Binary inputs, 24 V nominal threshold
- B 3 Binary inputs, 110 V nominal threshold
- C 3 Binary inputs, 220 V nominal threshold

Reserved for future use
- A N/A

Slots F, G, H, I, J, K, L, M, N (9 pcs)
- A Empty
- B 8 Binary inputs
- C 5 Output relays ****
- D Arc protection with 4 sensor channels, 2 x HSO, 1 x BI
- F 2 x mA input - 8 x RTD input **
- G 2 x RJ-45 100Mb Ethernet & IRIG-B */***
- H 2 x ST 100Mb Ethernet & IRIG-B */***
- I 4 x mA outputs - 1 x mA input **
- J Double LC 100Mb Ethernet (HSR, PRP redundant protocols) */***
- L RS-232 - Serial fiber (Plastic-Plastic) */***
- M RS-232 - Serial fiber (Plastic-Glass) */***
- N RS-232 - Serial fiber (Glass-Plastic) */***
- O RS-232 - Serial fiber (Glass-Glass) */***

* One card at most per IED
** Two cards at most per IED
*** Can only be applied to the last slot
**** Five cards at most per IED

Accessories

Order code	Description	Note	Manufacturer
AQ-ACC-ADAM4016	ADAM-4016 RTD 6 ch RTD module with Modbus	Requires external	Advanced Co. Ltd.
	(Pt100/1000, Balco500, Ni)	power module	
AQ-01A	Light point sensor unit (8000 Lux threshold)	Max. cable length 200m	Arcteq Ltd.
AQ-01B	Light point sensor unit (25000 Lux threshold)	Max. cable length 200m	Arcteq Ltd.
AQ-01C	Light point sensor unit (50000 Lux threshold)	Max. cable length 200m	Arcteq Ltd.
AQ-02A	Pressure and light point sensor unit	Max. cable length 200m	Arcteq Ltd.

	(8000 Lux threshold)		
AQ-02B	Pressure and light point sensor unit	Max. cable length 200m	Arcteq Ltd.
	(25000 Lux threshold)		
AQ-02C	Pressure and light point sensor unit	Max. cable length 200m	Arcteq Ltd.
	(50000 Lux threshold)		

11. Contact and reference information

Manufacturer

Arcteq Relays Ltd.

Visiting and postal address

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65200 Vaasa, Finland

Contacts

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Fax:	+358 10 3221 389
URL:	url: www.arcteq.fi
email sales:	sales@arcteq.fi
Technical support site:	https://arcteq.fi/support-landing/
Technical support:	+358 10 3221 388 (EET 8:00 – 16:00)