ARCTEQ®
PART OF ENSTO GROUP

AQ-T257

Transformer protection device

Instruction manual

Table of contents

1 Document information 6
1.1 Version 2 revision notes 6
1.2 Version 1 revision notes 9
1.3 Safety information 10
1.4 Abbreviations 11
2 General 13
3 Device user interface 14
3.1 Panel structure 14
3.1.1 Local panel structure 14
3.2 Configuring user levels and their passwords 15
4 Functions 17
4.1 Functions included in AQ-T257 17
4.2 Measurements 19
4.2.1 Current measurement and scaling in differential applications 19
4.2.2 Voltage measurement and scaling 32
4.2.3 Power and energy calculation 47
4.2.4 Frequency tracking and scaling 55
4.3 General menu 59
4.4 Protection functions 61
4.4.1 General properties of a protection function 61
4.4.2 Non-directional overcurrent protection (I>; 50/51) 71
4.4.3 Non-directional earth fault protection (I0>; 50N/51N) 76
4.4.4 Directional overcurrent protection (Idir>; 67) 81
4.4.5 Directional earth fault protection (I0dir>; 67N/32N) 87
4.4.6 Negative sequence overcurrent/ phase current reversal/ current unbalance protection (I2>; 46/46R/46L) 99
4.4.7 Harmonic overcurrent protection (Ih>; 50H/51H/68H) 104
4.4.8 Circuit breaker failure protection (CBFP; 50BF/52BF) 111
4.4.9 Overvoltage protection (U>; 59) 126
4.4.10 Undervoltage protection (U<; 27) 133
4.4.11 Neutral overvoltage protection (U0>; 59N) 141
4.4.12 Sequence voltage protection (U1/U2>/<; 47/27P/59PN) 147
4.4.13 Overfrequency and underfrequency protection (f>/<; 81O/81U) 155
4.4.14 Rate-of-change of frequency (df/dt>/<; 81R) 160
4.4.15 Power protection (P, Q, S>/<; 32) 164
4.4.16 Underexcitation protection (X<; 40) 169
4.4.17 Volts-per-hertz overexcitation protection (V/Hz>; 24) 173
4.4.18 Underimpedance protection (Z<; 21U) 179
4.4.19 Pole slip protection (78) 183
4.4.20 Transformer status monitoring 187
4.4.21 Transformer thermal overload protection (TT>; 49T) 196
4.4.22 Generator/transformer differential protection (Idb>/Idi>/I0dHV>/I0dLV>; 87T/87N/87G) 207
4.4.23 Resistance temperature detectors (RTD) 249
4.4.24 Programmable stage (PSx>/<; 99) 252
4.4.25 Arc fault protection (IArc>/I0Arc>; 50Arc/50NArc) 262
4.5 Control functions 271
4.5.1 Common signals 271
4.5.2 Automatic voltage regulator (90) 272
4.5.3 Parallel voltage regulator 301
4.5.4 Setting group selection 310
4.5.5 Object control and monitoring 317

4.5.6 Indicator object monitoring ... 328
4.5.7 Cold load pick-up (CLPU) ... 329
4.5.8 Switch-on-to-fault (SOTF) ... 338
4.5.9 Synchrocheck (ΔV/Δa/Δf; 25) ... 341
4.5.10 Milliampere output control ... 354
4.5.11 Vector jump (Δφ; 78) ... 357
4.5.12 Programmable control switch ... 362
4.5.13 User buttons ... 363
4.5.14 Analog input scaling curves ... 364
4.5.15 Logical outputs ... 366
4.5.16 Logical inputs ... 368
4.6 Monitoring functions ... 370
4.6.1 Current transformer supervision ... 370
4.6.2 Voltage transformer supervision (60) ... 380
4.6.3 Current total harmonic distortion (THD) ... 385
4.6.4 Voltage total harmonic distortion (THD) ... 390
4.6.5 Fault locator (21FL) ... 394
4.6.6 Disturbance recorder (DR) ... 396
4.6.7 Event logger ... 407
4.6.8 Measurement recorder ... 408
4.6.9 Measurement value recorder ... 413
5 Communication ... 418
5.1 Connections menu ... 418
5.2 Time synchronization ... 420
5.2.1 Internal ... 421
5.2.2 NTP ... 421
5.2.3 PTP ... 421
5.3 Communication protocols ... 423
5.3.1 IEC 61850 ... 423
5.3.1.1 Logical device mode and logical node mode ... 425
5.3.1.2 GOOSE ... 429
5.3.2 Modbus/TCP and Modbus/RTU ... 433
5.3.3 IEC 103 ... 434
5.3.4 IEC 101/104 ... 435
5.3.5 SPA ... 437
5.3.6 DNP3 ... 438
5.3.7 Modbus I/O ... 440
5.4 Analog fault registers ... 441
5.5 Modbus Gateway ... 442
6 Connections and application examples ... 447
6.1 Connections of AQ-T257 ... 447
6.2 Application example and its connections ... 448
6.3 Trip circuit supervision (95) ... 448
7 Construction and installation ... 453
7.1 Construction ... 453
7.2 CPU module ... 456
7.3 Current measurement module ... 459
7.4 Voltage measurement module ... 460
7.5 Option cards ... 461
7.5.1 Digital input module (optional) ... 461
7.5.2 Digital output module (optional) ... 464
7.5.3 Point sensor arc protection module (optional) ... 465
7.5.4 RTD input module (optional) ... 467
7.5.5 Serial RS-232 communication module (optional) ... 468
7.5.6 LC or RJ45 100 Mbps Ethernet communication module (optional) ... 470
7.5.7 Double ST 100 Mbps Ethernet communication module (optional) ... 471

7.5.8 Double RJ45 10/100 Mbps Ethernet communication module (optional) 472
7.5.9 Milliampere output (mA) I/O module (optional) 473
7.6 Dimensions and installation 474

8 Technical data 477

8.1 Hardware 477
8.1.1 Measurements 477
8.1.1.1 Current measurement 477
8.1.1.2 Voltage measurement 479
8.1.1.3 Voltage memory 479
8.1.1.4 Power and energy measurement 480
8.1.1.5 Frequency measurement 481
8.1.2 CPU & Power supply 481
8.1.2.1 Auxiliary voltage 481
8.1.2.2 CPU communication ports 482
8.1.2.3 CPU digital inputs 483
8.1.2.4 CPU digital outputs 483
8.1.3 Option cards 484
8.1.3.1 Digital input module 484
8.1.3.2 Digital output module 485
8.1.3.3 Point sensor arc protection module 486
8.1.3.4 Milliampere output module (mA out & mA in) 487
8.1.3.5 RTD input module 488
8.1.3.6 RS-232 & serial fiber communication module 488
8.1.3.7 Double LC 100 Mbps Ethernet communication module 489
8.1.3.8 Double ST 100 Mbps Ethernet communication module 489
8.1.4 Display 490
8.2 Functions 491
8.2.1 Protection functions 491
8.2.1.1 Non-directional overcurrent protection (I>; 50/51) 491
8.2.1.2 Non-directional earth fault protection (I0>; 50N/51N) 492
8.2.1.3 Directional overcurrent protection (Idir>; 67) 493
8.2.1.4 Directional earth fault protection (I0dir>; 67N/32N) 494
8.2.1.5 Negative sequence overcurrent/ phase current reversal/ current unbalance protection (I2>; 46/46R/46L) 495
8.2.1.6 Harmonic overcurrent protection (Ih>; 50H/51H/68H) 496
8.2.1.7 Circuit breaker failure protection (CBFP; 50BF/52BF) 498
8.2.1.8 Overvoltage protection (U>; 59) 498
8.2.1.9 Undervoltage protection (U<; 27) 499
8.2.1.10 Neutral overvoltage protection (U0>; 59N) 500
8.2.1.11 Sequence voltage protection (U1/U2>/<; 47/27P/59NP) 501
8.2.1.12 Overfrequency and underfrequency protection (f>/<; 81O/81U) 502
8.2.1.13 Rate-of-change of frequency protection (df/dt>/<; 81R) 503
8.2.1.14 Transformer thermal overload protection (TT>; 49T) 504
8.2.1.15 Power protection (P, Q, S>/<; 32) 505
8.2.1.16 Underimpedance protection (Z<; 21U) 505
8.2.1.17 Volts-per-hertz overexcitation protection (V/Hz>; 24) 506
8.2.1.18 Transformer status monitoring 507
8.2.1.19 Resistance temperature detectors (RTD) 507
8.2.1.20 Generator/transformer differential protection (Idb>/Idi>/I0dHV>/I0dLV>; 87T/87N/87G) 508
8.2.1.21 Arc fault protection (IArc>/I0Arc>; 50Arc/50NArc) (optional) 509
8.2.2 Control functions 510
8.2.2.1 Automatic voltage regulator (90) 510
8.2.2.2 Setting group selection 511
8.2.2.3 Object control and monitoring 511
8.2.2.4 Indicator object monitoring 512
8.2.2.5 Cold load pick-up (CLPU) 512
8.2.2.6 Switch-on-to-fault (SOTF) 513

8.2.2.7 Vector jump (Δφ; 78) 514
8.2.2.8 Synchrocheck (ΔV/Δa/Δf; 25) 514
8.2.3 Monitoring functions 515
8.2.3.1 Current transformer supervision 515
8.2.3.2 Voltage transformer supervision (60) 516
8.2.3.3 Current total harmonic distortion 517
8.2.3.4 Fault locator (21FL) 518
8.2.3.5 Disturbance recorder 518
8.2.3.6 Event logger 519
8.3 Tests and environmental 519
9 Ordering information 522
10 Contact and reference information 524

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.

Nothing contained in this document shall increase the liability or extend the warranty obligations of the manufacturer Arcteq Relays Ltd. The manufacturer expressly disclaims any and all liability for any damages and/or losses caused due to a failure to comply with the instructions contained herein or caused by persons who do not fulfil the aforementioned requirements. Furthermore, the manufacturer shall not be liable for possible errors in this document.

Please note that you must always comply with applicable local legislation and regulations. The manufacturer gives no warranties that the content of this document is in all respects in line with local laws and regulations and assumes no liability for such possible deviations.

You are advised to notify the manufacturer in case you become aware of any errors in this document or of defects in the equipment.

The manufacturer reserves the right to update or amend this document at any time.

Copyright

1 Document information

1.1 Version 2 revision notes

Table. 1.1 - 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 manual. - Every protection relay 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
Revision	2.02
Date	7.7.2020
Changes	- A number of image descriptions improved.
Revision	2.03
Date	27.8.2020

Changes	- Terminology consistency improved (e.g. binary inputs are now always called digital inputs). - Tech data modified to be more informative about what type of measurement inputs are used (phase currents/voltages, residual currents/voltages), what component of that measurement is available (RMS, TRMS, peak-to-peak) and possible calculated measurement values (powers, impedances, angles etc.). - Tech data updated: non-directional overcurrent - Tech data updated: non-directional earthfault - Tech data updated: directional earthfault - Tech data updated: current unbalance - Tech data updated: transformer differential - Tech data updated: overfrequency, underfrequency and rate-of-change-of-frequency. - Improvements to many drawings and formula images. - AQ-T257 Functions included list Added: Volts-per-Hertz, voltage memory, indicator objects, switch-on-to-fault, vector jump protection and fault locator. - Added "32N" ANSI code to directional earth fault protection modes "unearthed" and "petersen coil grounded". - Added 6th harmonic to harmonic overcurrent protection function. - Fixed reset ratio of under- and overfrequency protection function from 103 % / 97 % to +/- 20 mHz.. - Fixed reset ratio of rate-of-change-of-frequency protection function from 20 mHz/s to 100 mHz/s. - Added BCD and binary input coding description to automatic voltage regulator description. - Changed disturbance recorder maximum digital channel amount from 32 to 95. - Added residual current coarse and fine measurement data to disturbance recorder description. - Event read mode parameter added to Modbus description. - HSO1 and HSO2 connection swapped in arc protection card (was way wrong before). - Updated I01 and I02 rated current range. - Added inches to Dimensions and installation chapter. - Added raising frames, wall mounting bracket, combiflex frame to order code. - Added logical input and logical output function descriptions. - Additions to Abbreviations chapter. - Added button test description to Local panel structure chapter. - Added note to Configuring user levels and passwords chapter that AQ-250 frame units generate a time-stamped event from locking and unlocking user levels. - Added note to Configuring user levels and passwords chapter that user level with a password automatically locks itself after 30 minutes of inactivity. - Added more "Tripped stage" indications and fault types to Measurement value recorder function. - Updated: Digital input activation and release threshold setting ranges and added drop-off delay setting. - Added sample rate to voltage and current measurement tech data. - Fixed overvoltage, undervoltage, neutral overvoltage and sequence voltage stage misspelled IDMT curve formula. - Note added to power protection tech data.
Revision	2.04
Date	8.6.2021
Changes	- Increased the consistency in terminology - Various image upgrades - Visual update to the order codes
Revision	2.05
Date	22.6.2021

Changes	- Fixed phase current measurement continuous thermal withstand from 30A to 20A. - Fixed lots of timing errors written to registers table. "Prefault" is -200 ms from Start event, "Pretrigger" is -20 ms from trip (or start if fault doensn't progress to trip), "Fault" is start (or trip if fault doesn't progress to trip). - Added event history technical data
Revision	2.06
Date	21.6.2022
Changes	- Improved descriptions generally in many chapters. - Improved readability of a lot of drawings and images. - Order codes have been revised. - Added pole slip function description. - Added LN mode parameters to all functions (On, Blocked, Test, Test/Blocked, Off). - Added color themes parameter description. - Improved color sleep mode description. - Improved alarm function color behavior description and images. - Added operation time with different measurement values vs setting ratio in instant operation mode to non-directional overcurrent function description. - Fixed bias calculation formula for restricted earth fault function. Was correctly in the code, just written wrong in the manual. - Added power measurement side selection to power functions. - Added synchrocheck start check parameter description. - Added 30 s pretriggering time for disturbance recorder (AQ-250 devices only). - Added new trip detections and fault types to measurement value recorder. - Added user description parameter descriptions for digital inputs, digital outputs, logical inputs, logical outputs and GOOSE inputs. - Arc point sensor HSO1 and HSO2 position fixed. - Added spare part codes and compatibilities to option cards.
Revision	2.07
Date	7.7.2022
Changes	- Added THD voltage measurements. - Fixed number of logical inputs. - Added common signals function description. - Added PTP time synchronization description. - Added Modbus Gateway description.
Revision	2.08
Date	8.9.2022
Changes	- Added stage forcing parameter to function descriptions. - Fixes to "Real time signals to comm" description. - Added "Ethernet port" parameter description to IEC61850, IEC104 and Modbus TCP descriptions. - Removed "Measurement update interval" settings from Modbus description. No longer in use. - Renamed "System integration" chapter to "Communication" and restructured the chapters to be closer to how they are in the menus. - Added "Event logger" chapter. - Added more descriptions to new IEC 61850 ed2 GOOSE parameters. - Added "Condition monitoring / CB wear" description to object description. - Added "User button" description. - Added logical device and logical node mode descriptions.

Revision	2.09
Date	14.3.2023
Changes	- Updated the Arcteq logo on the cover page and refined the manual's visual look. - Added the "Safety information" chapter and changed the notes throughout the document accordingly. - Changed the "IED user interface" chapter's title to "Device user interface" and replaced all 'IED' terms with 'device' or 'unit'. - Updated the rated values for the change-over CPU digital outputs in "Technical data". - Updated the input impedance for the voltage measurement module in "Technical data". - Added double ethernet port configuration parameters to "Connections menu" chapter. - Added event overload detection description to "Event logger" chapter.
Revision	2.10
Date	19.6.2023
Changes	- Updated order codes.
Revision	2.11
Date	29.11.2023
Changes	- Added the 5 ms update time in the measurement chapters. - Added spring lock cage options for connectors. See the "Ordering information" chapter. - Added underexcitation protection (X<; 40). - Added underimpedance protection function. - Added cold load pick-up function. - Updated the contact address for technical support in the "Contact and reference information" chapter. - Circuit breaker wear is not integrated to the objects.

1.2 Version 1 revision notes

Table. 1.2 - 2. Version 1 revision notes

Revision	1.00
Date	13.4.2016
Changes	• The first revision for AQ-T256 and T257.
Revision	1.01
Date	10.2.2017
Changes	• Added the programmable stage description. • Order code updated.
Revision	1.02
Date	9.1.2018

Changes	• Measurement value recorder description added. • ZCT connection added to the current measurement description. • Internal harmonics blocking added to the I> and I0> function descriptions. • Non-standard delay curves added. • Event lists revised on several functions. • RTD & mA card description improved. • 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 the mA output option card description and updated the order code. • Added the HMI display technical data.

1.3 Safety information

This document contains important instructions that should be saved for future use. Read the document carefully before installing, operating, servicing, or maintaining this equipment. Please read and follow all the instructions carefully to prevent accidents, injury and damage to property.

Additionally, this document contains four (4) types of special messages to call the reader's attention to useful information as follows:

NOTICE!
"Notice" messages indicate relevant factors and conditions to the the concept discussed in the text, as well as to other relevant advice.

CAUTION!
"Caution" messages indicate a potentially hazardous situation which, if not avoided, could result in minor or moderate personal injury, in equipment/property damage, or software corruption.

WARNING!
"Warning" messages indicate a potentially hazardous situation which, if not avoided, could result in death or serious personal injury as well as serious damage to equipment/property.

DANGER!
"Danger" messages indicate an imminently hazardous situation which, if not avoided, will result in death or serious personal injury.

These symbols are added throughout the document to ensure all users' personal safety and to avoid unintentional damage to the equipment or connected devices.

Please note that although these warnings relate to direct damage to personnel and/or equipment, it should be understood that operating damaged equipment may also lead to further, indirect damage to personnel and/or equipment. Therefore, we expect any user to fully comply with these special messages.

1.4 Abbreviations

AI – Analog input

AR – Auto-recloser

ASDU – Application service data unit

AVR – Automatic voltage regulator

BCD – Binary-coded decimal

CB – Circuit breaker

CBFP – Circuit breaker failure protection

CLPU – Cold load pick-up

CPU – Central processing unit

CT – Current transformer

CTM – Current transformer module

CTS – Current transformer supervision

DG – Distributed generation

DHCP – Dynamic Host Configuration Protocol

DI – Digital input

DO – Digital output

DOL – Direct-on-line

DR – Disturbance recorder

DT – Definite time

FF – Fundamental frequency

FFT – Fast Fourier transform

FTP – File Transfer Protocol

GI – General interrogation

HMI – Human-machine interface

HR – Holding register

HV – High voltage

HW – Hardware

IDMT – Inverse definite minimum time

IGBT – Insulated-gate bipolar transistor

I/O – Input and output

IRIG-B – Inter-range instruction group, timecode B

LCD – Liquid-crystal display

LED – Light emitting diode

LV – Low voltage

NC – Normally closed

NO – Normally open

NTP – Network Time Protocol

RMS – Root mean square

RSTP – Rapid Spanning Tree Protocol

RTD – Resistance temperature detector

RTU – Remote terminal unit

SCADA – Supervisory control and data acquisition

SG – Setting group

SOTF – Switch-on-to-fault

SW – Software

THD – Total harmonic distortion

TRMS – True root mean square

VT – Voltage transformer

VTM – Voltage transformer module

VTS – Voltage transformer supervision

2 General

The AQ-T257 transformer protection device is a member of the AQ 250 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 device. For other AQ 200 and AQ 250 series products please consult their respective device manuals.

AQ-T257 is a transformer protection device with a differential protection function and an integrated automatic voltage regulator function. The AQ-T257 transformer protection device also provides complete current-based and voltage-based protection functions and full measurements. There are up to nine (9) option card slots available for additional I/O or communication cards for more comprehensive monitoring and control applications. AQ-T257 communicates using various protocols including the IEC 61850 substation communication standard.

3 Device user interface

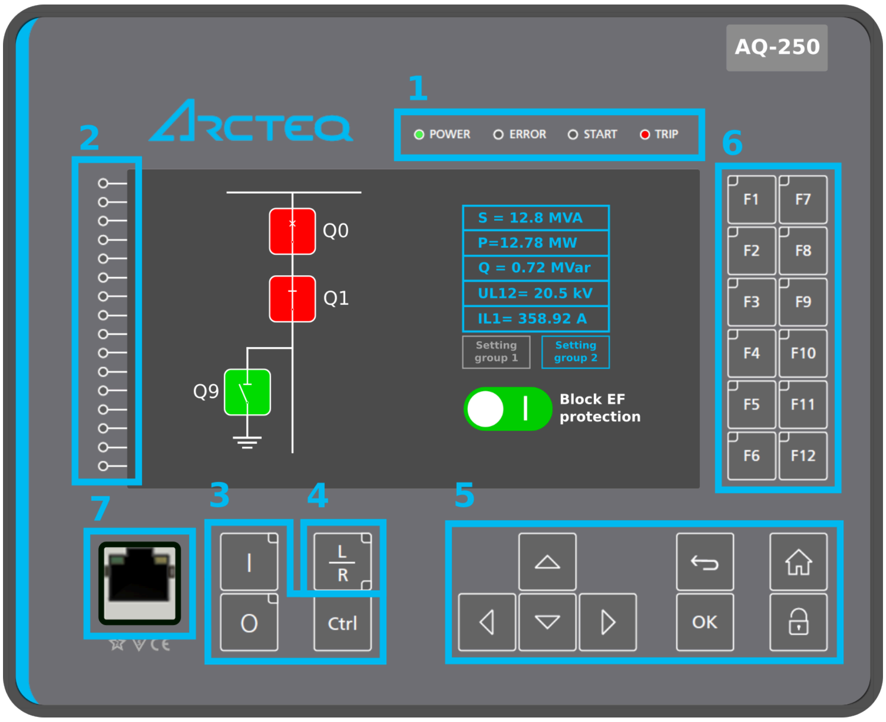
3.1 Panel structure

The user interface section of an AQ 200 or AQ 250 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 200 freeware software suite.

3.1.1 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.

Figure. 3.1.1 - 1. Local panel structure.



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

When the unit is powered on, the green "Power" LED is lit. When the red "Error" LED is lit, the device has an internal (hardware or software) error that affects the operation of the unit. The activation of the yellow "Start" LED and the red "Trip" LED are based on the setting the user has put in place in the software.

The sixteen freely configurable LEDs are located on the left side of the display. Their activation and color (green, orange, red) are based on the settings the user has put in place in the software.

The view in the screen is freely configurable. Virtual switches and buttons can be added which can be used to change the setting groups or control the device's general logic locally or remotely. 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, the device will return back to the default view.

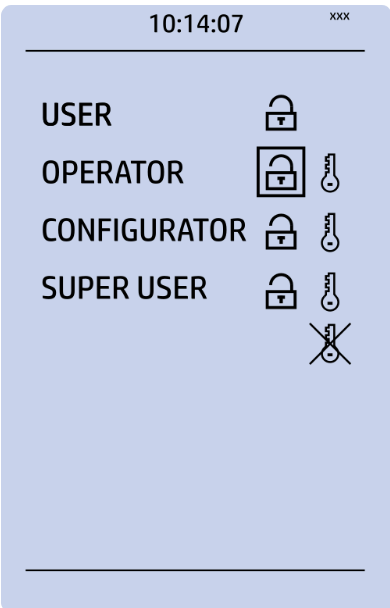
3.2 Configuring user levels and their passwords

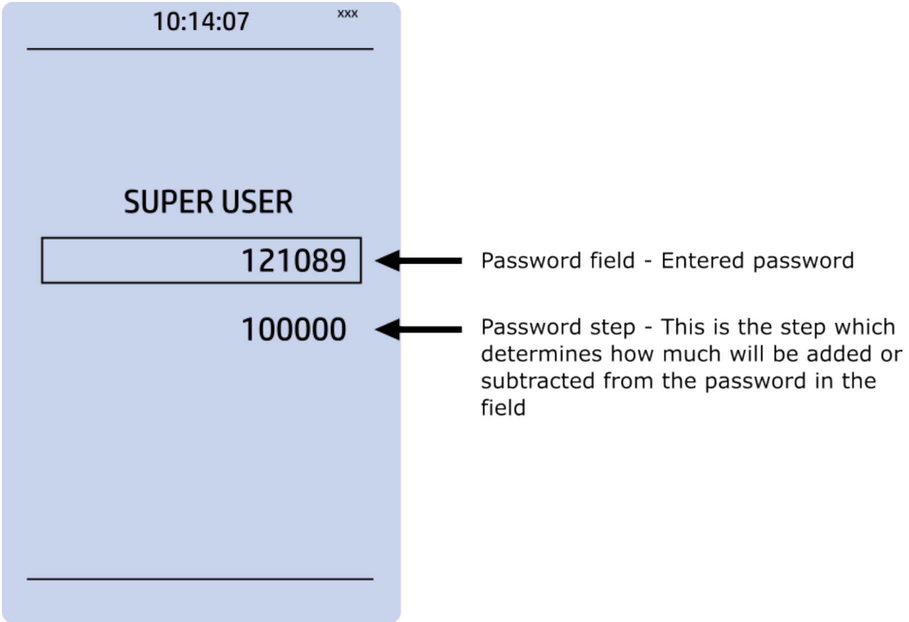
As a factory default, no user level is locked with a password in a device. In order to activate the different user levels, click the Lock button in the device's HMI and set the desired passwords for the different user levels.

> NOTICE!
> 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. To remove the password, set the password to "0" (zero). 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.

NOTICE!
Unlocking and locking a user level generates a time-stamped event to the event log in all AQ 250 series devices.

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

4 Functions

4.1 Functions included in AQ-T257

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

Table. 4.1 - 3. Protection functions of AQ-T257.

Name	IEC	ANSI	Description
NOC (4)	I> I>> I>>> I>>>>	50/51	Non-directional overcurrent protection
DOC (4)	Idir> Idir>> Idir>>> Idir>>>>	67	Directional overcurrent protection
NEF (4)	I0> I0>> I0>>> I0>>>>	50N/51N	Non-directional earth fault protection
DEF (4)	I0dir> I0dir>> I0dir>>> I0dir>>>>	67N/32N	Directional earth fault protection
OV (4)	U> U>> U>>> U>>>>	59	Overvoltage protection
UV (4)	U< U<< U<<< U<<<<<	27	Undervoltage protection
NOV (4)	U0> U0>> U0>>> U0>>>>	59N	Neutral overvoltage protection
FRQV (8)	f> f>> f>>> f>>>> f< f<< f<<< f<<<<<	81O/81U	Overfrequency and underfrequency protection
ROCOF (8)	df/dt>/< (1…8)	81R	Rate-of-change of frequency

Name	IEC	ANSI	Description
CUB (4)	I2> I2>> I2>>> I2>>>>	46/46R/46L	Negative sequence overcurrent/ phase current reversal/ current unbalance protection
VUB (4)	U1/U2>/< U1/U2>>/<< U1/U2>>>/<<< U1/U2>>>>/<<<<	47/27P/59PN	Sequence voltage protection
HOC (4)	Ih> Ih>> Ih>>> Ih>>>>	50H/51H/ 68H	Harmonic overcurrent protection
CBFP (1)	CBFP	50BF/52BF	Circuit breaker failure protection
PQS (4)	P, Q, S>/< P, Q, S>>/<< P, Q, S>>>/<<< P, Q, S>>>>/<<<<	32	Power protection
TRF	-	-	Transformer status monitoring
DIF (1)	Idb>/Idi>/I0dHV>/I0dLV>	87T/87N/87G	Generator/Transformer differential protection with integrated restricted earth fault protection.
TOLT (1)	TT>	49T	Transformer thermal overload protection
VHZ (1)	V/Hz>	24	Volts-per-hertz overexcitation protection
OOS (1)	Pslip	78	Pole slip protection
UIM (2)	Z< Z<<	21U	Underimpedance protection
URX (2)	X< X<<	21/40	Underreactance protection
RTD (1...16)	-	-	RTD alarms (Resistance temperature detector)
PGS (1)	PGx>/<	99	Programmable stage
ARC (1)	IArc>/I0Arc>	50Arc/ 50NArc	Arc fault protection (optional)

Table. 4.1 - 4. Control functions of AQ-T257.

Name	IEC	ANSI	Description
SGS	-	-	Setting group selection
OBJ	-	-	Object control and monitoring (10 objects available)
CIN	-	-	Indicator object monitoring (10 indicators available)
CLPU	CLPU	-	Cold load pick-up

Name	IEC	ANSI	Description
SOTF	SOTF	-	Switch-on-to-fault
VJP	Δφ	78	Vector jump
SYN	ΔV/Δa/Δf	25	Synchrocheck
VRG	-	90	Automatic voltage regulator (only included in Function package B!)

Table. 4.1 - 5. Monitoring functions of AQ-T257.

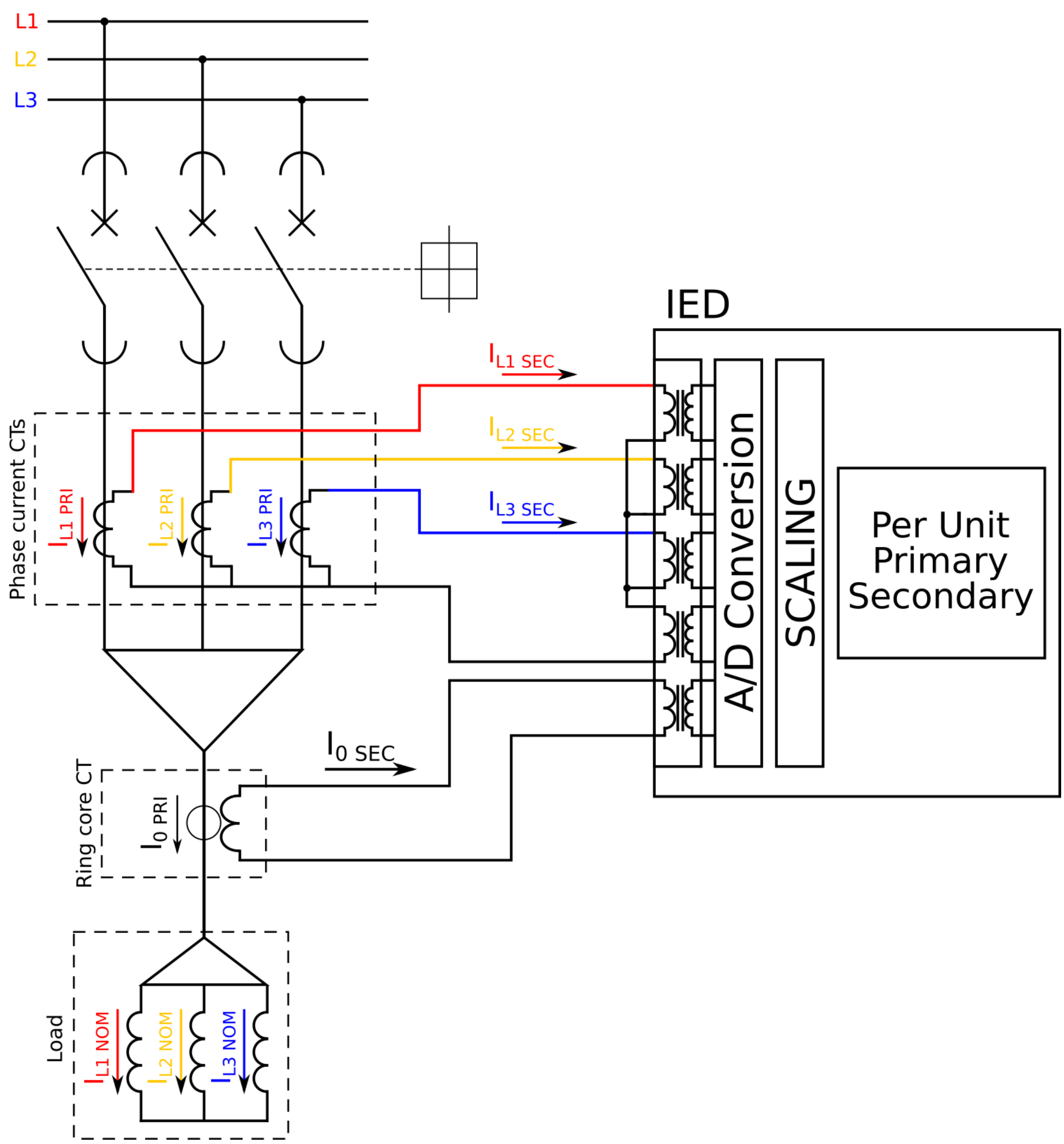
Name	IEC	ANSI	Description
CTS (2)	-	-	Current transformer supervision
VTS	-	60	Voltage transformer supervision
DR	-	-	Disturbance recorder
FLX	-	21FL	Fault locator
THD	-	-	Total harmonic distortion
CBW	-	-	Circuit breaker wear monitor
MREC	-	-	Measurement recorder
VREC	-	-	Measurement value recorder

4.2 Measurements

4.2.1 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 current measurements are updated every 5 milliseconds. 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. 4.2.1 - 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.

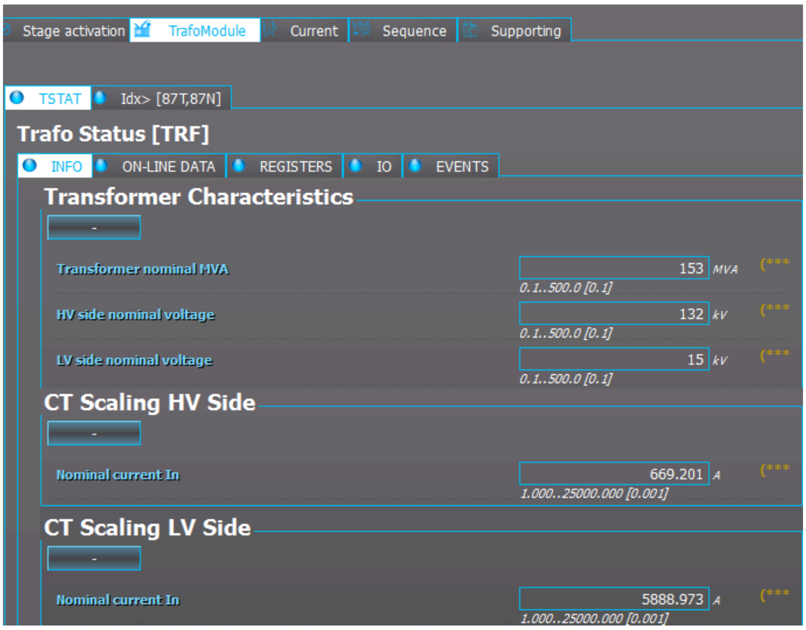
SEC: The secondary current, i.e. the current which the current transformer transforms according to its ratios. This current is measured by the device.

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 device calculates the scaling factors based on the set values of the CT primary, the CT secondary and the nominal current. The device 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 device 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. (per-unit) when the nominal current is known. Also, knowing what the transformer's nominal current is makes the unit protection much easier and more straightforward to configure. 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. 4.2.1 - 3. Nominal current calculation in differential protection devices.



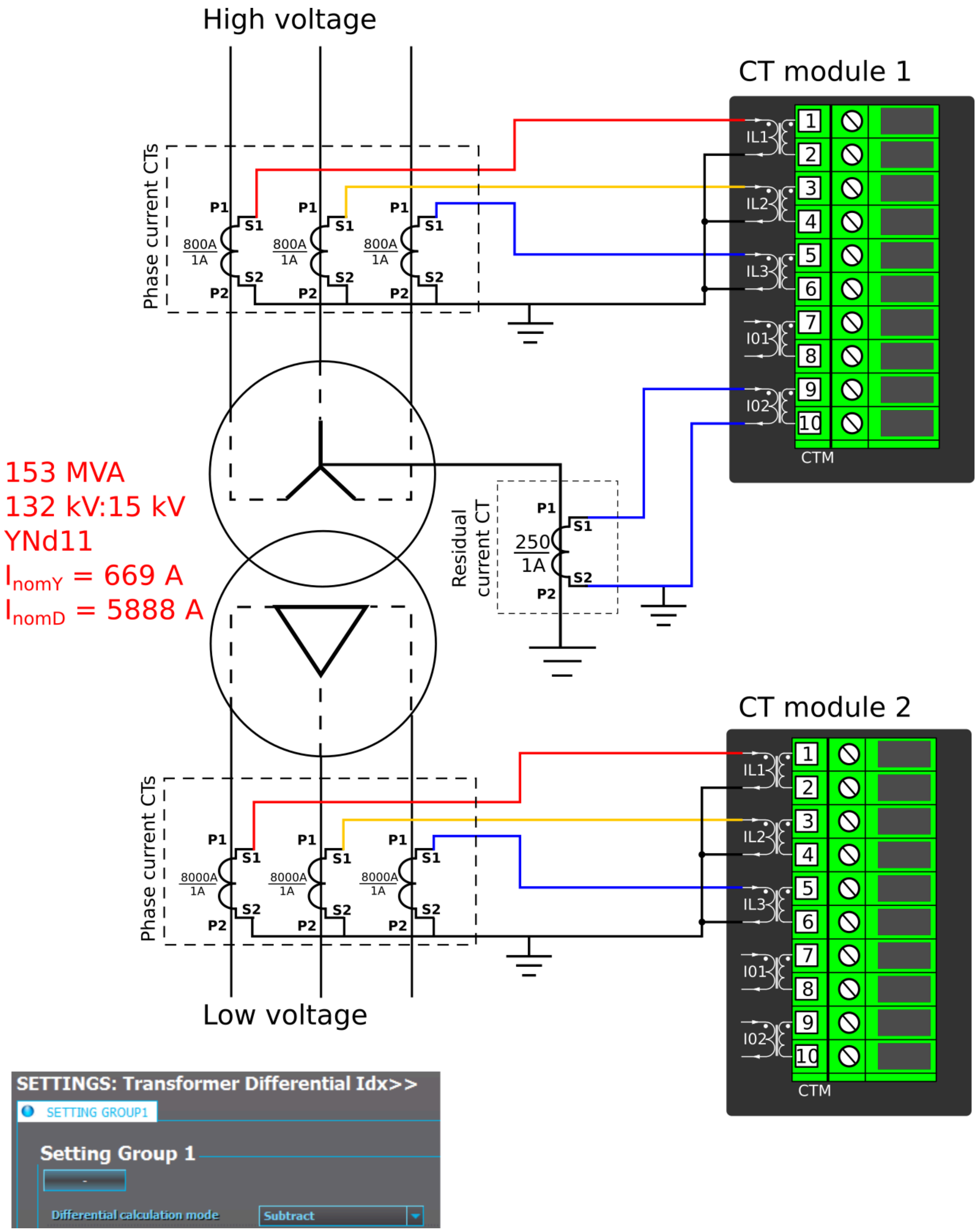
Normally, the primary current ratings for phase current transformers are ten amperes to thousands of amperes and their decimal multiples, while the secondary current ratings are 1 A and 5 A. Other, non-standard ratings can be directly connected as the scaling settings are flexible and have large ranges. 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 device 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 device'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. 4.2.1 - 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 device's perspective.

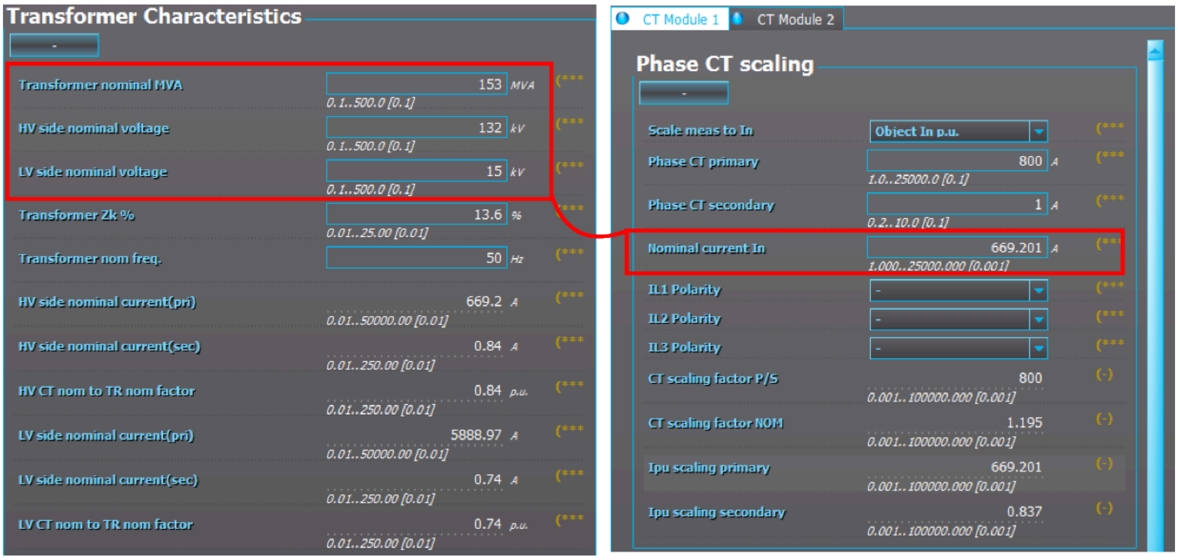
The following table presents the initial data of the connection as well as the ratings.

Table. 4.2.1 - 6. 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: 8 000 A • CT secondary: 1 A Low-voltage side nominal current: 5 888 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 devices and it cannot be changed.

Figure. 4.2.1 - 5. Phase CT scaling to machine nominal.



As seen in the image above, device 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:

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

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

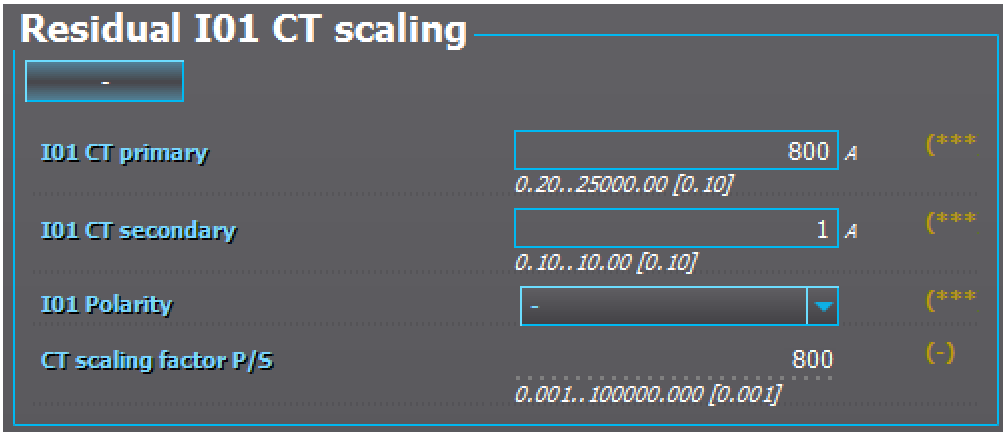
The secondary nominal current (in amperes) is the result of multiplying the per unit value with the phase CT secondary side current. This current can be used when the unit is commissioned and when the directions of CTs are checked. See the example calculation below:

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

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

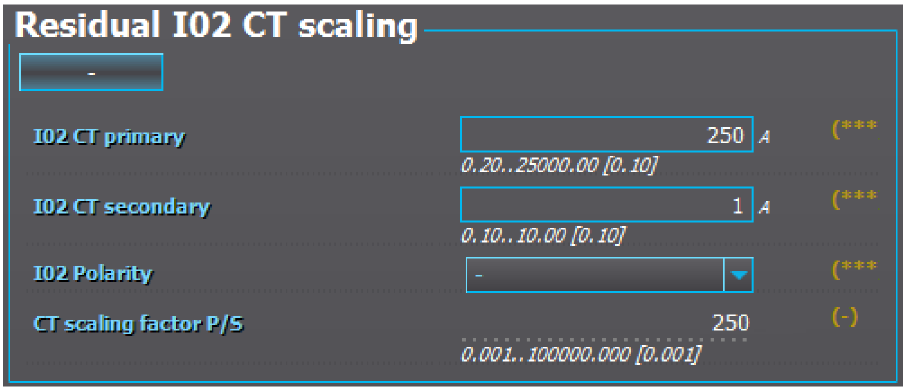
In case the phase current CTs are connected to the module via a Holmgren (summing) connection, the use of coarse residual current measurement settings is required: the "I01 CT" settings are set according to the phase current CTs' ratings (800/1 A).

Figure. 4.2.1 - 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).

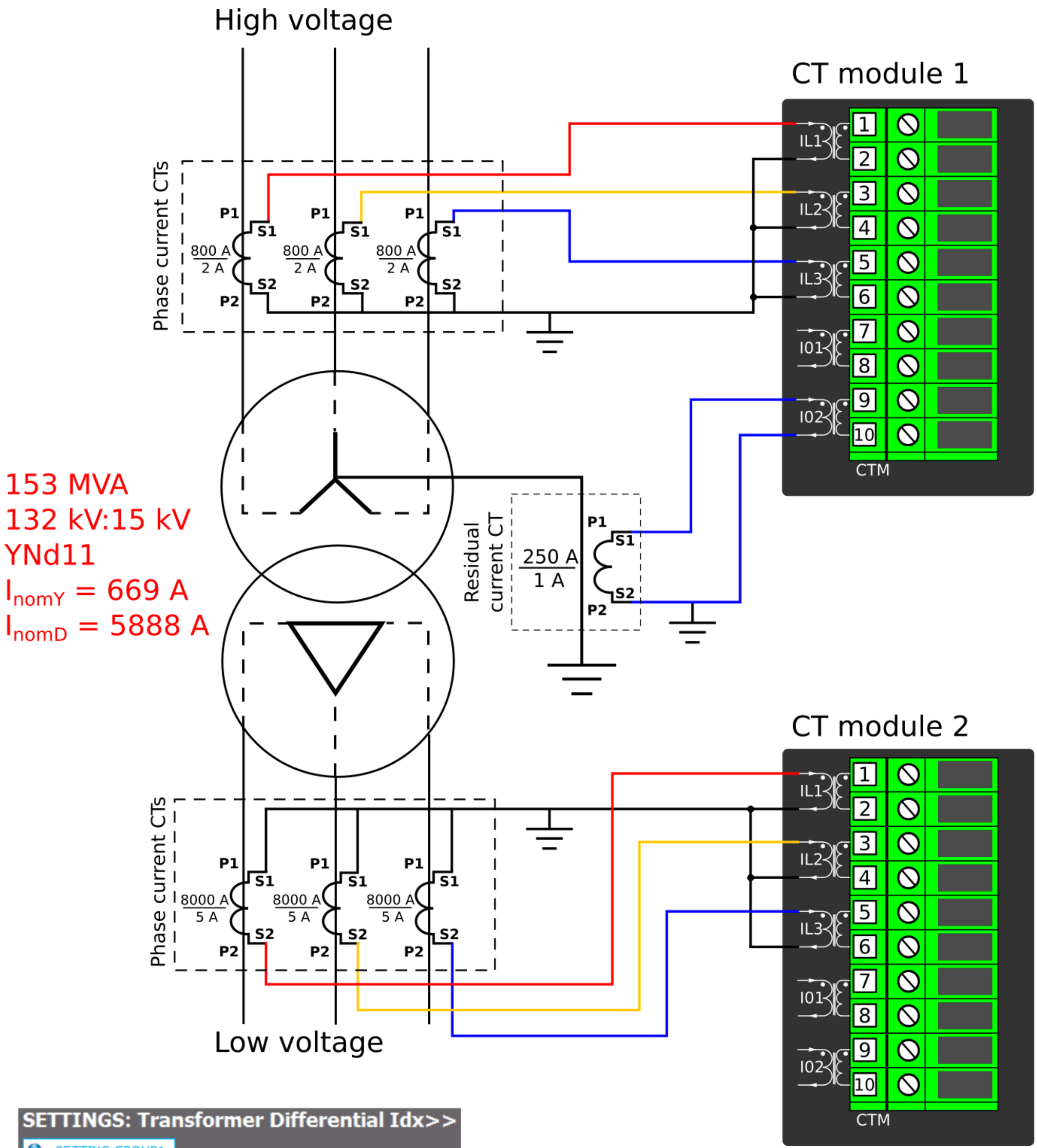
Figure. 4.2.1 - 7. Residual I02 CT scaling (sensitive).

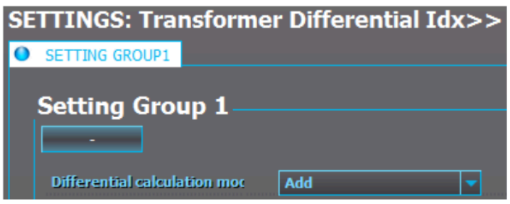


Example of CT scaling (application 2)

The following figure presents how the CTs are connected to the device'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. 4.2.1 - 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. 4.2.1 - 7. 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: 8 000 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. 4.2.1 - 8. Settings of the Phase CT scaling.

Name	Unit	Range	Step	Default	Description
Scale measurement to In	-	• CT nom p.u. • Object In p.u.	-	• CT nom p.u.	The selection of the reference used in the device's per-unit system scaling. Either the set phase current CT primary or the protected object's nominal current. CAUTION! Not applicable in machine protection!
Phase CT primary	A	1…25 000	0.001	100	The rated primary current of the current transformer.
Phase CT secondary	A	0.2…10	0.001	5	The rated secondary current of the current transformer.
Nominal current In	A	1…25 000	0.001	100	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	-	• - • Invert	-	• -	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	-	• - • Invert	-	• -	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	-	• - • Invert	-	• -	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 feedback value; the calculated scaling factor that is the ratio between the primary current and the secondary current.
CT scaling factor NOM	-	-	-	-	A feedback value; the calculated scaling factor that is the ratio between the set primary current and the set nominal current.

Name	Unit	Range	Step	Default	Description
Ipu scaling primary	-	-	-	-	A feedback value; the scaling factor for the primary current's per-unit value.
Ipu scaling secondary	-	-	-	-	A feedback value; the scaling factor for the secondary current's per-unit value.

Table. 4.2.1 - 9. Settings of the Residual I01 CT scaling.

Name	Unit	Range	Step	Default	Description
I01 CT primary	A	0.2…25 000	0.000 01	100	The rated primary current of the current transformer.
I01 CT secondary	A	0.1…10	0.000 01	1.0	The rated secondary current of the current transformer.
I01 Polarity	-	• - • Invert	-	-	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 feedback value; the calculated scaling factor that is the ratio between the primary current and the secondary current.

Table. 4.2.1 - 10. Settings of the Residual I02 CT scaling.

Name	Unit	Range	Step	Default	Description
I02 CT primary	A	1…25 000	0.000 01	100	The rated primary current of the current transformer.
I02 CT secondary	A	0.001…10	0.000 01	0.2	The rated secondary current of the current transformer.
I02 Polarity	-	• - • Invert	-	-	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 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. 4.2.1 - 11. Per-unit phase current measurements.

Name	Unit	Range	Step	Description
Phase current ILx ("Pha.curr.ILx")	× In	0.000…1 250.000	0.001	The RMS current measurement (in p.u.) from each of the phase current channels.

Name	Unit	Range	Step	Description
Phase current ILx TRMS ("Pha.curr.ILx TRMS")	× In	0.000…1 250.000	0.001	The TRMS current (inc. harmonics up to 31^{st}) measurement (in p.u.) from each of the phase current channels.
Peak-to-peak current ILx ("P-P curr.ILx")	× In	0.000…500.000	0.001	The peak-to-peak current measurement (in p.u.) from each of the phase current channels.

Table. 4.2.1 - 12. Primary phase current measurements.

Name	Unit	Range	Step	Description
Primary phase current ILx ("Pri.Pha.curr.ILx")	A	0.000…1 000 000.000	0.001	The primary RMS current measurement from each of the phase current channels.
Primary phase current ILx TRMS ("Pha.curr.ILx TRMS Pri")	A	0.000…1 000 000.000	0.001	The primary TRMS current (inc. harmonics up to 31^{st}) measurement from each of the phase current channels.

Table. 4.2.1 - 13. Secondary phase current measurements.

Name	Unit	Range	Step	Description
Secondary phase current ILx "Sec.Pha.curr.ILx")	A	0.000…300.000	0.001	The primary RMS current measurement from each of the phase current channels.
Secondary phase current ILx TRMS ("Pha.curr.ILx TRMS Sec")	A	0.000…300.000	0.001	The primary TRMS current (inc. harmonics up to 31^{st}) measurement from each of the phase current channels.

Table. 4.2.1 - 14. Phase current angle measurements.

Name	Unit	Range	Step	Description
Phase angle ILx ("Pha.angle ILx")	deg	0.000…360.000	0.001	The phase angle measurement from each of the three phase current inputs.

Table. 4.2.1 - 15. Per-unit residual current measurements.

Name	Unit	Range	Step	Description
Residual current I0x ("Res.curr.I0x")	× In	0.000…1 250.000	0.001	The RMS current measurement (in p.u.) from the residual current channel I01 or I02.
Calculated I0	× In	0.000…1 250.000	0.001	The RMS current measurement (in p.u.) from the calculated I0 current channel.

Name	Unit	Range	Step	Description
Phase current I0x TRMS ("Res.curr.I0x TRMS")	× In	0.000…1 250.000	0.001	The TRMS current (inc. harmonics up to 31^{st}) measurement (in p.u.) from the residual current channel I01 or I02.
Peak-to-peak current I0x ("P-P curr.I0x")	× In	0.000…500.000	0.001	The peak-to-peak current measurement (in p.u.) from the residual current channel I01 or I02.

Table. 4.2.1 - 16. Primary residual current measurements.

Name	Unit	Range	Step	Description
Primary residual current I01 ("Pri.Res.curr.I0x")	A	0.000…1 000 000.000	0.001	The primary RMS current measurement from the residual current channel I01 or I02.
Primary calculated I0 ("Pri.calc.I0")	A	0.000…1 000 000.000	0.001	The primary RMS current measurement from the calculated current channel I0.
Primary residual current I0x TRMS ("Res.curr.I01 TRMS Pri")	A	0.000…1 000 000.000	0.001	The TRMS current (inc. harmonics up to 31^{st}) measurement from the primary residual current channel I01 or I02.

Table. 4.2.1 - 17. Secondary residual current measurements.

Name	Unit	Range	Step	Description
Secondary residual current I0x ("Sec.Res.curr.I0x")	A	0.000…300.000	0.001	The secondary RMS current measurement from the residual current channel I01 or I02.
Secondary calculated I0 ("Sec.calc.I0")	A	0.000…300.000	0.001	The secondary RMS current measurement from the calculated current channel I0.
Secondary residual current I0x TRMS ("Res.curr.I0x TRMS Sec")	A	0.000…300.000	0.001	The secondary TRMS current (inc. harmonics up to 31^{st}) measurement from the secondary residual current channel I01 or I02.

Table. 4.2.1 - 18. Residual current phase angle measurements.

Name	Unit	Range	Step	Description
Residual current angle I0x ("Res.curr.angle I0x")	deg	0.000…360.000	0.001	The residual current angle measurement from the I01 or I02 current input.
Calculated I0 angle	deg	0.000…360.000	0.001	The calculated residual current angle measurement.

Table. 4.2.1 - 19. Per-unit sequence current measurements.

Name	Unit	Range	Step	Description
Positive sequence current ("Positive sequence curr.")	× In	0.00…1 250.0	0.001	The measurement (in p.u.) from the calculated positive sequence current.
Negative sequence current ("Negative sequence curr.")	× In	0.00…1 250.0	0.001	The measurement (in p.u.) from the calculated negative sequence current.
Zero sequence current ("Zero sequence curr.")	× In	0.00…1 250.0	0.001	The measurement (in p.u.) from the calculated zero sequence current.

Table. 4.2.1 - 20. Primary sequence current measurements.

Name	Unit	Range	Step	Description
Primary positive sequence current ("Pri.Positive sequence curr.")	A	0.00…1 000 000.0	0.001	The primary measurement from the calculated positive sequence current.
Primary negative sequence current ("Pri.Negative sequence curr.")	A	0.00…1 000 000.0	0.001	The primary measurement from the calculated negative sequence current.
Primary zero sequence current ("Pri.Zero sequence curr.")	A	0.00…1 000 000.0	0.001	The primary measurement from the calculated zero sequence current.

Table. 4.2.1 - 21. Secondary sequence current measurements.

Name	Unit	Range	Step	Description
Secondary positive sequence current ("Sec.Positive sequence curr.")	A	0.000…300.000	0.001	The secondary measurement from the calculated positive sequence current.
Secondary negative sequence current ("Sec.Negative sequence curr.")	A	0.000…300.000	0.001	The secondary measurement from the calculated negative sequence current.
Secondary zero sequence current ("Sec.Zero sequence curr.")	A	0.000…300.000	0.001	The secondary measurement from the calculated zero sequence current.

Table. 4.2.1 - 22. Sequence phase angle measurements.

Name	Unit	Range	Step	Description
Positive sequence current angle ("Positive sequence curr.angle")	deg	0.000…360.0	0.001	The calculated positive sequence current angle.
Negative sequence current angle ("Negative sequence curr.angle")	deg	0.000…360.0	0.001	The calculated negative sequence current angle.
Zero sequence current angle ("Zero sequence curr.angle")	deg	0.000…360.0	0.001	The calculated zero sequence current angle.

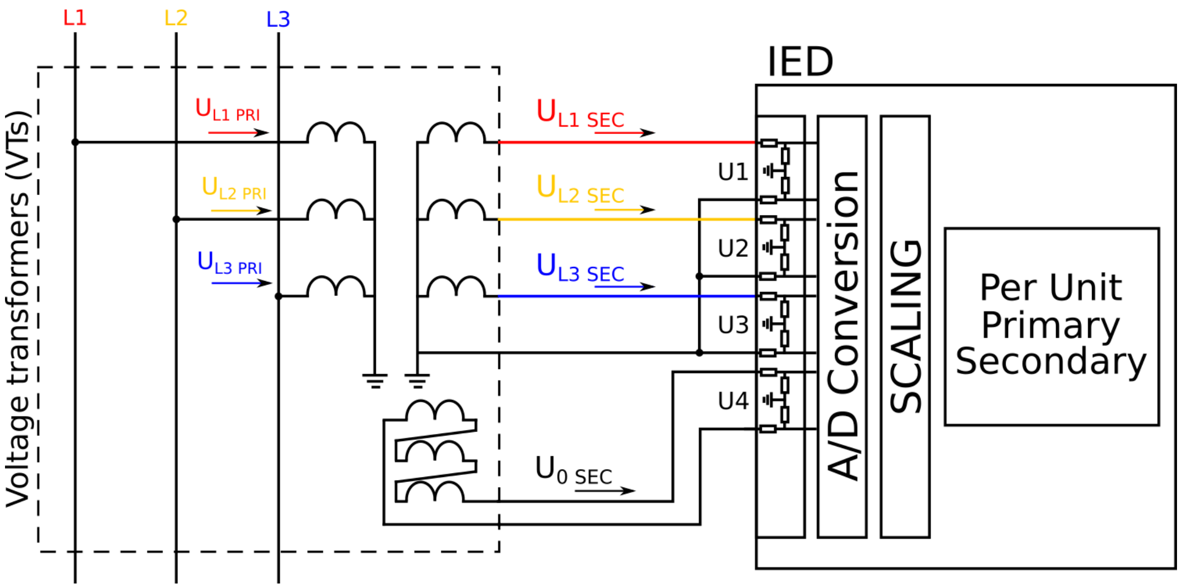
Table. 4.2.1 - 23. Harmonic current measurements.

Name	Unit	Range	Step	Default	Description
Harmonics calculation values ("Harm Abs.pr Perc.")	-	• Percent • Absolute	-	Percent	Defines whether the harmonics are calculated as percentage or absolute values.
Harmonics display	-	• Per unit • Primary A • Secondary A	-	Per unit	Defines how the harmonics are displayed: in p.u. values, as primary current values, or as secondary current values.
Maximum harmonics value ("IxxMaximum harmonic")	A	0.000…1 000 000.000	0.001	-	Displays the maximum harmonics value of the selected current input ILx or I0x.
Fundamental frequency ("Ixx fundamental")	A	0.000…1 000 000.000	0.001	-	Displays the current value of the fundamental frequency measurement (RMS) from the selected current input ILx or I0x.
Ixx harmonics (2^{nd}…31^{st} harmonic)	A	0.000…1 000 000.000	0.001	-	Displays the selected harmonic from the current input ILx or I0x.

4.2.2 Voltage measurement and scaling

The voltage measurement module (VT module, or VTM) is used for measuring the voltages from voltage transformers. The voltage measurements are updated every 5 milliseconds. 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 voltage measurements to be able to get correct measurements.

Figure. 4.2.2 - 9. Voltage measurement terminology



PRI: The primary voltage, i.e. the voltage in the primary circuit which is connected to 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 device.

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.

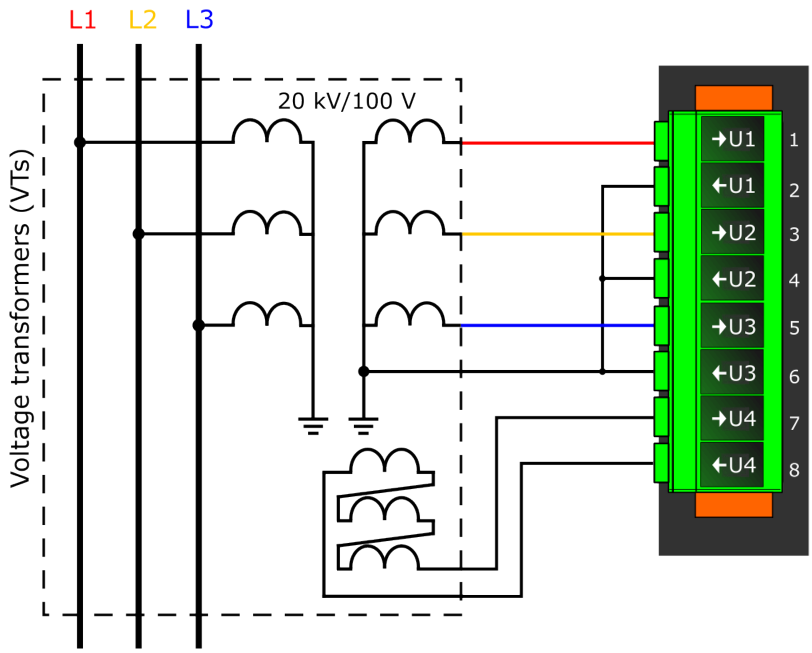
The device calculates the scaling factors based on the set VT primary, and secondary voltage values. The device measures secondary voltages, which are the voltage outputs from the VT installed into the application's primary circuit. The voltage can be measured directly from the system as well (up to 400 V nominal line to neutral voltage). When connecting voltage directly, measuring mode must be set to 3LN+U4 mode. The rated primary and secondary voltages of the VT need to be set for the device 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 device'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. 4.2.2 - 10. Connections.



The following table presents the initial data of the connection.

Table. 4.2.2 - 24. Initial data.

Phase voltage VT - VT primary: 20 000 V - VT secondary: 100 V	Zero sequence voltage VT - U4 VT primary: 20 000 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 device.	

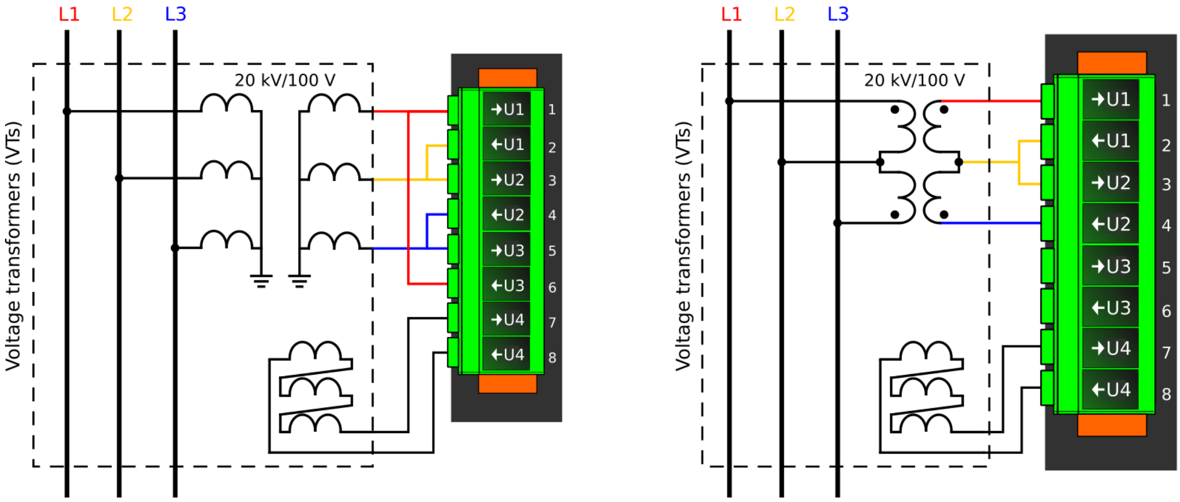
Once the settings have been sent to the device, device calculates the scaling factors and displays them for the user. The "VT scaling factor P/S" describes the ratio between the primary voltage and the secondary voltage. The per-unit scaling factors ("VT scaling factor p.u.") for both primary and secondary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

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

- 3LN+U4 (three line-to-neutral voltages and U4 can be used for either zero sequence voltage or synchrochecking)
- 3LL+U4 (three line-to-line voltages and U4 can be used either for zero sequence voltage or synchrochecking)
- 2LL+U3+U4 (two line-to-line voltages and the U3 and the U4 channels can be used for synchrochecking, zero sequence voltage, or for both)

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. 4.2.2 - 11. Example connections for voltage line-to-line measurement.

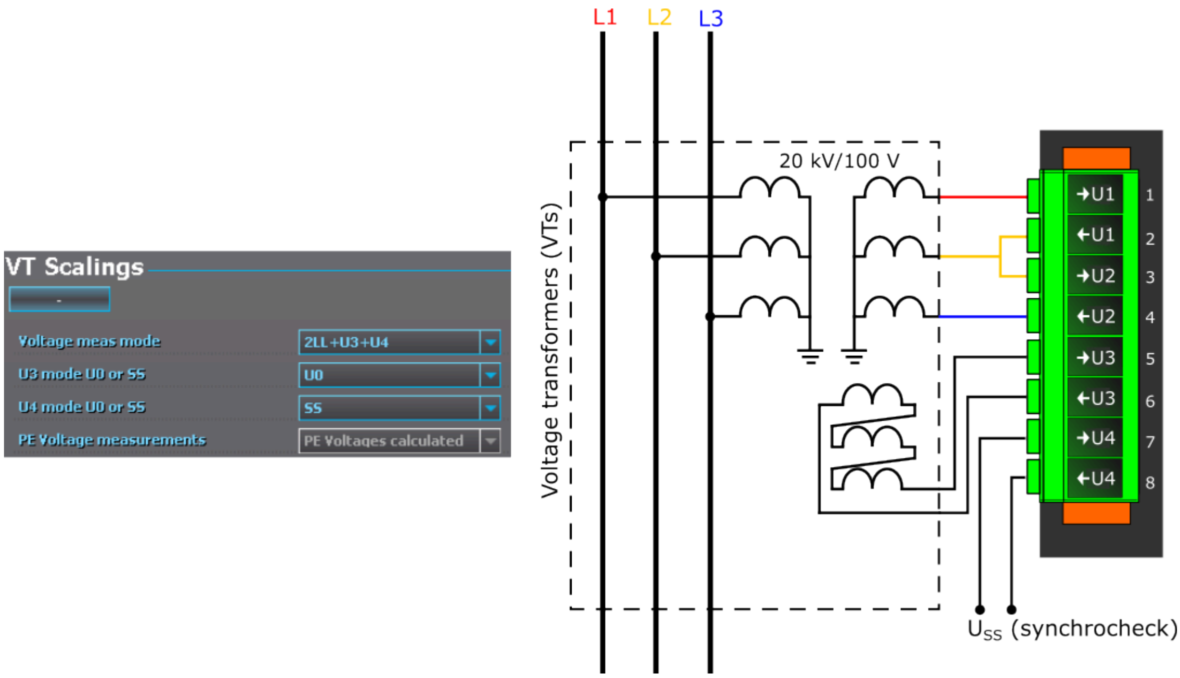


If only two line-to-line voltages are measured, the third one (U_{L31}) is calculated based on the U_{L12} and U_{L23} vectors. When measuring line-to-line voltages, the line-to-neutral voltages can also be calculated as long as the value of U0 is measured.

The voltage measurement channel U4 can be used to measure the zero sequence voltage (U0), the side 2 voltage of the circuit breaker (Synchrocheck), or for automatic voltage regulator function. 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.

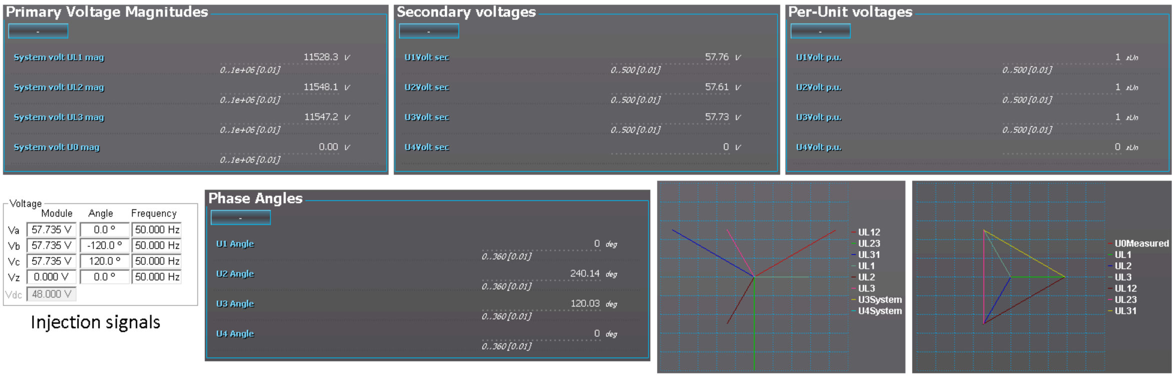
In the image below is an example of 2LL+U0+SS, that is, two line-to-line measurements with the zero sequence voltage and voltage from side 2 for Synchrocheck. Since U0 is available, line-to-neutral voltages can be calculated.

Figure. 4.2.2 - 12. 2LL+U0+SS settings and connections.



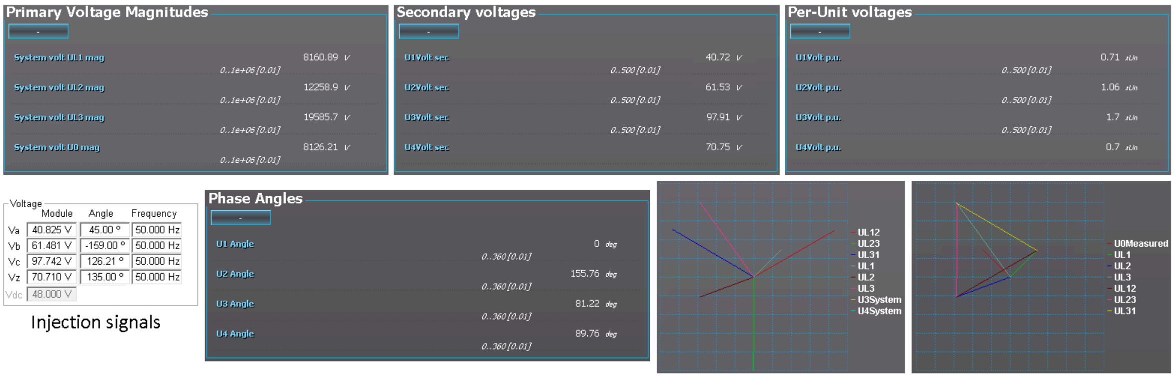
The image collection below presents the device's behavior when nominal voltage is injected into the device via secondary test equipment. The measurement mode is 3LN+U4 which means that the device is measuring line-to-neutral voltages. The VT scaling has been set to 20 000 : 100 V. The U4 channel measures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

Figure. 4.2.2 - 13. Measurement behavior when nominal voltage injected.



The image collection below presents the device's behavior when voltage is injected into the device via secondary test equipment during an earth fault. The measurement mode is 3LN+U4 which means that the device 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).

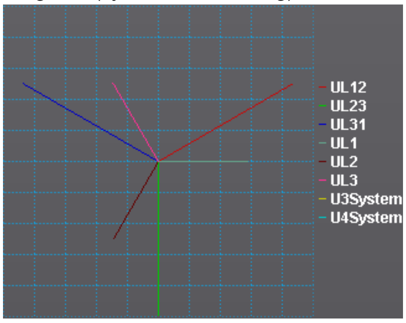
Figure. 4.2.2 - 14. Device behavior when voltage injected during an earth fault.



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 with the connected voltage transformer (*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 device.

Problem	Check / Resolution
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 device settings, go to *Measurement → Phasors* and check the "System voltage vectors" diagram. When all connections are correct, the diagram (symmetric feeding) should look like this: 

Alternative

Settings

Table. 4.2.2 - 25. Settings of the VT scaling.

Name	Range	Step	Default	Description
Voltage measurement mode	• 3LN+U4 • 3LL+U4 • 2LL+U3+U4	-	3LN+U4	The device's voltage wiring method. The voltages are scaled according the set voltage measurement mode.
U3 mode U0 or SS	• Not Used • U0 • SS	-	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.
U4 mode U0 or SS				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 (U3) Measured from	• Broken Delta • Neutral point • Open delta	-	Broken delta	Defines how the secondary voltage is scaled to the primary. "Broken Delta" is the most common mode. 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. Example with scaling 20000/100 for Uo and injection 10V secondary: • Broken delta: 1155V (10%) • Neutral point: 2000 V (17.34%) • Open delta: 667V (5.78%)

Name	Range	Step	Default	Description
U0 (U4) Measured from				Defines how the secondary voltage is scaled to the primary. "Broken Delta" is the most common mode. 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. Example with scaling 20000/100 for Uo and injection 10V secondary: • Broken delta: 1155V (10%) • Neutral point: 2000 V (17.34%) • Open delta: 667V (5.78%)
Voltage memory	• Disabled • Activated	-	Disabled	Activates the voltage memory. The "Voltage memory" chapter describes the function in more detail.
P-E Voltage measurements	• No P-E voltages available • P-E Voltages calculated • 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 measured line-to-line and zero sequence voltages.
VT primary	1.0…1 000 000.0V	0.1V	20 000.0V	The rated primary voltage of the voltage transformer.
VT secondary	0.2…400.0V	0.1V	100.0V	The rated secondary voltage of the voltage transformer.
U3 Res/SS VT primary	1.0…1 000 000V	0.1V	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…400.0V	0.1V	100.0V	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	1.0…1 000 000.0V	0.1V	20 000.0V	The primary nominal voltage of the connected U0 or SS VT.
U4 Res/SS VT secondary	0.2…400.0V	0.1V	100.0V	The secondary nominal voltage of the connected U0 or SS VT.
U1 Polarity	• - • Invert	-	-	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				The selection of the second voltage measurement channel's (U2) polarity (direction). The default setting is for the positive voltage to flow from connector 3 to connector 4, with the secondary voltage's starpoint pointing towards the line.
U3 Polarity				The selection of the third voltage measurement channel's (U3) polarity (direction). The default setting is for the positive voltage to flow from connector 5 to connector 6, with the secondary voltage's starpoint pointing towards the line.

Name	Range	Step	Default	Description
U4 Polarity				The selection of the fourth voltage measurement channel's (U4) polarity (direction). The default setting is for the positive voltage to flow from connector 7 to connector 8, with the secondary voltage's starpoint pointing towards the line.

Table. 4.2.2 - 26. Read-only parameters of the VT scaling.

Name	Description
VT scaling factor P/S	A 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 feedback value; the scaling factor for the primary voltage's per-unit value.
VT scaling factor p.u. Sec	A feedback value; the scaling factor for the secondary voltage's per-unit value.
U3 VT scaling factor P/S U0/ SS	A 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 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 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 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 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 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. 4.2.2 - 27. Per-unit voltage measurements.

Name	Range	Step	Description
Voltage Ux ("UxVolt p.u.")	$0.00…500.00xU_N$	$0.01xU_N$	The voltage measurement fundamental frequency component (in p.u.) from each of the voltage channels.
Voltage Ux TRMS ("UxVolt TRMS p.u.")	$0.00…500.00xU_N$	$0.01xU_N$	The TRMS voltage (inc. harmonics up to 31^{st}) measurement (in p.u.) from each of the voltage channels.

Table. 4.2.2 - 28. Secondary voltage measurements.

Name	Range	Step	Description
Secondary voltage Ux ("Ux Volt sec")	0.00…500.00V	0.01V	The secondary voltage measurement fundamental frequency component from each of the voltage channels.
Secondary voltage Ux TRMS ("UxVolt TRMS sec")	0.00…500.00V	0.01V	The secondary TRMS voltage (inc. harmonics up to 31st) measurement from each of the voltage channels.

Table. 4.2.2 - 29. Voltage phase angle measurements.

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

Table. 4.2.2 - 30. Per-unit sequence voltage measurements.

Name	Range	Step	Description
Positive sequence voltage ("Pos.seq.Volt.p.u.")	0.00…500.00×U_N	0.01xU_N	The measurement (in p.u.) from the calculated positive sequence voltage.
Negative sequence voltage ("Neg.seq.Volt.p.u.")	0.00…500.00xU_N	0.01xU_N	The measurement (in p.u.) from the calculated negative sequence voltage.
Zero sequence voltage ("Zero.seq.Volt.p.u.")	0.00…500.00xU_N	0.01xU_N	The measurement (in p.u.) from the calculated zero sequence voltage.

Table. 4.2.2 - 31. Primary sequence voltage measurements.

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

Table. 4.2.2 - 32. Secondary sequence voltage measurements.

Name	Range	Step	Description
Secondary positive sequence voltage ("Pos.seq.Volt.sec")	0.00…4 800.00V	0.01V	The secondary measurement from the calculated positive sequence voltage.
Secondary negative sequence voltage ("Neg.seq.Volt.sec")	0.00…4 800.00V	0.01V	The secondary measurement from the calculated negative sequence voltage.
Secondary zero sequence voltage ("Zero.seq.Volt.sec")	0.00…4 800.00V	0.01V	The secondary measurement from the calculated zero sequence voltage.

Table. 4.2.2 - 33. Sequence voltage angle measurements.

Name	Range	Step	Description
Positive sequence voltage angle ("Pos.seq.Volt.Angle")	0.00…360.00°	0.01°	The calculated positive sequence voltage angle.
Negative sequence voltage angle ("Neg.seq.Volt.Angle")	0.00…360.00°	0.01°	The calculated negative sequence voltage angle.
Zero sequence voltage angle ("Zero.seq.Volt.Angle")	0.00…360.00°	0.01°	The calculated zero sequence voltage angle.

Table. 4.2.2 - 34. System primary voltage measurements.

Name	Range	Step	Description
System voltage magnitude UL12 ("System volt UL12 mag")	0.00…1 000 000.00V	0.01V	The primary line-to-line UL12 voltage fundamental frequency component (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…1 000 000.00V	0.01V	The primary line-to-line UL23 voltage fundamental frequency component (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…1 000 000.00V	0.01V	The primary line-to-line UL31 voltage fundamental frequency component (measured or calculated). You can also select the row where the unit for this is kV.

Name	Range	Step	Description
System voltage magnitude UL1 ("System volt UL1 mag")	0.00…1 000 000.00V	0.01V	The primary line-to-neutral UL1 voltage fundamental frequency component (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…1 000 000.00V	0.01V	The primary line-to-neutral UL2 voltage fundamental frequency component (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…1 000 000.00V	0.01V	The primary line-to-neutral UL3 voltage fundamental frequency component (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…1 000 000.00V	0.01V	The primary zero sequence U0 voltage fundamental frequency component (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…1 000 000.00V	0.01V	The primary measured Synchrocheck voltage fundamental frequency component (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…1 000 000.00V	0.01V	The primary measured Synchrocheck voltage fundamental frequency component (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. 4.2.2 - 35. Primary system voltage angles.

Name	Range	Step	Description
System voltage angle UL12 ("System volt UL12 ang")	0.00…360.00°	0.01°	The primary line-to-line angle UL12 (measured or calculated).

Name	Range	Step	Description
System voltage angle UL23 ("System volt UL23 ang")	0.00…360.00°	0.01°	The primary line-to-line angle UL23 (measured or calculated).
System voltage angle UL31 ("System volt UL31 ang")	0.00…360.00°	0.01°	The primary line-to-line angle UL23 (measured or calculated).
System voltage angle UL1 ("System volt UL1 ang")	0.00…360.00°	0.01°	The primary line-to-neutral angle UL1 (measured or calculated).
System voltage angle UL2 ("System volt UL2 ang")	0.00…360.00°	0.01°	The primary line-to-neutral angle UL2 (measured or calculated).
System voltage angle UL3 ("System volt UL3 ang")	0.00…360.00°	0.01°	The primary line-to-neutral angle UL3 (measured or calculated).
System voltage angle U0 ("System volt U0 ang")	0.00…360.00°	0.01°	The primary zero sequence angle U0 (measured or calculated).
System voltage angle U3 ("System volt U3 ang")	0.00…360.00°	0.01°	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…360.00°	0.01°	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. 4.2.2 - 36. Harmonic voltage measurements.

Name	Range	Step	Description
Harmonics calculation values ("Harm Abs.or Perc.")	• Percent • Absolute	-	Defines whether the harmonics are calculated as percentages or absolute values.
Harmonics display	• Per unit • Primary V • Secondary V	-	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…100 000.00V	0.01V	Displays the maximum harmonics value of the selected voltage input Ux.
Fundamental frequency ("Ux Fund")	0.00…100 000.00V	0.01V	Displays the voltage value of the fundamental frequency component of the selected voltage input Ux.
Ux harmonics (2^{nd}...31^{st} harmonic)	0.00...100 000.00V	0.01V	Displays the selected harmonic from the voltage input Ux.
Ux Amplitude THD	0.000...100.000V	0.001V	Amplitude ratio THD voltage. Recognized by IEC.
Ux Power THD	0.000...100.000V	0.001V	Power ratio THD voltage. Recognized by the IEEE.

Voltage memory

Certain protection functions (such as impedance or directional overcurrent) use the device'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/tripping area) and the actual measured quantity. The function then produces an output when the required terms are met.

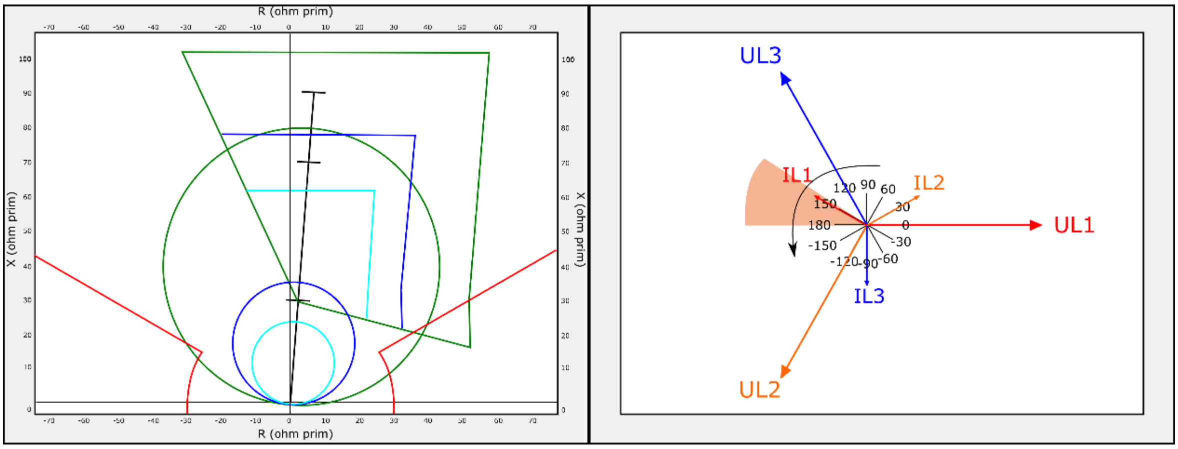
In close-in faults the system voltage on the secondary side may fall down to a few volts or close to nothing. In such cases, when the measured voltage is absent, the fault direction cannot be solved. As backup, non-directional protection can be used for tripping, but in such cases the selectivity of 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 device 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>.

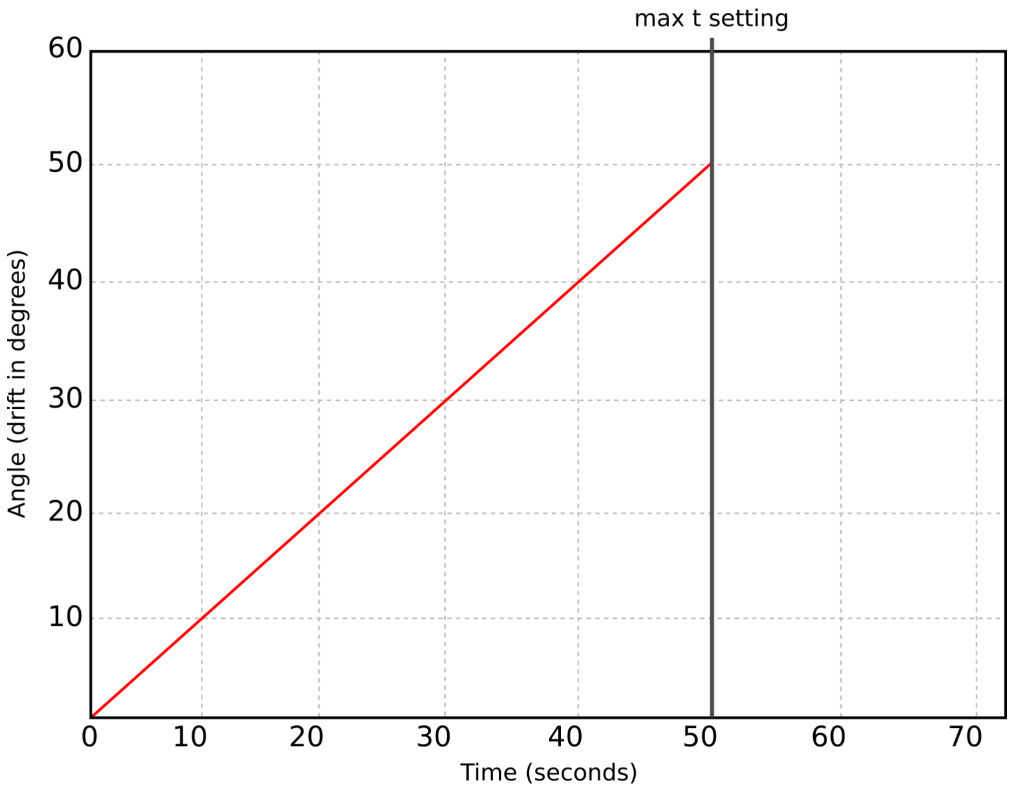
Figure. 4.2.2 - 15. Distance protection characteristics and directional overcurrent.



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 activated, 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. 4.2.2 - 16. 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.

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.

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.

Table. 4.2.2 - 37. Voltage memory event messages.

Event block name	Event names
M1VT1	Voltage memory enabled
M1VT1	Voltage memory disabled
M1VT1	Voltage low detected ON
M1VT1	Voltage low detected OFF
M1VT1	Current high detected ON
M1VT1	Current high detected OFF
M1VT1	Frequency tracked from CT ON
M1VT1	Frequency tracked from CT OFF
M1VT1	Using Voltage memory ON

Event block name	Event names
M1VT1	Using Voltage memory OFF
M1VT1	Voltage memory blocked ON
M1VT1	Voltage memory blocked OFF

4.2.3 Power and energy calculation

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. The power and energy measurements are updated every 5 milliseconds.

Line-to-neutral voltages available

Power is calculated from line-to-neutral voltages and phase currents. If line-to-line voltages are connected, the device 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. 4.2.3 - 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. 4.2.3 - 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. 4.2.3 - 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:

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

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

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

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

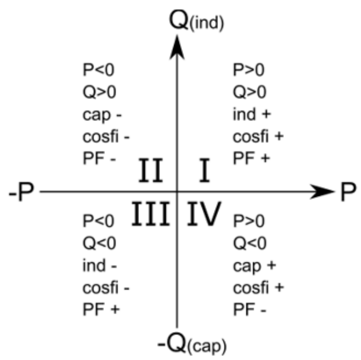
The direction of reactive power is divided into four quadrants. Reactive power may be inductive or capacitive on both forward and reverse directions. Reactive power quadrant can be indicated with Tan (φ) (tangent phi), which is calculated according the following formula:

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

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

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

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



Power factor calculation is done similarly to the Cosine phi 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. 4.2.3 - 38. Power and energy measurement settings

Name	Range	Step	Default	Description
Power measurement currents from	• CT1 • CT2	-	CT1	Defines which current transformer module is used in power and energy calculation.
3ph active energy measurement	• Disabled • Enabled	-	Disabled	Enables/disables the active energy measurement.
3ph reactive energy measurement	• Disabled • Enabled	-	Disabled	Enables/disables the reactive and apparent energy measurement.
3ph energy megas or kilos	• Mega • Kilo	-	Mega	Defines whether energy is measured with the prefix 'kilo' (10^3) or 'mega' (10^6).
Edit energy values	• Disabled • Enabled	-	Disabled	When this parameter is enabled it is possible to manually edit exported and imported active energy values. NOTICE! "E 3ph M or k" parameter has to be set to "kilo" for this feature to function.
Invert imp/ exp energy directions	• Not inverted • Inverted	-	Not inverted	Inverts the direction of imported and exported energy without affecting the direction of power calculation.
Nominal power kVA	0.10...500000.00kVA	0.01kVA	100kVA	Defines the nominal power of the protected object.

Name	Range	Step	Default	Description
PQ Quadrant	• Undefined • Q1 Fwd Ind • Q2 Rev Cap • Q3 Rev Ind • Q4 Fwd Cap	-	Undefined	Indicates what the power PQ quadrant is at that moment.
VA Quadrant	• Undefined • Q1 Fwd Cap AV • Q2 Rev Ind AV • Q3 Rev Cap VA • Q4 Fwd Ind VA	-	Undefined	Indicates what the power VA quadrant is at that moment.
Reset energy calculators ("Reset 3ph Energies")	• - • Reset	-	-	Resets the memory of the three-phase energy calculators. Goes automatically back to the "-" state after the reset is finished.
Phase active energy measurement	• Disabled • Enabled	-	Disabled	Enables/disables the active energy per phase measurement.
Phase reactive energy measurement	• Disabled • Enabled	-	Disabled	Enables/disables the reactive energy per phase measurement.
Phase energies megas or kilos	• Mega • Kilo	-	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")	• - • Reset	-	-	Resets the memory of the indivisual phase energy calculator. Goes automatically back to the "-" state after the reset is finished.

Table. 4.2.3 - 39. Energy Dose Counter 1 settings

Name	Range	Step	Default	Description
Energy dose counter mode	• Disabled • Activated	-	Disabled	Enables/disables energy dose counters generally.
Energy dose counter LN mode	• On • Blocked • Test • Test/Blocked • Off	-	On	Set mode of DOS block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
Energy does counter LN behaviour	• On • Blocked • Test • Test/Blocked • Off	-	-	Displays the mode of DOS block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.

Name	Range	Step	Default	Description
Clear pulse counter	• - • Clear	-	-	Resets the "DC 1…4 Pulses sent" counters back to zero.
DC 1…4 enable	• Disabled • Enabled	-	Disabled	Enables/disables the energy dose counter 1…4 individually.
DC 1…4 Input signal select	• 3PH.Fwd.Act.EP • 3PH.Rev.Avt.EP • 3PH.Fwd.React.EQ.CAP • 3PH.Fwd.React.EQ.IND • 3PH.Rev.React.EQ.CAP • 3PH.Rev.React.EQ.IND	-	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	$-1 \times 10^6 \ldots 1 \times 10^6$	0.01	-	The total amount of energy consumed.
DC 1…4 Pulse magnitude	0…1800kW/var	0.005kW/var	1kW/Var	The set pulse size. An energy pulse is given every time the set magnitude is exceeded.
DC 1…4 Pulse length	0…1800s	0.005s	1s	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. 4.2.3 - 40. 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. 4.2.3 - 41. Three-phase power calculations.

Name	Range	Step	Description
3PH Apparent power (S)	$-1x10^6 \ldots 1x10^6$kVA	0.01kVA	The total three-phase apparent power in kilo-volt-ampere
3PH Active power (P)	$-1x10^6 \ldots 1x10^6$kW	0.01kW	The total three-phase active power in kilowatts
3PH Reactive power (Q)	$-1x10^6 \ldots 1x10^6$kVar	0.01kVar	The total three-phase reactive power in kilovars
3PH Apparent power (S MVA)	$-1x10^5 \ldots 1x10^5$MVA	0.01MVA	The total three-phase apparent power in megawatts
3PH Active power (P MW)	$-1x10^5 \ldots 1x10^5$MW	0.01MW	The total three-phase active power in mewatts

Name	Range	Step	Description
3PH Reactive power (QMVar)	$-1x10^{5}...1x10^{5}$MVar	0.01MVar	The total three-phase active power in megavars
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 Power factor	$-1x10^{6}...1x10^{6}$	0.0001	The three-phase power factor

Table. 4.2.3 - 42. Single-phase power calculations (L1...L3).

Name	Unit	Range	Step	Description
Lx Apparent power (S)	kVA	$-1x10^{6}...1x10^{6}$	0.01	The apparent power of Phase Lx in kilo-volt-amperes
Lx Active power (P)	kW	$-1x10^{6}...1x10^{6}$	0.01	The active power of Phase Lx in kilowatts
Lx Reactive power (Q)	kVar	$-1x10^{6}...1x10^{6}$	0.01	The reactive power of Phase Lx kilovars
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 Power factor	-	$-1x10^{6}...1x10^{6}$	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. 4.2.3 - 43. Three-phase energy calculations.

Name	Range	Step	Description
Exported Active Energy (P) (kWh or MWh)	$-1x10^{9}...1x10^{9}$	0.01	The total amount of exported active energy.
Imported Active Energy (P) (kWh or MWh)	$-1x10^{9}...1x10^{9}$	0.01	The total amount of imported active energy.
Active Energy (P) Export/Import balance (kWh or MWh)	$-1x10^{9}...1x10^{9}$	0.01	The sum of imported and exported active energy.
Exported (Q) while Export (P) (kVarh or MVarh)	$-1x10^{9}...1x10^{9}$	0.01	The total amount of exported reactive energy while active power is exported.
Imported (Q) while Export (P). (kVarh or MVarh)	$-1x10^{9}...1x10^{9}$	0.01	Total amount of imported reactive energy while active energy is exported.
Reactive energy (Q) balance while export (P) (kVarh or MVarh)	$-1x10^{9}...1x10^{9}$	0.01	The sum of imported and exported reactive capacitive energy while active power is exported.
Exported (Q) while Import (P) (kVarh or MVarh)	$-1x10^{9}...1x10^{9}$	0.01	The total amount of exported reactive energy while active energy is imported.

Name	Range	Step	Description
Imported (Q) while Import (P) (kVarh or MVarh)	$-1x10^9...1x10^9$	0.01	The total amount of imported reactive energy while active energy is imported.
Reactive energy (Q) balance while Import (P) (kVarh or MVarh)	$-1x10^9...1x10^9$	0.01	The sum of imported and exported reactive energy while active energy is imported.
Apparent Energy (S) while Export (P) (kVAh or MVAh)	$-1x10^9...1x10^9$	0.01	The total amount of exported apparent energy while active energy is exported.
Apparent Energy (S) while Import (P) (kVAh or MVAh)	$-1x10^9...1x10^9$	0.01	The total amount of exported apparent energy while active energy is imported.
Apparent Energy (S) Net	$-1x10^9...1x10^9$	0.01	Total amount of apparent energy.
Real Energy (P) Net	$-1x10^9...1x10^9$	0.01	The sum of active energy supply and demand.
Reactive Energy (Q) Net	$-1x10^9...1x10^9$	0.01	The sum of reactive energy supply and demand.
Real Energy (P) Supply	$-1x10^9...1x10^9$	0.01	Total amount of active energy supplied. Default supply direction towards busbar.
Reactive Energy (Q) Supply	$-1x10^9...1x10^9$	0.01	Total reactive energy supplied. Default supply direction towards busbar.
Real Energy (P) Demand	$-1x10^9...1x10^9$	0.01	Total amount of active energy demand. Default demand direction from busbar.
Reactive Energy (Q) Demand	$-1x10^9...1x10^9$	0.01	Total amount of reactive energy demand. Default demand direction from busbar.

Table. 4.2.3 - 44. Single-phase energy calculations (L1...L3).

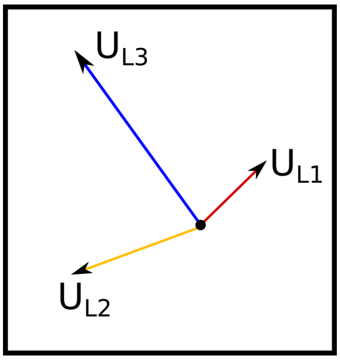
Name	Range	Step	Description
Export Active Energy Lx (kWh or MWh)	$-1x10^9...1x10^9$	0.01	The exported active energy of the phase.
Import Active Energy (kWh or MWh)	$-1x10^9...1x10^9$	0.01	The imported active energy of the phase.
Active Energy (P) Export/Import balance (kWh or MWh)	$-1x10^9...1x10^9$	0.01	The sum of the phase's imported and exported active energy.
Exported (Q) while Export (P) Lx (kVarh or MVarh)	$-1x10^9...1x10^9$	0.01	The exported reactive energy of the phase while active energy is exported.
Imported (Q) while Export (P) Lx (kVarh or MVarh)	$-1x10^9...1x10^9$	0.01	The imported reactive energy of the phase while active energy is exported.
Reactive Energy (Q) balance while Export (P) Lx (kVarh or MVarh)	$-1x10^9...1x10^9$	0.01	The sum of the phase's imported and exported reactive energy while active energy is exported.
Exported (Q) while Import (P) Lx (kVarh or MVarh)	$-1x10^9...1x10^9$	0.01	The exported reactive energy of the phase while active energy is imported.
Imported (Q) while Import (P) Lx (kVarh or MVarh)	$-1x10^9...1x10^9$	0.01	The imported reactive energy of the phase while active energy is imported.

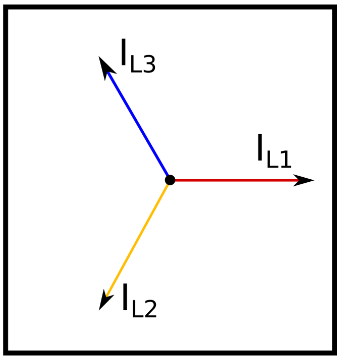
Name	Range	Step	Description
Reactive energy (Q) balance while Import (P) Lx (kVarh or MVarh)	$-1x10^9...1x10^9$	0.01	The sum of the phase's imported and exported reactive energy while active energy is imported.
Apparent Energy (S) while Export (P) Lx	$-1x10^9...1x10^9$	0.01	The apparent energy of the phase while active energy is exported.
Apparent Energy (S) while Import (P) Lx	$-1x10^9...1x10^9$	0.01	The apparent energy of the phase while active energy is imported.

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°





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

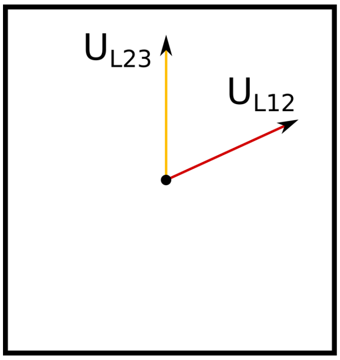
$$P_{L1} = U_{L1} \times I_{L1} \cos\varphi = 40.825\text{ V} \times 2.5\text{ A}\cos(45° - 0°) = 72.2\text{ W (secondary) } 2.89\text{ MW (primary)}$$

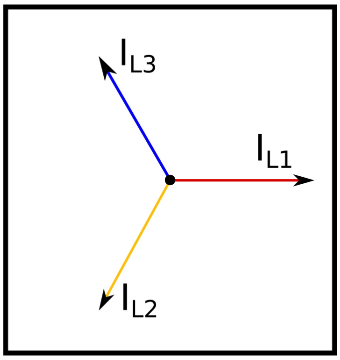
$$Q_{L1} = U_{L1} \times I_{L1} \sin\varphi = 40.825\text{ V} \times 2.5\text{ A}\sin(45° - 0°) = 72.2\text{ var (secondary) } 2.89\text{ MVar (primary)}$$

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

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°





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

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

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

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

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

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

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

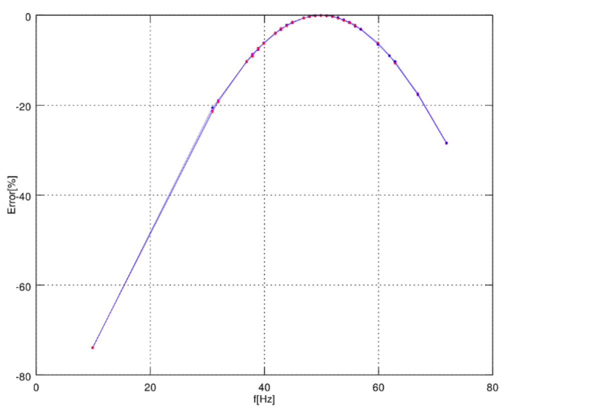
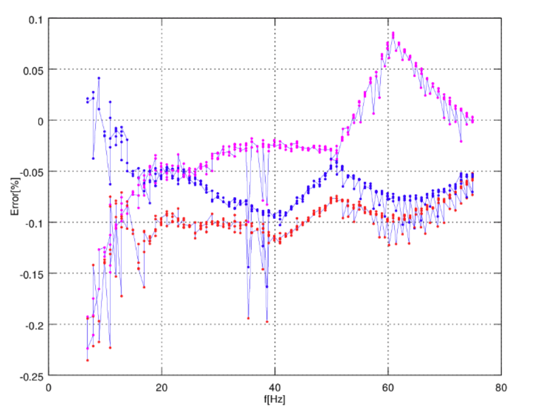
Name	Values
3PH (S)	20.00 MVA
3PH (P)	17.32 MW
3PH (Q)	0.00 Mvar
3PH Tan	0.00
3PH Cos	0.87

4.2.4 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.

Frequency independent current and voltage measurement accuracy is achieved with algorithms specified in patent US 10,809,287.

Table. 4.2.4 - 45. Frequency tracking effect (FF changes from 6 Hz to 75 Hz).

<table>
<tr>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>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.</td>
<td>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.</td>
</tr>
</table>

As the figures above show, the sampling frequency has a major effect on the device'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 % error in the whole frequency range.

AQ -200 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* → "Sampling mode") so the device adjusts the frequency itself.
The frequency readings are wrong.	In Tracking mode the device 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. 4.2.4 - 46. Settings of the frequency tracking.

Name	Range	Step	Default	Description
Sampling mode	• Fixed • Tracking	-	Fixed	Defines which measurement sampling mode is in use: the fixed user-defined frequency, or the tracked system frequency.
System nominal frequency	7.000…75.000Hz	0.001Hz	50Hz	The user-defined system nominal frequency that is used when the "Sampling mode" setting has been set to "Fixed".
Tracked system frequency	0.000…75.000Hz	0.001Hz	-	Displays the rough measured system frequency.
Sampling frequency in use	0.000…75.000Hz	0.001Hz	-	Displays the tracking frequency that is in use at that moment.
Frequency reference 1	• None • CT1IL1 • CT2IL1 • VT1U1 • VT2U1	-	CT1IL1	The first reference source for frequency tracking.
Frequency reference 2	• None • CT1IL2 • CT2IL2 • VT1U2 • VT2U2	-	CT1IL2	The second reference source for frequency tracking.
Frequency reference 3	• None • CT1IL3 • CT2IL3 • VT1U3 • VT2U3	-	CT1IL3	The third reference source for frequency tracking.
Frequency tracking quality	• No trackable channels • Reference 1 trackable • Reference 2 trackable • References 1 & 2 trackable • Reference 3 trackable • Reference 1 & 3 trackable • References 2 & 3 trackable • 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	• No track ch • Ref1 • Ref2 • Ref3	-	-	Indicates which reference is used at the moment for frequency tracking.

Name	Range	Step	Default	Description
Start behavior	• Start tracking immediately • First nominal or tracked	-	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	• Use track frequency • Use nom frequency	-	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	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".
Tracked f channel A	0.000…75.000Hz	0.001Hz	-	Displays the rough value of the tracked frequency in Channel A.
Tracked f channel B	0.000…75.000Hz	0.001Hz	-	Displays the rough value of the tracked frequency in Channel B.
Tracked f channel C	0.000…75.000Hz	0.001Hz	-	Displays the rough value of the tracked frequency in Channel C.
System measured frequency	• One f measured • Two f measured • Three f measured	-	-	Displays the amount of frequencies that are measured.
f.atm. Protections	0.000…75.000Hz	0.001Hz	-	Frequency measurement value used by protection functions. When frequency is not measurable this value returns to value set to "System nominal frequency" parameter.
f.atm. Display	0.000…75.000Hz	0.001Hz	-	Frequency measurement value used in display. When frequency is not measurable this value is "0 Hz".
f measurement from	• Not measurable • Avg Ref 1 • Avg Ref 2 • Avg Ref 3 • Track Ref 1 • Track Ref 2 • Track Ref 3 • Fast Ref 1 • Fast Ref 2 • Fast Ref 3	-	-	Displays which reference is used for frequency measurement.
SS1.meas.frqs SS2.meas.frqs	0.000…75.000Hz	0.001Hz	-	Displays frequency used by "system set" channel 1 and 2.

Name	Range	Step	Default	Description
SS1f meas.from	• Not measurable • Fast Ref U3 • Fast Ref U4	-	-	Displays which voltage channel frequency reference is used by "system set" voltage channel.
SS2f meas.from	• Not measurable • Fast Ref U4	-	-	Displays if U4 channel frequency reference is measurable or not when the channel has been set to "system set" mode.

4.3 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. 4.3 - 47. The *General* menu read-only parameters

Name	Description
Serial number	The unique serial number identification of the unit.
Firmware version	The firmware software version of the unit.
Hardware configuration	The order code identification of the unit.
System phase rotating order at the moment	The selected system phase rotating order. Can be changed with parameter "System phase rotating order".
UTC time	The UTC time value which the device's clock uses.

Table. 4.3 - 48. Parameters and indications in the *General* menu.

Name	Range	Default	Description
Device name	-	Unitname	The file name uses these fields when loading the .aqs configuration file from the AQ-200 unit.
Device location	-	Unitlocation	
Enable stage forcing	• Disabled • Enabled	Disabled	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 *Force status to* parameter.
Allow setting of device mode	• Prohibited • From HMI/ setting tool only • Allowed	Prohibited	Allows global mode to be modified from setting tool, HMI and IEC61850. Prohibited: Cannot be changed. From HMI/setting tool only: Can only be changed from the setting tool or HMI Allowed: Can be changed from the setting tool, HMI, and IEC 61850 client.

Name	Range	Default	Description
Allow setting of individual LN mode	• Prohibited • From HMI/ setting tool only • Allowed	Prohibited	Allow local modes to be modified from setting tool, HMI and IEC61850. Prohibited: Cannot be changed. From HMI/setting tool only: Can only be changed from the setting tool or HMI Allowed: Can be changed from the setting tool, HMI, and IEC 61850 client.
System phase rotating order	• A-B-C • A-C-B	A-B-C	Allows the user to switch the expected order in which the phase measurements are wired to the unit.
Language	• User defined • English • Finnish • Chinese • Spanish • French • German • Russian • Ukrainian • Kazakh	English	Changes the language of the parameter descriptions in the HMI. If the language has been set to "Other" in the settings of the AQtivate setting tool, AQtivate follows the value set into this parameter.
AQtivate ethernet port	• All • COM A • Double Ethernet card	All	If the device has a double Ethernet option card it is possible to choose which ports are available for connecting with AQtivate software.
Clear events	• - • Clear	-	Clears the event history recorded in the AQ-200 device.
Display brightness	0…8	4	Changes the display brightness. Brightness level 0 turns the display off.
Display sleep timeout	0…3600s	0s	If no buttons are pressed after a set time, the display changes the brightness to whatever is set on the "Display sleep brightness" parameter. If set to 0 s, this feature is not in use. When the device is in sleep mode pressing any of the buttons on the front panel of the device will wake the display.
Display sleep brightness	0…8	0	Defines the brightness of the display when the set display sleep timeout has elapsed. The brightness level "0" turns the display off.
Return to default view	0…3600s	0s	If the user navigates to a menu and gives no input after a period of time defined with this parameter, the unit automatically returns to the default view. If set to 0 s, this feature is not in use.
LED test	• - • Activated	-	When activated, all LEDs are lit up. LEDs with multiple possible colors blink each color.
HMI restart	• - • Restart	-	When activated, display restarts.
Display color theme	• Light theme • Dark theme	Light theme	Defines the color theme used in the HMI.

Name	Range	Default	Description
Reset latches	• - • Reset	-	Resets the latched signals in the logic and the matrix. When a reset command is given, the parameter automatically returns back to "-".
Measurement recorder	• Disabled • Enabled	Disabled	Enables the measurement recorder tool, further configured in *Tools → Misc → Measurement recorder.*
I/0 default object selection	• OBJ1 • OBJ2 • OBJ3 • OBJ4 • OBJ5 • OBJ6 • OBJ7 • OBJ8 • OBJ9 • OBJ10	OBJ1	"I" and "0" push buttons on the front panel of the device have an indication LED. This parameter defines which objects' status push buttons follow when lighting up the LEDs.
Device Mode	• On • Blocked • Test • Test/ Blocked • Off	On	Set mode of device block. This parameter is visible only when *Allow setting of device mode* is enabled in *General* menu.
Reconfigure mimic	• - • Reconfigure	-	Reloads the mimic to the unit.

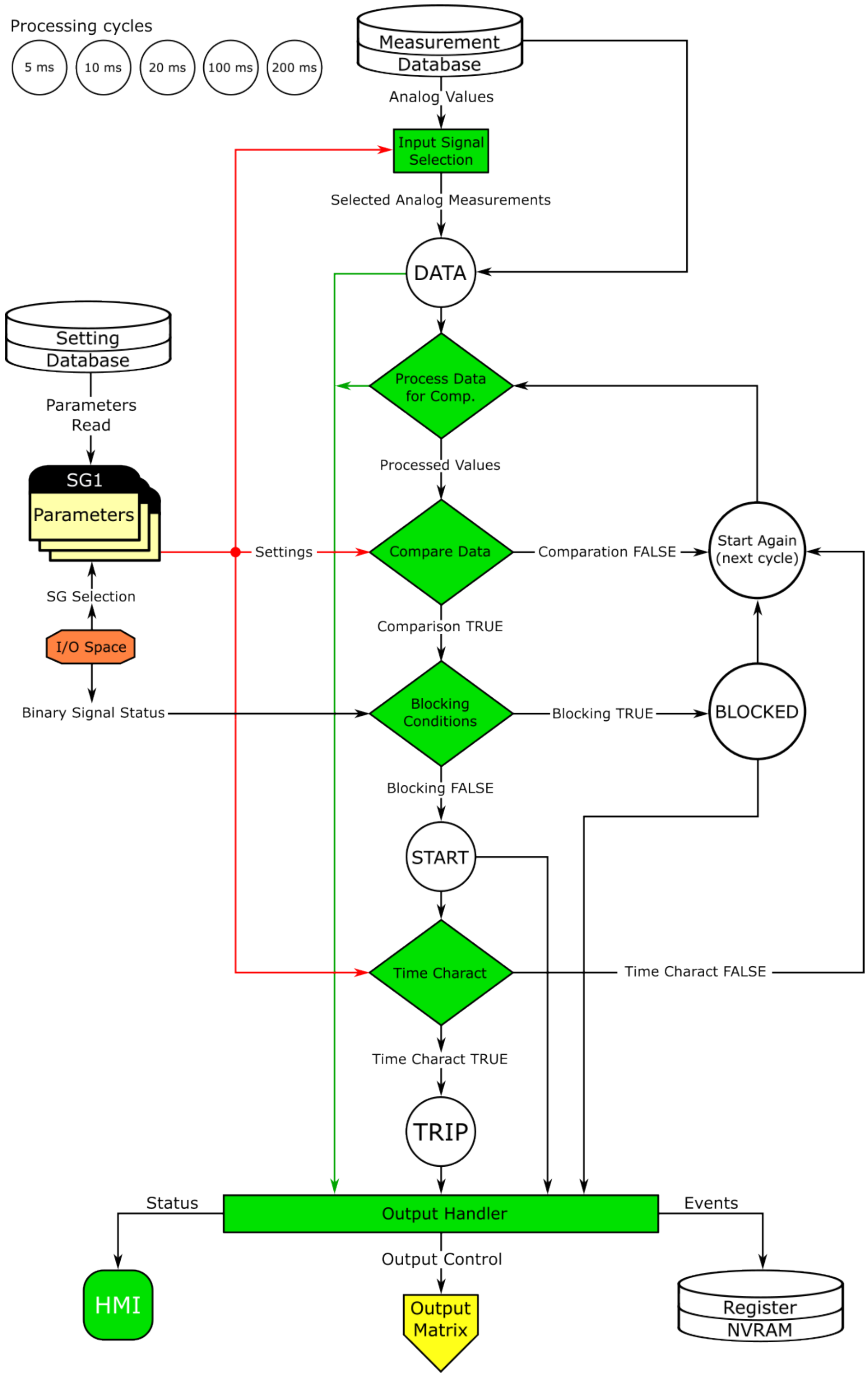
Table. 4.3 - 49. General menu logical inputs.

Name	Description
Reset last fault registers	Signal set to this point can be used for resetting latest recorded fault register.
Reset latches	Signals set to this point can be used for resetting latched signals. An alternative to using the "Back" button on the front panel of the device.
Ph.Rotating Logic control 0=A-B-C, 1=A-C-B	Signals set to this point can be used for switching the expected phase rotating order.

4.4 Protection functions

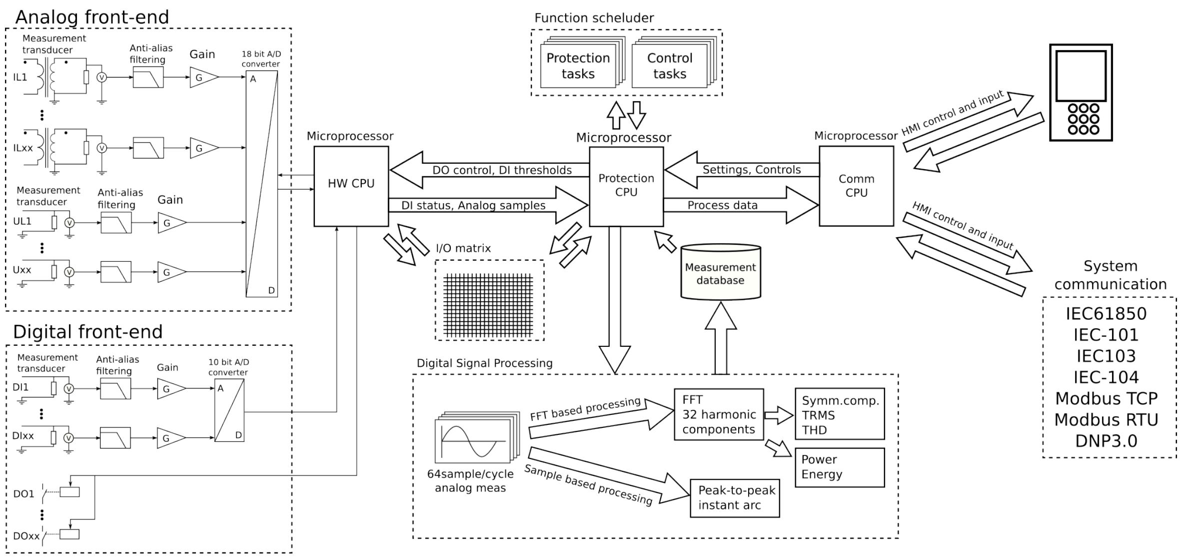
4.4.1 General properties of a protection function

The following flowchart describes the basic structure of any protection function. The basic structure is composed of analog measurement values being compared to the pick-up values and operating time characteristics.



The protection function is run in a completely digital environment with a protection CPU microprocessor which also processes the analog signals transformed into the digital form.

Figure. 4.4.1 - 20. Principle diagram of the protection device platform.



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

Pick-up

The X_{set} parameter defines the pick-up level of the function, and this in turn defines the maximum or minimum allowed measured magnitude (in per unit, absolute or percentage value) before the function takes action. The function constantly calculates the ratio between the pick-up parameter set by the user and the measured magnitude (X_m). The reset ratio of 97 % is built into the function and is always relative to the X_{set} value. If a function's pick-up characteristics vary from this description, they are defined in the function section in the manual.

Figure. 4.4.1 - 21. Pick up and reset.

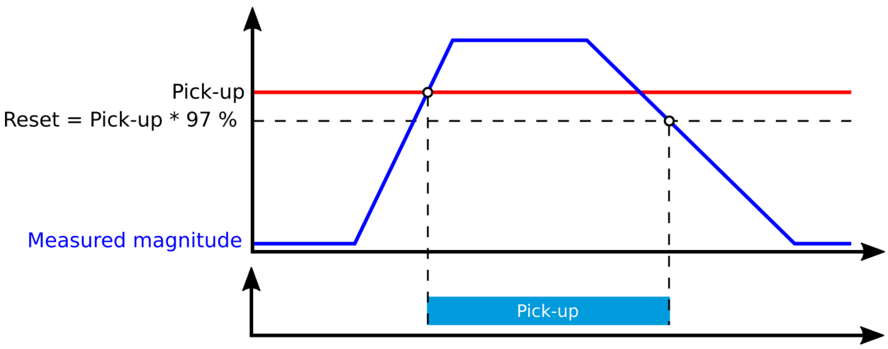
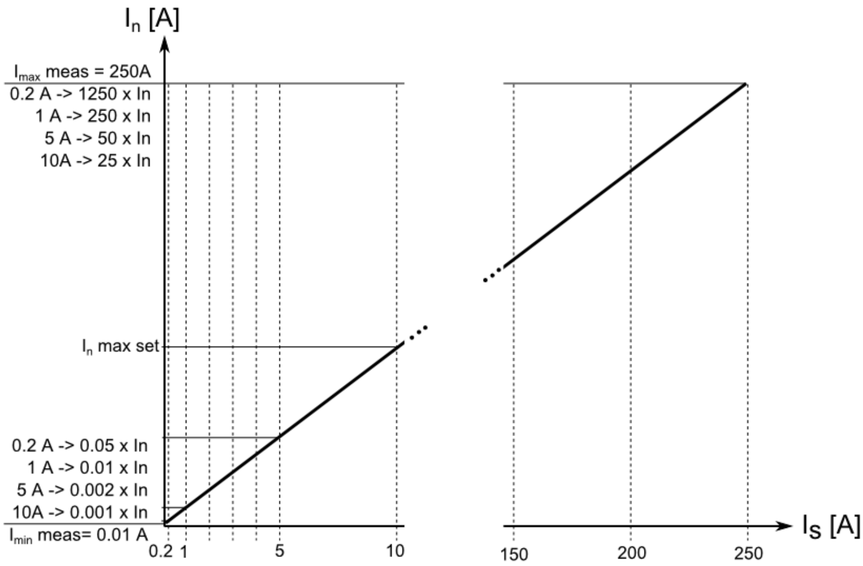


Figure. 4.4.1 - 22. Measurement range in relation to the nominal current.



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

Function blocking

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

If the blocking signal is active when pick-up element activates, a BLOCKED signal is generated and the function will 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 variables users 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 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: activates the trip signal with no additional time delay simultaneously with the start signal.
- Definite time operation (DT): activates the trip signal after a user-defined time delay regardless of the measured current as long as the current is above or below the X_{set} value and thus the pick-up element is active (independent time characteristics).
- Inverse definite minimum time (IDMT): activates the trip signal after a time which is in relation to the set pick-up value X_{set} and the measured value X_m (dependent time characteristics).

Both IEC and IEEE/ANSI standard characteristics as well as user settable parameters are available for the IDMT operation. Please note that in the IDMT mode *Definite (Min)* operating time delay is also determines the minimum time for protection tripping (see the figure below). If this function is not desired the parameter should be set to 0 seconds.

Figure. 4.4.1 - 23. Operating time delay: *Definite (Min)* and the minimum for tripping.

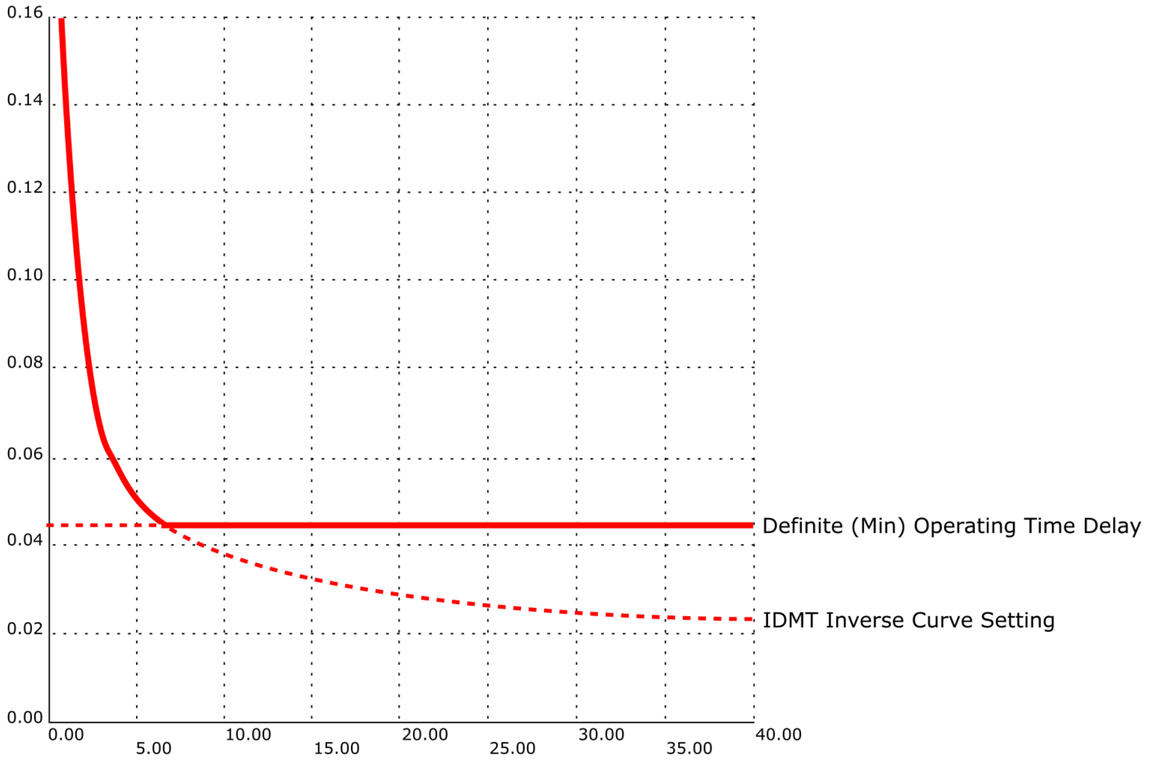


Table. 4.4.1 - 50. Operating time characteristics setting parameters (general).

Name	Range	Step	Default	Description
Delay type	• DT • IDMT	-	DT	Selects the delay type for the time counter. The selection is made between dependent (IDMT) and independent (DT) characteristics.
Definite (min) operating time delay	0.000…1800.000s	0.005s	0.040s	When the "Delay type" parameter is set to "DT", this parameter acts as the expected operating time for the protection function. When set to 0 s, the stage operates instantaneously without any additional delay. When the parameter is set to 0.005...1800 s, the stage operates as independent delayed. When the "Delay type" parameter has been set to "IDMT", this parameter can be used to determine the minimum operating time for the protection function. Example of this is presented in the figure above.
Delay curve series	• IEC • IEEE	-	IEC	Selects whether the delay curve series for an IDMT operation follows either IEC or IEEE/ANSI standard defined characteristics. This setting is active and visible when the "Delay type" parameter is set to "IDMT".

Name	Range	Step	Default	Description
Delay characteristics IEC	• NI • EI • VI • LTI • Param	-	NI	Selects the IEC standard delay characteristics. The options include the following: Normally Inverse ("NI"), Extremely Inverse ("EI"), Very Inverse ("VI") and Long Time Inverse ("LTI") characteristics. Additionally, the "Param" option allows the tuning of the constants A and B which then allows the setting of characteristics following the same formula as the IEC curves mentioned here. This setting is active and visible when the "Delay type" parameter is set to "IDMT" and the "Delay curve series" parameter is set to "IEC".
Delay characteristics IEEE	• ANSI NI • ANSI VI • ANSI EI • ANSI LTI • IEEE MI • IEEE VI • IEEE EI • Param	-	ANSI NI	Selects the IEEE and ANSI standard delay characteristics. The options for ANSI include the following: Normal Inverse ("ANSI NI"), Very Inverse ("ANSI VI"), Extremely inverse ("ANSI EI"), Long time inverse ("ANSI LTI") characteristics. IEEE: Moderately Inverse ("IEEE MI"), Very Inverse ("IEEE VI"), Extremely Inverse ("IEEE EI") characteristics. Additionally, the "Param" option allows the tuning of the constants A, B and C which then allows the setting of characteristics following the same formula as the IEEE curves mentioned here. This setting is active and visible when the "Delay type" parameter is set to "IDMT" and the "Delay curve series" parameter is set to "IEEE".
Time dial setting k	0.01…25.00s	0.01s	0.05s	Defines the time dial/multiplier setting for IDMT characteristics. This setting is active and visible when the "Delay type" parameter is set to "IDMT".
A	0.0000…250.0000	0.0001	0.0860	Defines the Constant A for IEC/IEEE characteristics. This setting is active and visible when the "Delay type" parameter is set to "IDMT" and the "Delay characteristic" parameter is set to "Param".
B	0.0000…5.0000	0.0001	0.1850	Defines the Constant B for IEC/IEEE characteristics. This setting is active and visible when the "Delay type" parameter is set to "IDMT" and the "Delay characteristic" parameter is set to "Param".
C	0.0000…250.0000	0.0001	0.0200	Defines the Constant C for IEEE characteristics. This setting is active and visible when the "Delay type" parameter is set to "IDMT" and the "Delay characteristic" parameter is set to "Param".

Figure. 4.4.1 - 24. Inverse operating time formulas for IEC and IEEE standards.

IEC	IEEE/ANSI
$t = \frac{kA}{\left(\frac{I_m}{I_{set}}\right)^B - 1}$	$t = k\left(\frac{A}{\left(\frac{I_m}{I_{set}}\right)^C - 1} + B\right)$
t = Operating delay (s) k = Time dial setting I_m = Measured maximum current I_{set} = Pick-up setting A = Operating characteristics constant B = Operating characteristics constant	t = Operating delay (s) k = Time dial setting I_m = Measured maximum current I_{set} = Pick-up setting A = Operating characteristics constant B = Operating characteristics constant C = Operating characteristics constant

Standard delays IEC constants

Type	**A**	**B**
Normally Inverse (*NI*)	0,14	0,02
Extremely Inverse (*EI*)	80	2
Very Inverse (*VI*)	13,5	1
Long Time Inverse (*LTI*)	120	1

Standard delays ANSI constants

Type	**A**	**B**	**C**
Normally Inverse (*NI*)	8,934	0,1797	2,094
Very Inverse (*VI*)	3,922	0,0982	2
Extremely Inverse (*EI*)	5,64	0,02434	2
Long Time Inverse (*LTI*)	5,614	2,186	1

Standard delays IEEE constants

Type	**A**	**B**	**C**
Moderately Inverse (*MI*)	0,0515	0,114	0,02
Very Inverse (*VI*)	19,61	0,491	2
Extremely Inverse (*EI*)	28,2	0,1217	2

Non-standard delay characteristics

In addition to the previously mentioned delay characteristics, some functions also have delay characteristics that deviate from the IEC or IEEE standards. These functions are the following:

- overcurrent stages
- residual overcurrent stages
- directional overcurrent stages
- directional residual overcurrent stages.

The setting parameters and their ranges are documented in the chapters of the respective function blocks.

Table. 4.4.1 - 51. Inverse operating time formulas for nonstandard characteristics.

RI-type	RD-type
Used to get time grading with mechanical relays.	Mostly used in earth fault protection which grants selective tripping even in non-directional protection. NOTE: when "k" has been set lower than 0.3 calculated operation time can be lower than 0 seconds with some measurement values. In these cases operation time will be instant.
$t = \frac{k}{0.339 - 0.236 * \frac{I_{set}}{I_m}}$	$t = 5.8 - 1.35 * \ln\left(\frac{I_m}{k * I_{set}}\right)$

RI-type	RD-type
t = Operating delay (s) k = Time dial setting I_m = Measured maximum current I_{set} = Pick-up setting	t = Operating delay (s) k = Time dial setting I_m = Measured maximum current I_{set} = Pick-up setting

NOTICE!
When using RD-type and "k" has been set lower than 0.3 calculated operation time can be lower than 0 seconds with some measurement values. In these cases operation time will be instant.

Table. 4.4.1 - 52. Setting parameters for reset time characteristics.

Name	Range	Step	Default	Description
Delayed pick-up release	• No • Yes	-	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.
Release time delay	0.000…150.000s	0.005s	0.06s	Resetting time. The time allowed between pick-ups if the pick-up has not led into a trip operation. If the "Delayed pick-up release" setting is active, the START signal is held on for the duration of the timer.
Op.Time calculation 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 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	• No • Yes	-	No	Time calculation characteristics selection. If activated, the operating time counter continues until a set release time even if the pick-up element is reset.

The behavior of the stages with different release time configurations are presented in the figures below.

Figure. 4.4.1 - 25. No delayed pick-up release.

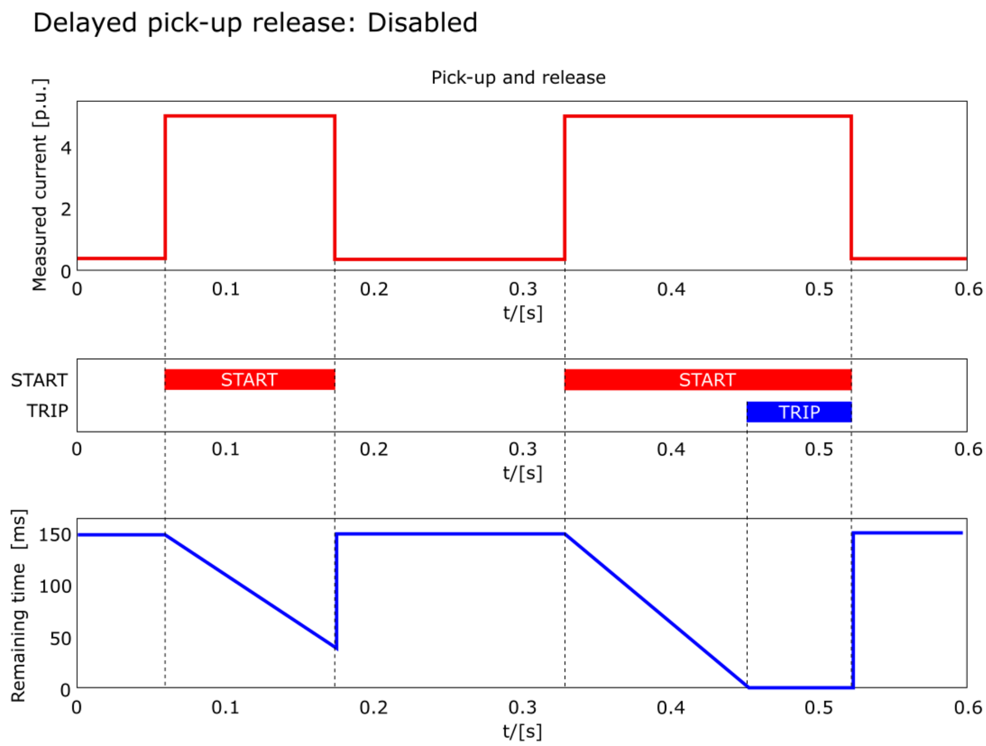


Figure. 4.4.1 - 26. Delayed pick-up release, delay counter is reset at signal drop-off.

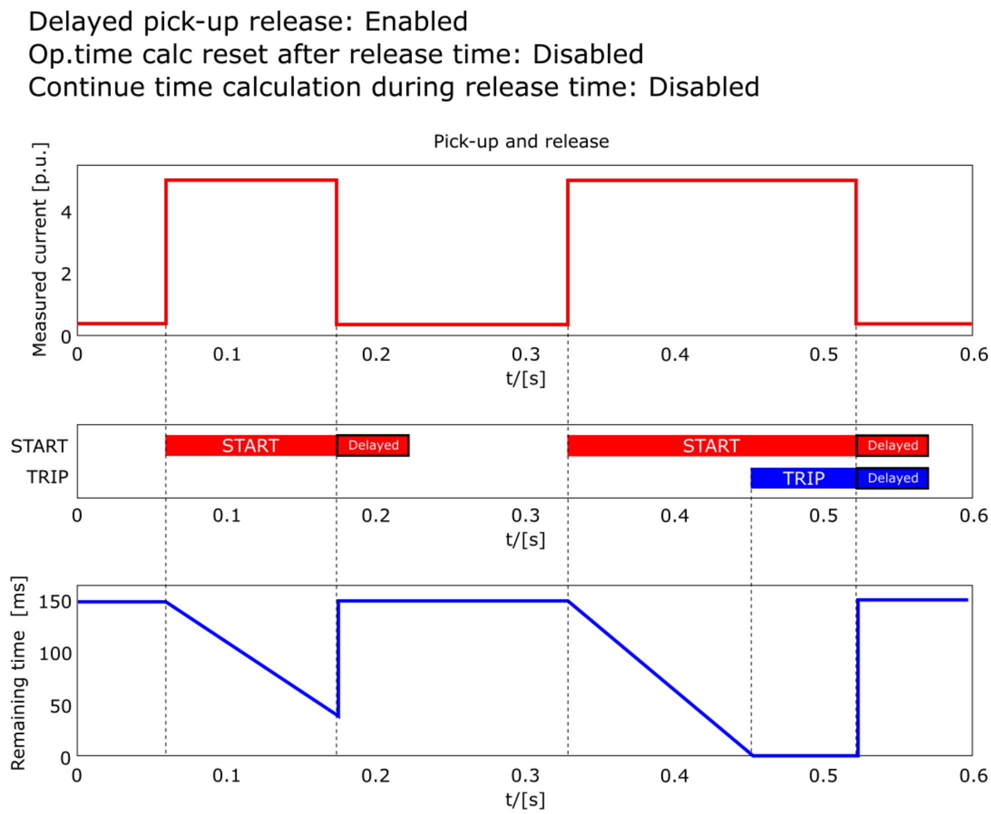


Figure. 4.4.1 - 27. Delayed pick-up release, delay counter value is held during the release time.

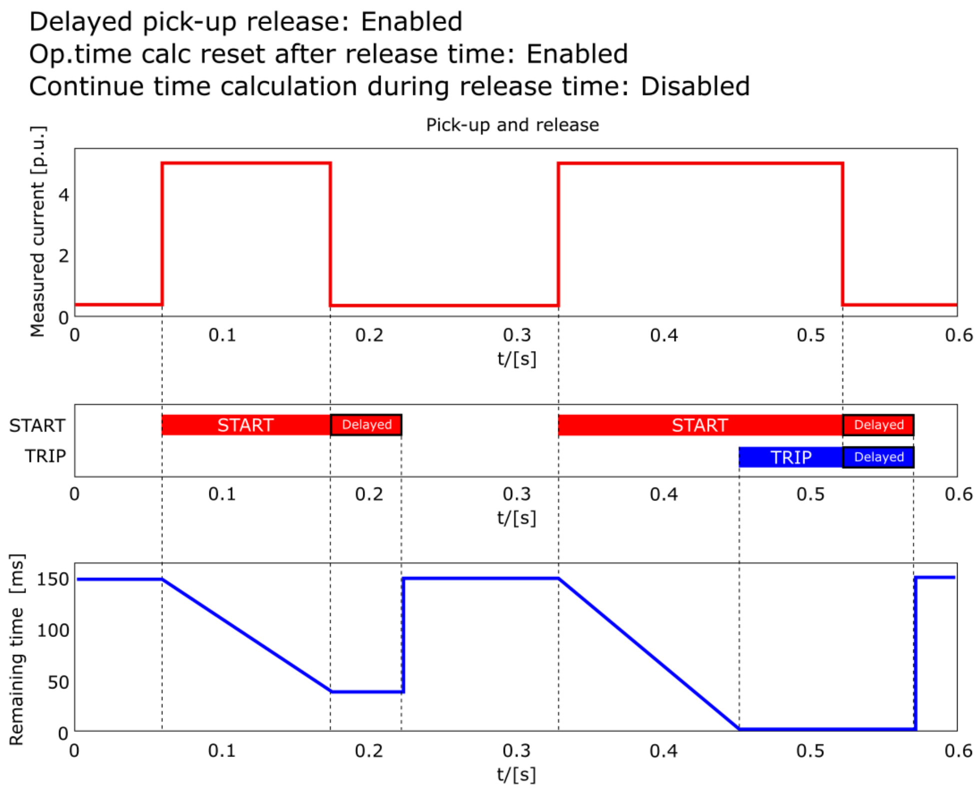
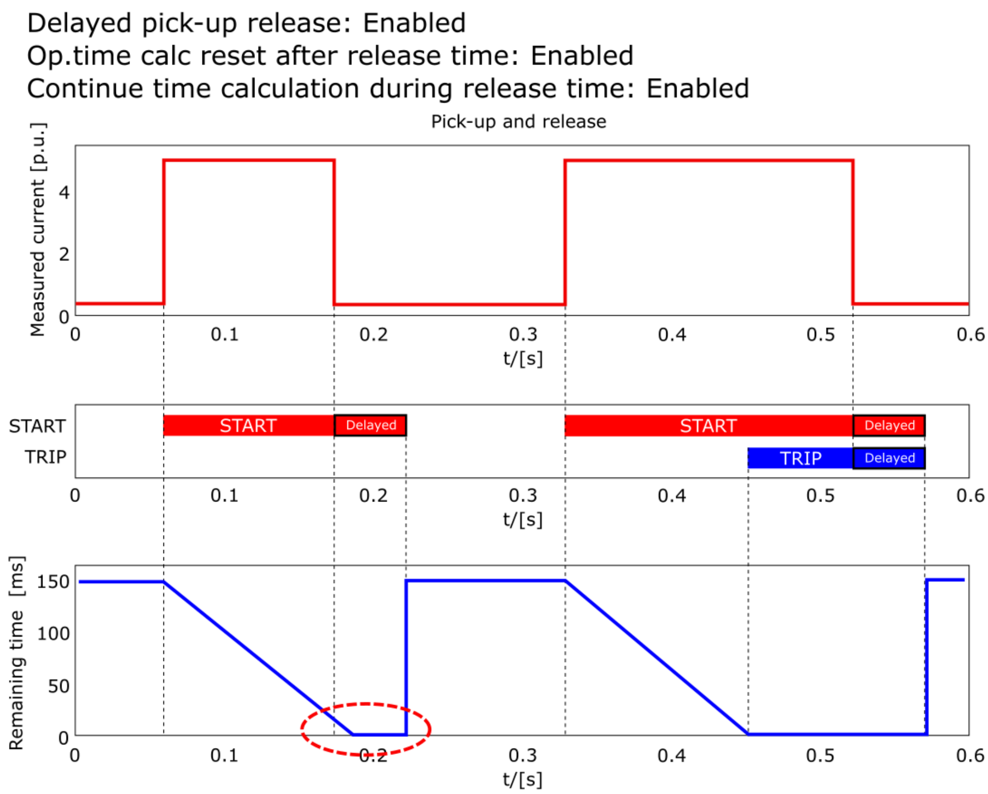


Figure. 4.4.1 - 28. Delayed pick-up release, delay counter value is decreasing during the release time.



The resetting characteristics can be set according to the application. The default setting is delayed 60 ms and the time calculation is held during the release time.

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

Stage forcing

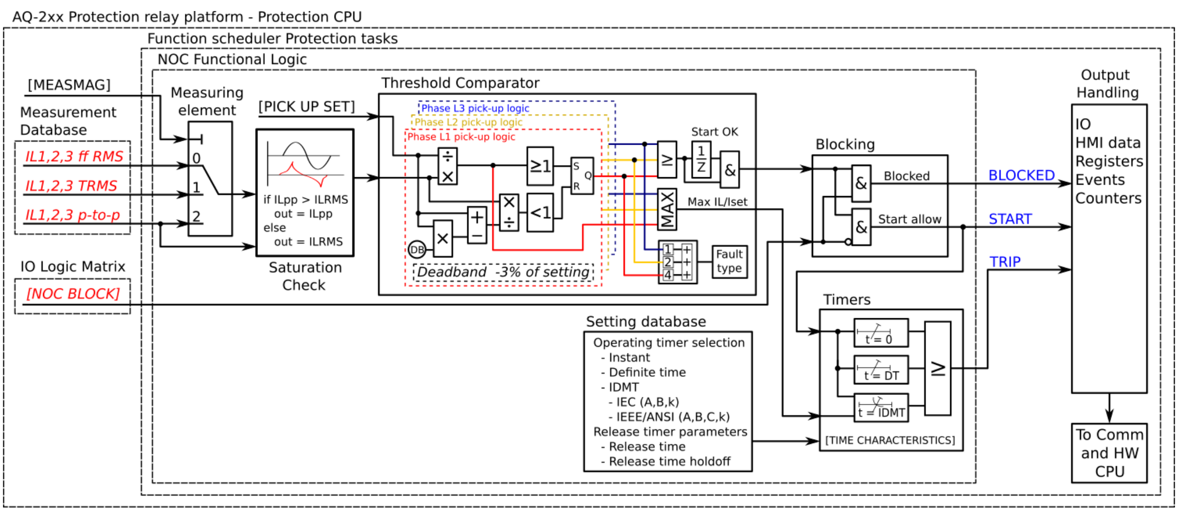
It is possible to test the logic, event processing and the operation of the device's logic by controlling the state of the protection functions manually without injecting any current into the device with stage forcing. To enable *Stage forcing* set the *Enable stage forcing* to ENABLED in the *General*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

> NOTICE!
> When *Stage forcing* is enabled protection functions will also change state through user input. Injected currents/voltages also affect the behavior of the device. Regardless, it is recommended to disable *Stage Forcing* after testing has ended.

4.4.2 Non-directional overcurrent protection (I>; 50/51)

The non-directional overcurrent function is used for instant and time-delayed overcurrent and short-circuit protection. The function is used for one-phase, two-phase or three-phase overcurrent and short circuit protection. The function offers four (4) independent stages. The operating decisions are based on phase current magnitude, constantly measured by the function.

Figure. 4.4.2 - 29. Simplified function block diagram of the I> function.



Measured input

The function block uses phase current measurement values. The user can select the monitored magnitude to be equal either to RMS values (fundamental frequency component), to TRMS values from the whole harmonic specter of 32 components, or to peak-to-peak values.

Table. 4.4.2 - 53. Measurement inputs of the I> function.

Signal	Description	Time base
I_{L1}RMS	Fundamental frequency component of phase L1 (A) current measurement	5ms
I_{L2}RMS	Fundamental frequency component of phase L2 (B) current measurement	5ms

Signal	Description	Time base
I_{L3}RMS	Fundamental frequency component of phase L3 (C) current measurement	5ms
I_{L1}TRMS	TRMS measurement of phase L1 (A) current	5ms
I_{L2}TRMS	TRMS measurement of phase L2 (B) current	5ms
I_{L3}TRMS	TRMS measurement of phase L3 (C) current	5ms
I_{L1}PP	Peak-to-peak measurement of phase L1 (A) current	5ms
I_{L2}PP	Peak-to-peak measurement of phase L2 (B) current	5ms
I_{L3}PP	Peak-to-peak measurement of phase L3 (C) current	5ms

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. 4.4.2 - 54. General settings of the function.

Name	Range	Default	Description
Setting control from comm bus	• Disabled • Allowed	• Disabled	Activating this parameter allows changing the pick-up level of the protection stage via SCADA.
I> LN mode	• On • Blocked • Test • Test/ Blocked • Off	• On	Set mode of NOC block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
I> force status to	• Normal • Start • Trip • Blocked • Start A • Start B • Start C • Trip A • Trip B • Trip C • Start AB • Start BC • Start CA • Start ABC • Trip AB • Trip BC • Trip CA • Trip ABC	• Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.

Name	Range	Default	Description
Measured magnitude	• RMS • TRMS • Peak-to-peak	• RMS	Defines which available measured magnitude is used by the function.
Measurement side	• Side 1 • Side 2	• Side 1	Defines which current measurement module is used by the function.

Pick-up settings

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.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.4.2 - 55. Pick-up settings.

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

Read-only parameters

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

Table. 4.4.2 - 56. Information displayed by the function.

Name	Range	Step	Description
I> LN behaviour	• On • Blocked • Test • Test/Blocked • Off	-	Displays the mode of NOC block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
I> condition	• Normal • Start • Trip • Blocked	-	Displays status of the protection function.

Name	Range	Step	Description
I> phases condition	• Normal • Start A • Start B • Start C • Trip A • Trip B • Trip C • Start AB • Start BC • Start CA • Start ABC • Trip AB • Trip BC • Trip CA • Trip ABC	-	Displays the status of phases individually.
Expected operating time	0.000...1800.000s	0.005s	Displays the expected operating time when a fault occurs. When IDMT mode is used, the expected operating time depends on the measured highest phase current value. If the measured current changes during a fault, the expected operating time changes accordingly.
Time remaining to trip	-1800.000...1800.000s	0.005s	When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs.
I_{meas}/I_{set} at the moment	0.00...1250.00	0.01	The ratio between the highest measured phase current 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. Additionally, the 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. 4.4.2 - 57. Internal inrush harmonic blocking settings.

Name	Range	Step	Default	Description
Inrush harmonic blocking (internal-only trip)	• No • Yes	-	• No	Enables and disables the 2^{nd} harmonic blocking.
2^{nd} harmonic blocking limit (Iharm/Ifund)	0.10…50.00%I_{fund}	0.01%I_{fund}	0.01%I_{fund}	Defines the limit of the 2^{nd} harmonic blocking.

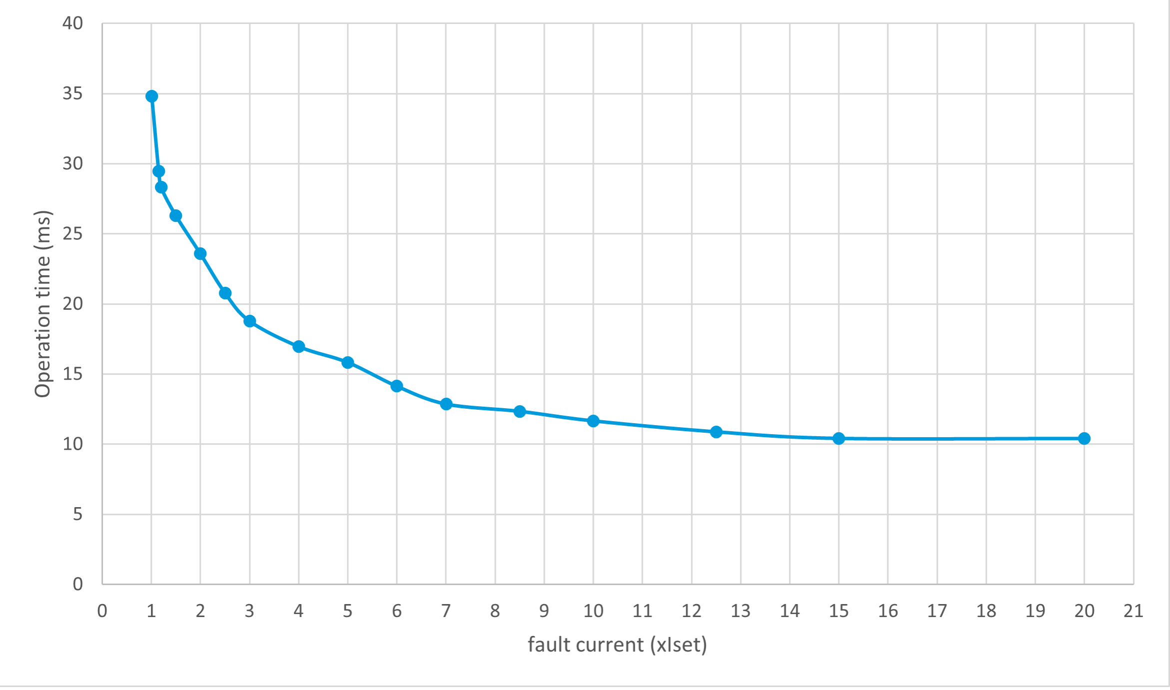
If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when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

The 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".

Figure. 4.4.2 - 30. Typical operation time delays with different current to setting ratios in instant operation mode.



Events and registers

The non-directional overcurrent function (abbreviated "NOC" in event block names) generates events and registers from the status changes in the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's output can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

Table. 4.4.2 - 58. Event messages.

Event block name	Event names
NOC1...NOC4	Start ON
NOC1...NOC4	Start OFF
NOC1...NOC4	Trip ON
NOC1...NOC4	Trip OFF
NOC1...NOC4	Block ON
NOC1...NOC4	Block OFF
NOC1...NOC4	Phase A Start ON

Event block name	Event names
NOC1...NOC4	Phase A Start OFF
NOC1...NOC4	Phase B Start ON
NOC1...NOC4	Phase B Start OFF
NOC1...NOC4	Phase C Start ON
NOC1...NOC4	Phase C Start OFF
NOC1...NOC4	Phase A Trip ON
NOC1...NOC4	Phase A Trip OFF
NOC1...NOC4	Phase B Trip ON
NOC1...NOC4	Phase B Trip OFF
NOC1...NOC4	Phase C Trip ON
NOC1...NOC4	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.

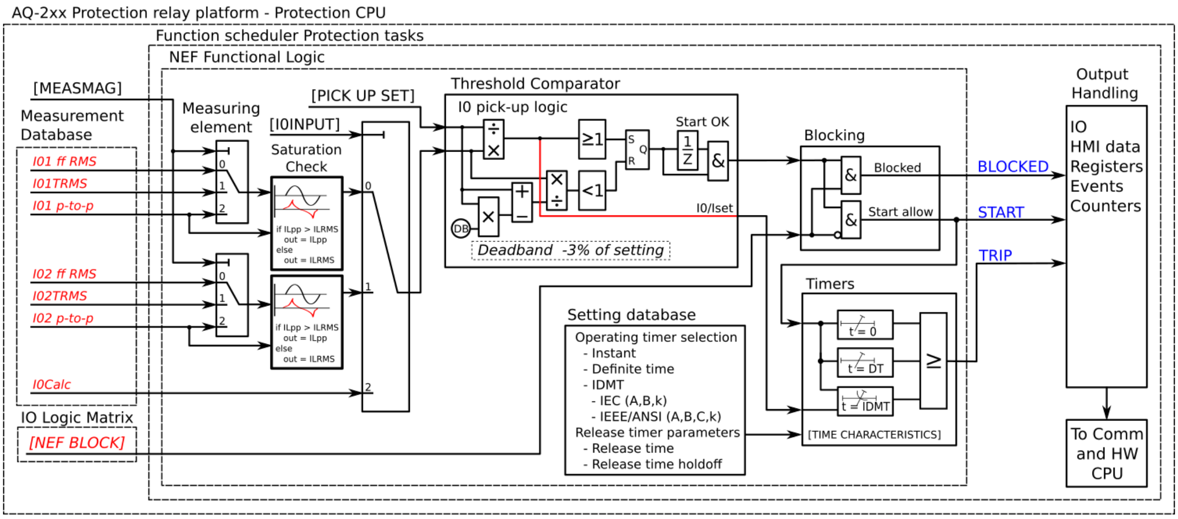
Table. 4.4.2 - 59. Register content.

Name	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
Fault type	L1-E…L1-L2-L3
Pre-trigger current	Start/Trip -20ms current
Fault current	Start/Trip current
Pre-fault current	Start -200ms current
Trip time remaining	0 ms...1800s
Setting group in use	Setting group 1...8 active.

4.4.3 Non-directional earth fault protection (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 magnitude which the function measures constantly.

Figure. 4.4.3 - 31. Simplified function block diagram of the I0> fucntion.



Measured input

The function block uses residual current measurement values. The available analog measurement channels are I_{01} and I_{02} (residual current measurement) and I_{0Calc} (residual current calculated from phase current). The user can select the monitored magnitude to be equal either to RMS values (fundamental frequency component), to TRMS values from the whole harmonic specter of 32 components, or to peak-to-peak values.

Table. 4.4.3 - 60. Measurement inputs of the I0> function.

Signal	Description	Time base
I_{01}RMS	Fundamental frequency component of coarse residual current measurement input I01	5 ms
I_{01}TRMS	TRMS measurement of coarse residual current measurement input I01	5 ms
I_{01}PP	Peak-to-peak measurement of coarse residual current measurement input I01	5 ms
I_{02}RMS	Fundamental frequency component of sensitive residual current measurement input I02	5 ms
I_{02}TRMS	TRMS measurement of coarse sensitive current measurement input I02	5 ms
I_{02}PP	Peak-to-peak measurement of sensitive residual current measurement input I02	5 ms
I_{0Calc}	Fundamental frequency component of the calculated zero sequence current calculated from the three phase currents	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 editing the setting group.

Table. 4.4.3 - 61. General settings of the function.

Name	Range	Default	Description
Setting control from comm bus	• Disabled • Allowed	Disabled	Activating this parameter permits changing the pick-up level of the protection stage via SCADA.
I0> LN mode	• On • Blocked • Test • Test/ Blocked • Off	On	Set mode of NEF block. This parameter is visible only when Allow setting of individual LN mode is enabled in General menu.
I0> force status to	• Normal • Start • Trip • Blocked	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.
Measured magnitude	• RMS • TRMS • Peak-to-peak	RMS	Defines which available measured magnitude is used by the function. This parameter is available when "Input selection" has been set to "I01" or "I02".
Measurement side	• Side 1 • Side 2	Side 1	Defines which current measurement module is used by the function.
Input selection	• I01 • I02 • I0Calc	I01	Defines which measured residual current is used by the function.

Pick-up settings

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.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.4.3 - 62. Pick-up settings.

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

Read-only parameters

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

Table. 4.4.3 - 63. Information displayed by the function.

Name	Range	Step	Description
I0> LN behaviour	• On • Blocked • Test • Test/Blocked • Off	-	Displays the mode of NEF block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
I0> condition	• Normal • Start • Trip • Blocked	-	Displays status of the protection function.
Detected I0 angle	-360.00...360.00 deg	0.01 deg	Angle of I0 against reference. If phase voltages are available, positive sequence voltage angle is used as reference. If voltages are not available, positive sequence current angle is used as reference.
Detected fault type	• - • A-G-R • B-G-F • C-G-R • A-G-F • B-G-R • C-G-F	-	Displays the detected fault type and direction of previous fault. "A/B/C" stand for one of the three phases. "G" stands for "ground". "F" stands for "forward" direction and "R" stands for "reverse" direction.
Expected operating time	-1800.000...1800.000 s	0.005 s	Displays the expected operating time when a fault occurs. When IDMT mode is used, the expected operating time depends on the measured current value. If the measured current changes during a fault, the expected operating time changes accordingly.
Time remaining to trip	0.000...1800.000 s	0.005 s	When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs.
I_{meas}/I_{set} at the moment	0.00...1250.00	0.01	The ratio between the measured current 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. Additionally, the 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. 4.4.3 - 64. Internal inrush harmonic blocking settings.

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

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 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 the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The function offers four (4) independent stages; the events are segregated for each stage operation.

Table. 4.4.3 - 65. Event messages.

Event block name	Event names
NEF1...NEF4	Start ON
NEF1...NEF4	Start OFF
NEF1...NEF4	Trip ON
NEF1...NEF4	Trip OFF
NEF1...NEF4	Block ON
NEF1...NEF4	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. 4.4.3 - 66. Register content.

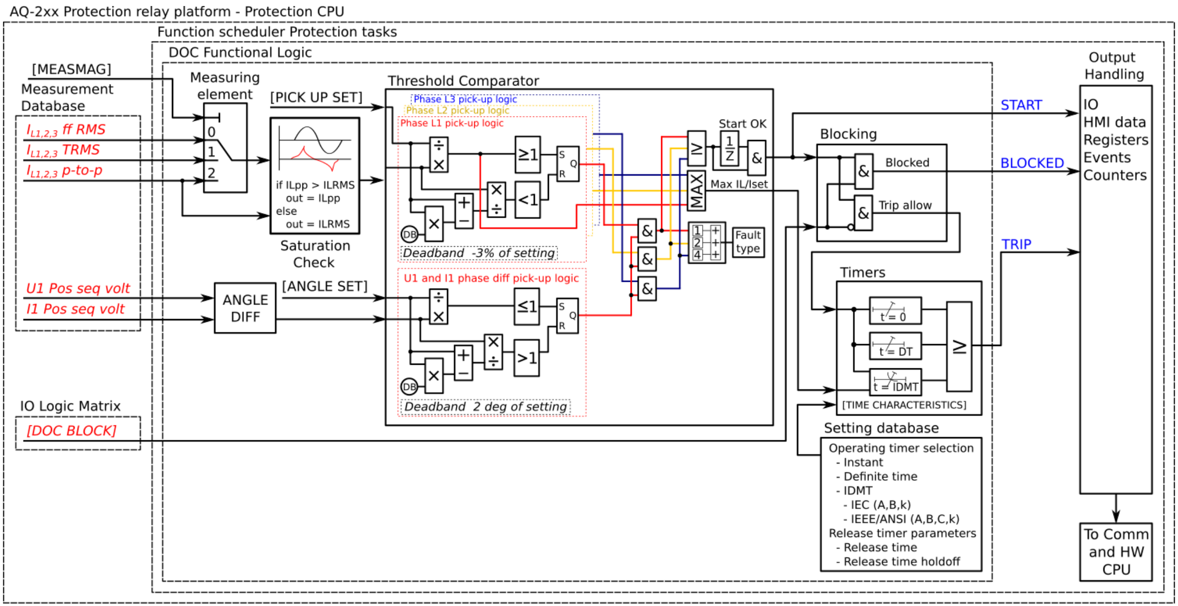
Name	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
Fault type	A-G-R...C-G-F
Pre-trigger current	Start/Trip -20ms current

Name	Description
Fault current	Start/Trip current
Pre-fault current	Start -200ms current
Trip time remaining	0 ms...1800s
Setting group in use	Setting group 1...8 active.

4.4.4 Directional overcurrent protection (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.

Figure. 4.4.4 - 32. Simplified function block diagram of the Idir> function.



Measured input

The function block uses phase current and voltage measurement values. The user can select the monitored current magnitude to be equal either to RMS values (fundamental frequency component), to TRMS values from the whole harmonic specter of 32 components, or to peak-to-peak values.

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. 4.4.4 - 67. Measurement inputs of the Idir> function.

Signal	Description	Time base
I_{L1}RMS	Fundamental frequency component of phase L1 (A) current measurement	5ms

Signal	Description	Time base
I_{L2}RMS	Fundamental frequency component of phase L2 (B) current measurement	5ms
I_{L3}RMS	Fundamental frequency component of phase L3 (C) current measurement	5ms
I_{L1}TRMS	TRMS measurement of phase L1 (A) current	5ms
I_{L2}TRMS	TRMS measurement of phase L2 (B) current	5ms
I_{L3}TRMS	TRMS measurement of phase L3 (C) current	5ms
I_{L1}PP	Peak-to-peak measurement of phase L1 (A) current	5ms
I_{L2}PP	Peak-to-peak measurement of phase L2 (B) current	5ms
I_{L3}PP	Peak-to-peak measurement of phase L3 (C) current	5ms
U_1RMS	Fundamental frequency component of U_1/V voltage measurement	5ms
U_2RMS	Fundamental frequency component of U_2/V voltage measurement	5ms
U_3RMS	Fundamental frequency component of U_3/V voltage measurement	5ms
U_4RMS	Fundamental frequency component of U_4/V voltage measurement	5ms

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. 4.4.4 - 68. General settings of the function.

Name	Range	Default	Description
Idir> LN mode	• On • Blocked • Test • Test/ Blocked • Off	On	Set mode of DOC block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
Idir> force status to	• Normal • Start • Trip • Blocked	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.
Measured magnitude	• RMS • TRMS • Peak-to-peak	RMS	Defines which available measured magnitude is used by the function.
Measurement side	• Side 1 • Side 2	Side 1	Defines which current measurement module is used by the function. Visible if the unit has more than one current measurement module.

Pick-up settings

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.

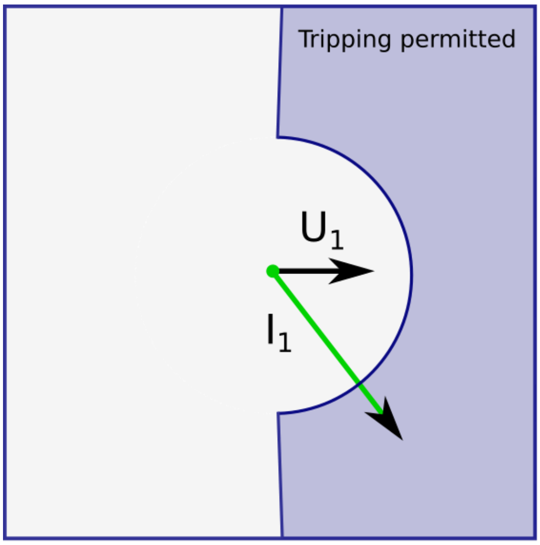
If the voltage drops below 1 V in the secondary side, the angle memory is used for 0.5 seconds. The angle memory forces the reference angle to be equal to the value measured or calculated before the fault. The angle memory captures the measured voltage angle 100 ms before the fault starts. After 0.5 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°.

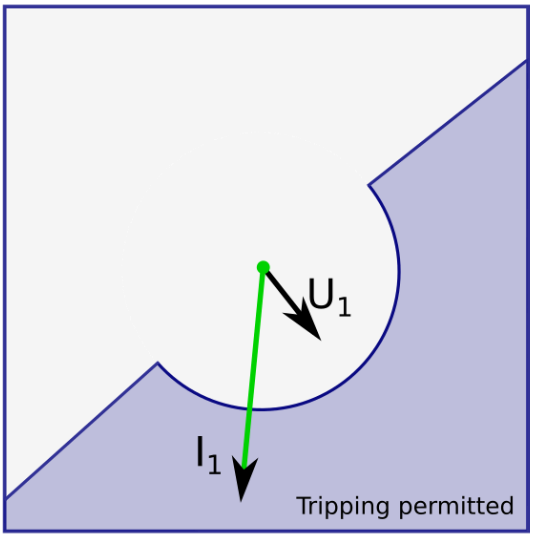
Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.4.4 - 69. Pick-up settings.

Name	Range	Step	Default	Description
Characteristic direction	• Directional • Non-directional	-	Directional	Switches between directional and non-directional overcurrent mode.
Operating sector size (+ / -)	±1.0…170.0°	0.1°	±88°	Pick-up area size in degrees.
Operating sector center	-180.0…180.0°	0.1°	0°	Turns the operating sector
Pick-up setting I_{set}	0.10…40.00×I_n	0.01×I_n	1.20×I_n	Pick-up setting

Figure. 4.4.4 - 33. 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.

Figure. 4.4.4 - 34. Operation sector area when the sector center has been set to -45 degrees.

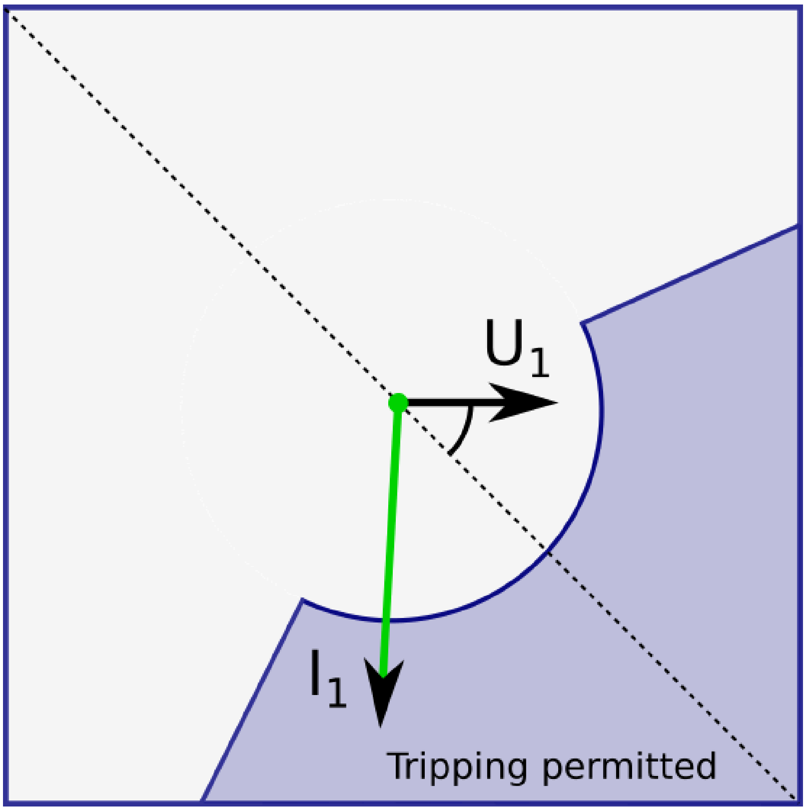
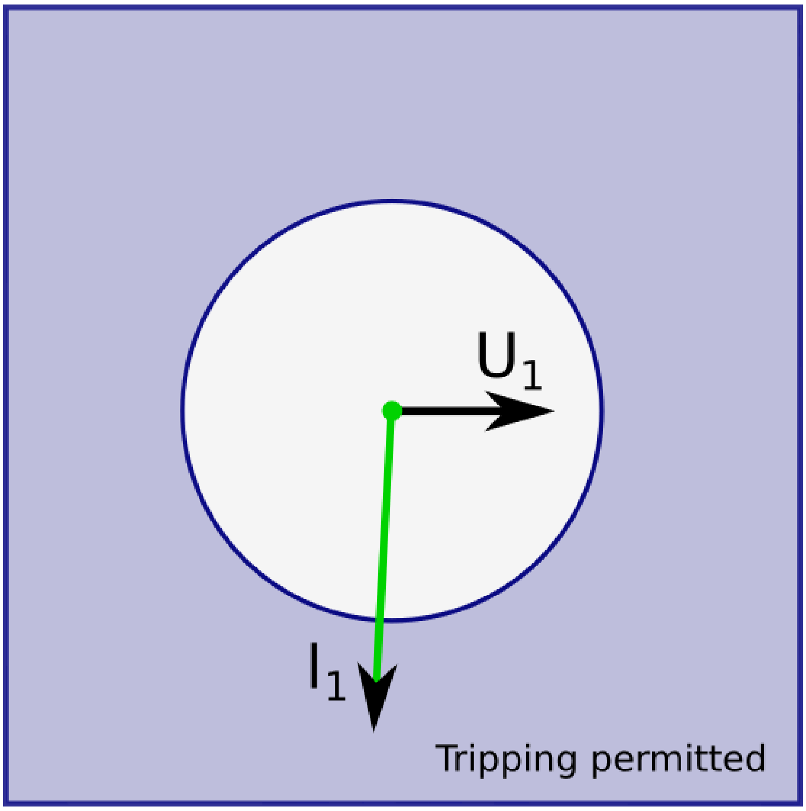


Figure. 4.4.4 - 35. When Idir> function has been set to "Non-directional" the function works basically just like a traditional non-directional overcurrent protection function.



Read-only parameters

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

Table. 4.4.4 - 70. Information displayed by the function.

Name	Range	Step	Description
Idir> LN behaviour	• On • Blocked • Test • Test/Blocked • Off	-	Displays the mode of DOC block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
Operating angle now	-360.00...360.00deg	0.01deg	The positive sequence current angle in relation to the positive sequence voltage.
Expected operating time	0.000...1800.00s	0.005s	Displays the expected operating time when a fault occurs. When IDMT mode is used, the expected operating time depends on the highest measured phase current value. If the measured current changes during a fault, the expected operating time changes accordingly.
Time remaining to trip	-1800.000...1800.00s	0.005s	When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs.

Name	Range	Step	Description
I_{meas}/I_{set} at the moment	$0.00...1250.00 I_m/I_{set}$	$0.01 I_m/I_{set}$	The ratio between the highest measured phase current 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. Additionally, the function includes an internal inrush harmonic blocking option which is applied according to the parameters set by the user. When the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

Table. 4.4.4 - 71. Internal inrush harmonic blocking settings.

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

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, time characteristics are reset and the release time characteristics are processed similarly to when the pick-up signal is reset.

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 the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The function offers four (4) independent stages; the events are segregated for each stage operation.

Table. 4.4.4 - 72. Event messages.

Event block name	Event names
DOC1...DOC4	Start ON

Event block name	Event names
DOC1...DOC4	Start OFF
DOC1...DOC4	Trip ON
DOC1...DOC4	Trip OFF
DOC1...DOC4	Block ON
DOC1...DOC4	Block OFF
DOC1...DOC4	No voltage, Blocking ON
DOC1...DOC4	Voltage measurable, Blocking OFF
DOC1...DOC4	Measuring live angle ON
DOC1...DOC4	Measuring live angle OFF
DOC1...DOC4	Using voltmem ON
DOC1...DOC4	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.

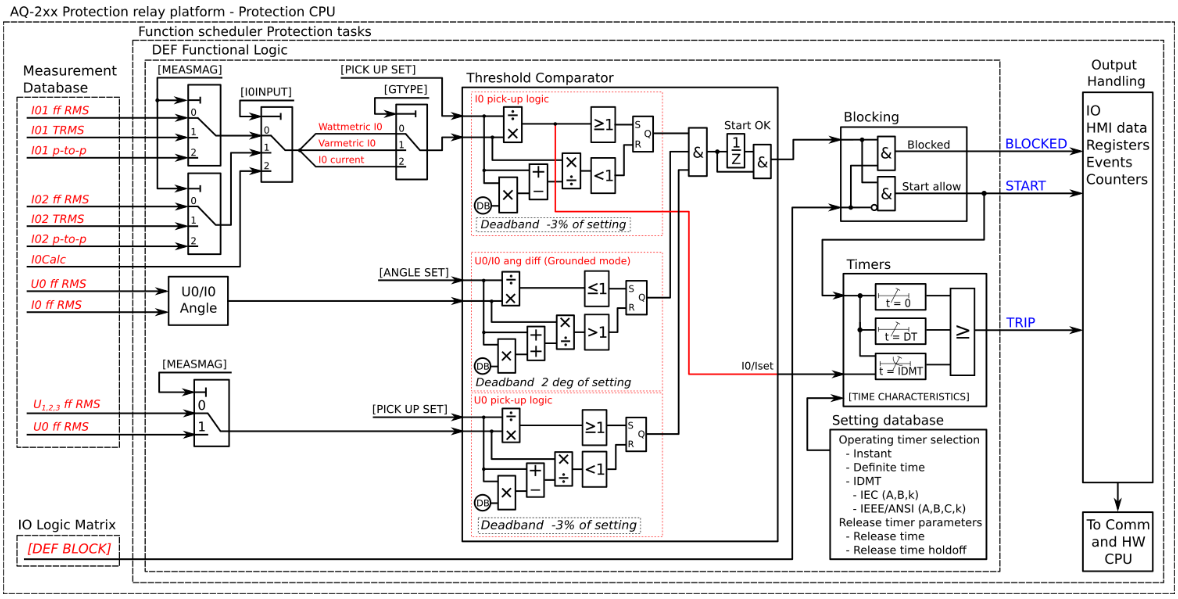
Table. 4.4.4 - 73. Register content.

Register name	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
Fault type	L1-E...L1-L2-L3
Pre-trigger current	Start/Trip -20ms current
Fault current	Start/Trip current
Pre-fault current	Start -200ms averages
Trip time remaining	0s...1800s
Setting group in use	Setting group 1...8 active
Operating angle	0...250°

4.4.5 Directional earth fault protection (I0dir>; 67N/32N)

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 and voltage magnitudes which the function constantly measures.

Figure. 4.4.5 - 36. Simplified function block diagram of the I0dir> function.



Measured input

The function block uses residual current measurement values and neutral voltage measurement values. The available residual current measurement channels are I_{01} and I_{02} (residual current measurement) and I0Calc (residual current calculated from phase current).The user can select the monitored current magnitude to be equal either to RMS values (fundamental frequency component), to TRMS values from the whole harmonic specter of 32 components, or to peak-to-peak values.

The fault current angle is based on comparing the neutral voltage U_0 angle to the residual current I_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. 4.4.5 - 74. Measurement inputs of the I0dir> function.

Signal	Description	Time base
I_{01}RMS	Fundamental frequency component of coarse residual current measurement input I01	5ms
I_{01}TRMS	TRMS measurement of coarse residual current measurement input I01	5ms
I_{01}PP	Peak-to-peak measurement of coarse residual current measurement input I01	5ms
I_{02}RMS	Fundamental frequency component of sensitive residual current measurement input I02	5ms
I_{02}TRMS	TRMS measurement of coarse sensitive current measurement input I02	5ms
I_{02}PP	Peak-to-peak measurement of sensitive residual current measurement input I02	5ms
I_{0Calc}	Fundamental frequency component of residual current calculated from the three phase currents	5ms
U_0RMS	Fundamental frequency component of zero sequence voltage measurement input U0	5ms
U_{0Calc}	Fundamental frequency component of of the zero sequence voltage calculated from the three phase voltages	5ms

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. 4.4.5 - 75. General settings of the function.

Name	Range	Default	Description
I0dir> LN mode	On Blocked Test Test/Blocked Off	On	Set mode of DEF block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
I0dir> force status to	• Normal • Start • Trip • Blocked • Unearthed Start • Unearthed Trip • Compensated Start • Compensated Trip	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.
U0 directional phase	• U0 • -U0	U0	If the connected neutral voltage polarity is opposite to the connected residual current, this parameter can swap the angle reference.
U0> Meas input select	• Select • U0 Calculated • U3 Input • U4 Input	Select	Defines which available neutral voltage measurement is used. Available neutral voltages depend on measurement settings (*Measurements → Transformers → VT module*).
Measured magnitude	• RMS • TRMS • Peak-to-peak	RMS	Defines which available measured magnitude is used by the function. This parameter is available when "Input selection" has been set to "I01" or "I02".
Measurement side	• Side 1 • Side 2	Side 1	Defines which current measurement module is used by the function.
Input selection	• I01 • I02 • I0Calc	I01	Defines which measured residual current is used by the function.

Pick-up settings

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.

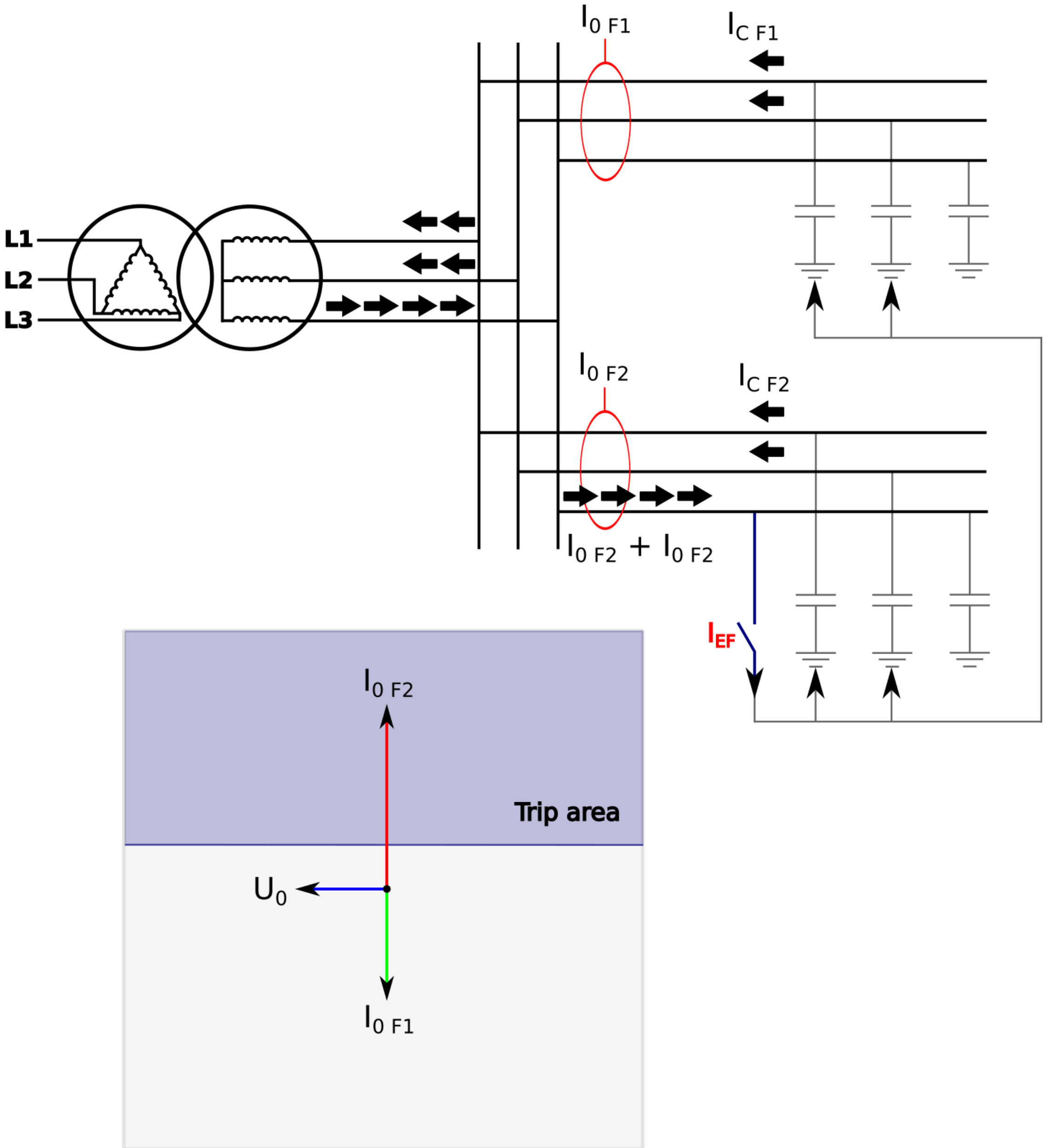
Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.4.5 - 76. Pick-up settings.

Name	Range	Step	Default	Description
$I0_{set}$	0.005…40.00×I_n	0.001×I_n	1.20×I_n	Current pick-up setting
$U0_{set}$	1…75%U_n	0.01%U_n	20%U_n	Voltage pick-up setting
Grounding type	• Unearthed [32N Var] • Petersen coil GND [32N Watt] • Grounded [67N] • $I0_{Cos}$ & $I0_{Sin}$ broad range with MCD [32N Var/ Watt]	-	Unearthed	Network grounding method
Multi-criteria detection	• Not used • Used	-	Not used	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.
Unearthed/ Compensated border angle	-45.0…90°	0.1°	45°	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.
Angle	±45.0…135.0°	0.1°	±88°	Tripping area size (earthed network)
Angle offset	0.0…360.0°	0.1°	0.0°	Protection area direction (earthed network)
Angle blinder	-90.0…0.0°	0.1°	-90°	I0 angle blinder (Petersen coil earthed)

Unearthed network

Figure. 4.4.5 - 37. Angle tracking of I0dir> function (unearthed network model) (32N)



When the unearthed (capacitive) network mode is chosen, the function 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 feeder 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.

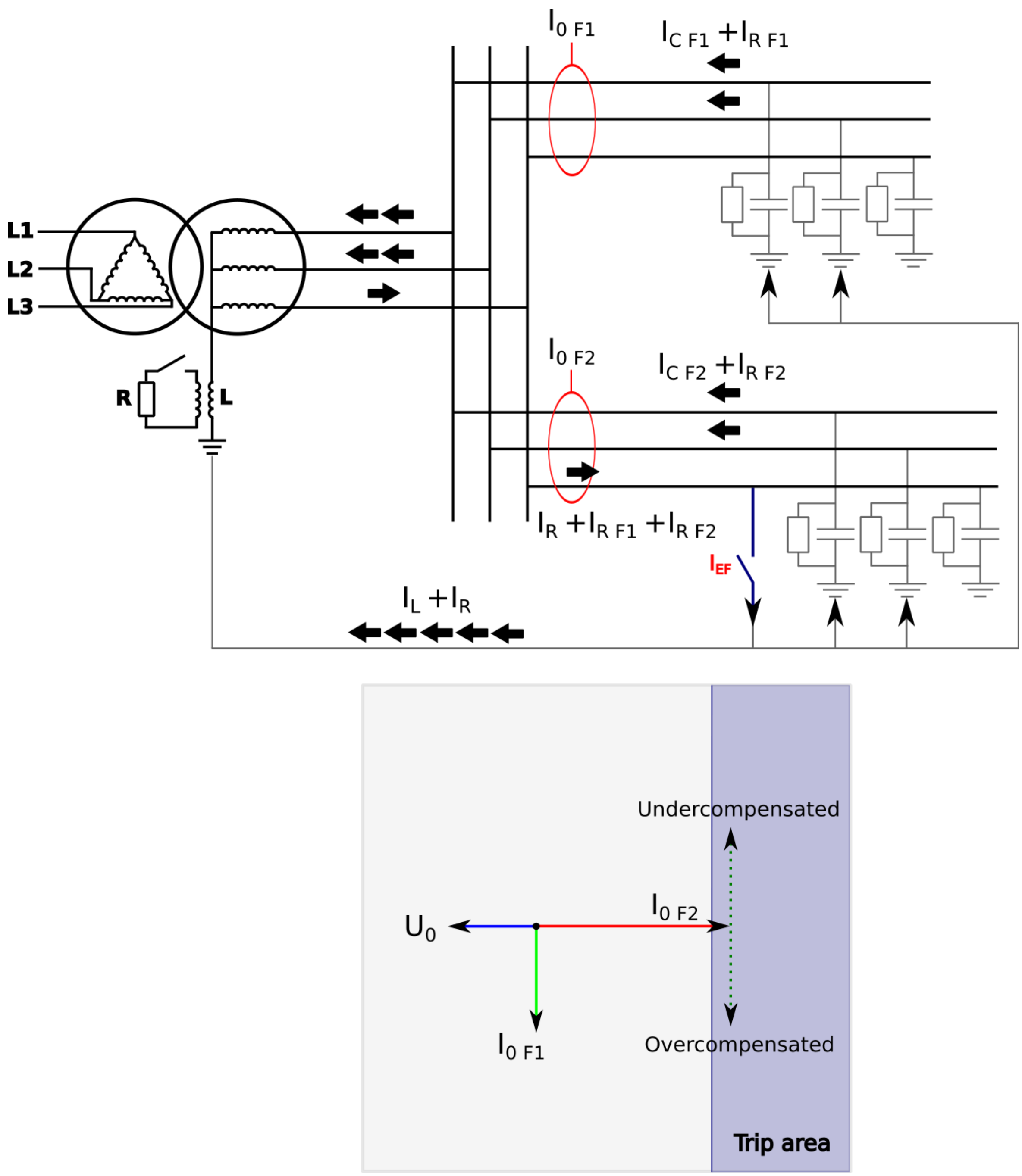
The amplitude of the fault current depends on the capacitance of the network. The outgoing feeders are the sources for capacitive currents. The bigger the network the greater the capacitive current during a fault. Each outgoing feeder produces capacitance according to the zero sequence capacitive reactance 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 (32N)

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 with an earth fault can be used for a specific time.

Figure. 4.4.5 - 38. Angle tracking of I0dir> function (Petersen coil earthed network model).

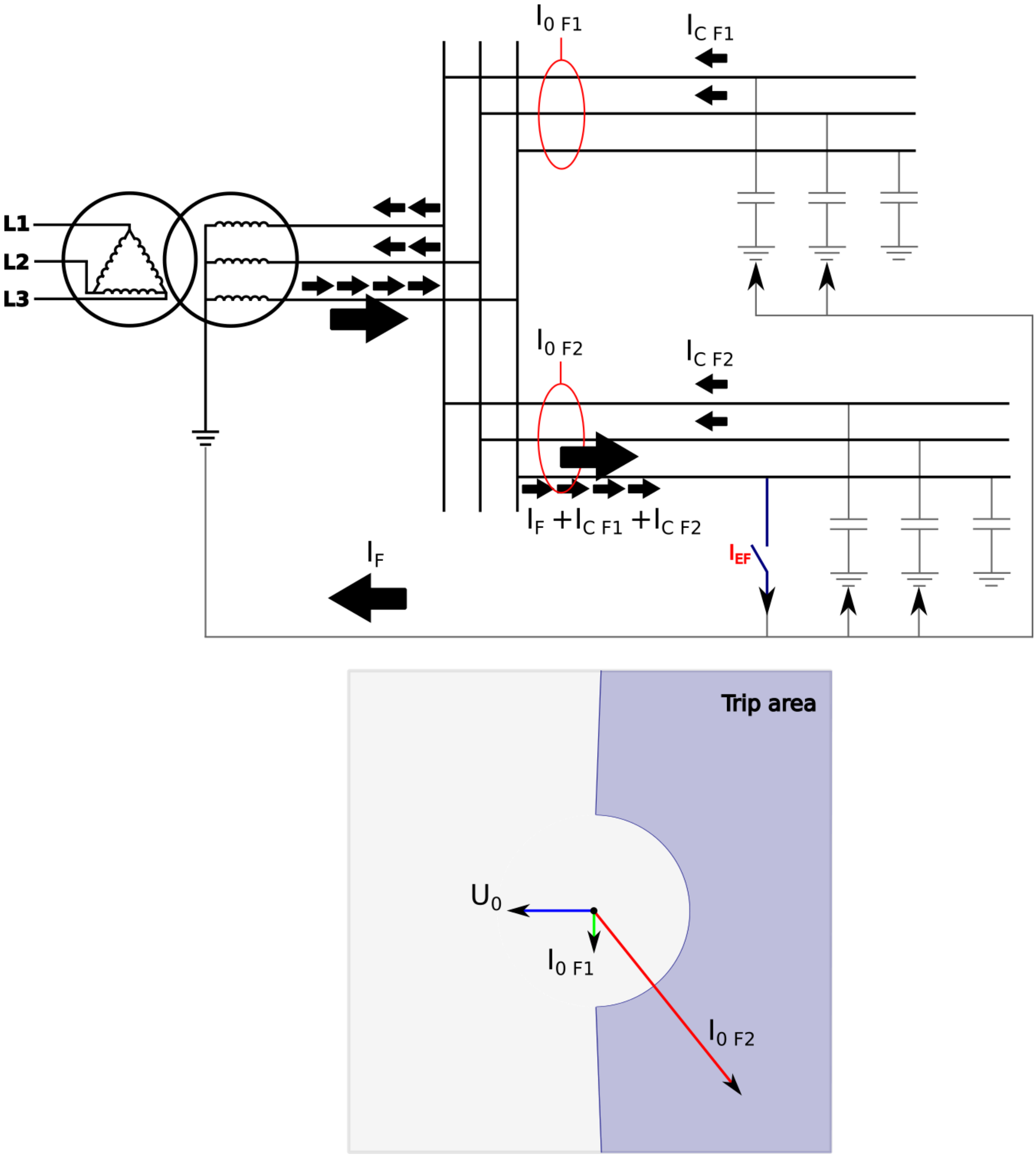


When the Petersen coil earthed (compensated) network mode is chosen, the function expects the fault current to be in the opposite direction to the zero sequence voltage. Healthy phases of both healthy and faulty feeders produce a capacitive current similar to the unearthed network. The inductance of 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 feeder 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 in 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 (67N)

Figure. 4.4.5 - 39. Angle tracking of I0dir> function (directly earthed or small impedance network).



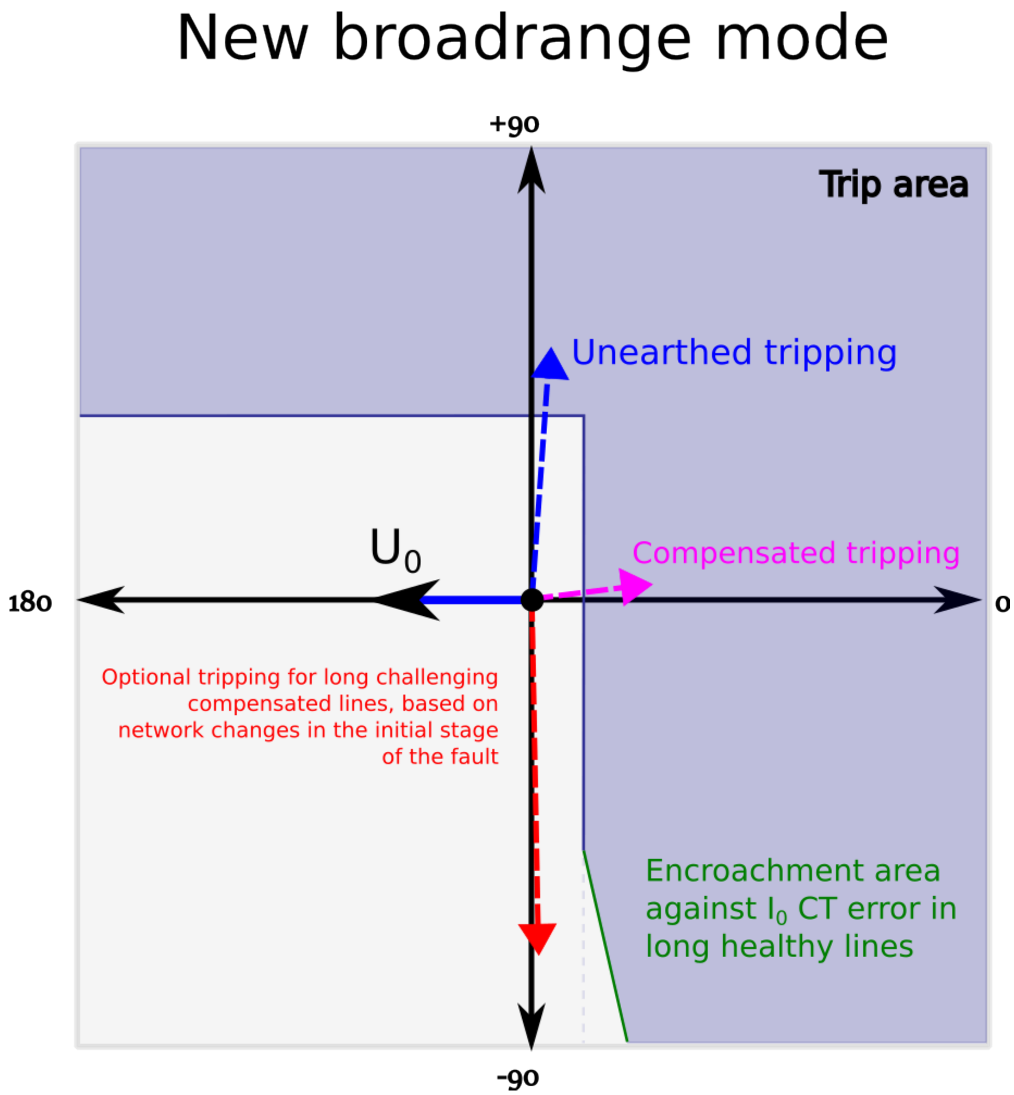
In a directly earthed network the amplitude of a single-phase fault current is similar to the amplitude of a short-circuit current. Directly earthed or small impedance network schemes are normal in transmission, distribution and industry.

The phase angle setting of the tripping 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 relays 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.

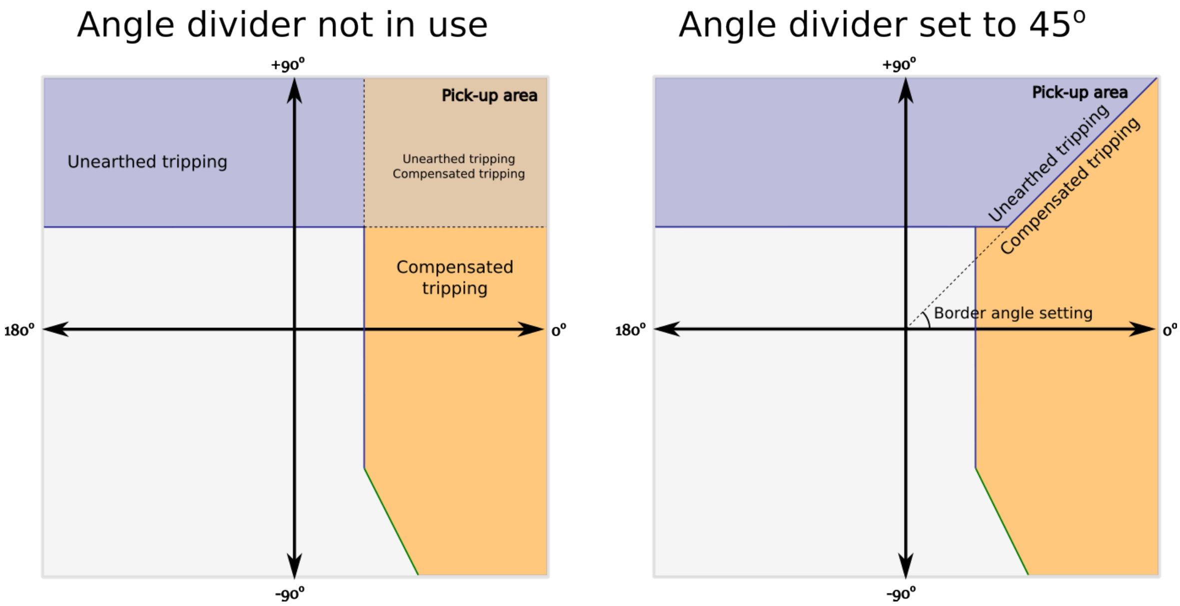
Figure. 4.4.5 - 40. Angle tracking of the I0dir> function (broad range mode).



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. 4.4.5 - 41. 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.

Read-only parameters

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

Table. 4.4.5 - 77. Information displayed by the function.

Name	Range	Step	Description
I0dir> LN behaviour	• On • Blocked • Test • Test/Blocked • Off	On	Set mode of NOC block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.

Name	Range	Step	Description
I0dir> condition	• Normal • Start • Trip • Blocked	-	Displays the status of the protection function.
U0> Measuring now	• No U0 avail! • U0Calc • U3 Input • U4 Input	-	Displays which voltage channel is used by the function. If no voltage channel has been selected the function defaults to calculated residual voltage if line-to-neutral voltages have been connected to device. If no channel is set to "U0" mode and line-to-line voltages are connected, no residual voltage is available and "No U0 avail!" will be displayed.
U0> Pick-up setting	0.0...1 000 000V	0.1V	The required residual voltage on the primary side for the function to trip.
Detected U0/ I0 angle (fi)	-360.00...360.00deg	0.01deg	The angle in degrees between the monitored residual voltage and the current.
I0 Magnitude	0.000...250.000×$I0_n$	0.001×$I0_n$	The per-unit-value of the monitored residual current.
I0 Wattmetric I0xCos(fi)	-250.000...250.000×$I0_n$	0.001×$I0_n$	The wattmetric per-unit-value of the monitored residual current.
I0 Varmetric I0xSin(fi)	-250.000...250.000×$I0_n$	0.001×$I0_n$	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	-250.000...250.000×$I0_n$	0.001×$I0_n$	The ratio between the monitored residual current and the pick-up value.
U0 measurement now	0.000...500.000%$U0_n$	0.001%$U0_n$	The measured voltage in the chosen voltage channel.
Expected operating time	0.000...1800.000s	0.005s	Displays the expected operating time when a fault occurs. When IDMT mode is used, the expected operating time depends on the measured current value. If the measured current changes during a fault, the expected operating time changes accordingly.
Time remaining to trip	-1800.000...1800.000s	0.005s	When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs.

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 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. 4.4.5 - 78. Internal inrush harmonic blocking settings.

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

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 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 the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a cumulative counter for the START, TRIP and BLOCKED events.

The function offers four (4) independent stages; the events are segregated for each stage operation.

Table. 4.4.5 - 79. Event messages.

Event block name	Event name
DEF1...DEF4	Start ON
DEF1...DEF4	Start OFF
DEF1...DEF4	Trip ON
DEF1...DEF4	Trip OFF
DEF1...DEF4	Block ON
DEF1...DEF4	Block OFF
DEF1...DEF4	I0Cosfi Start ON
DEF1...DEF4	I0Cosfi Start OFF
DEF1...DEF4	I0Sinfi Start ON

Event block name	Event name
DEF1...DEF4	I0Sinfi Start OFF
DEF1...DEF4	I0Cosfi Trip ON
DEF1...DEF4	I0Cosfi Trip OFF
DEF1...DEF4	I0Sinfi Trip ON
DEF1...DEF4	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. 4.4.5 - 80. Register content.

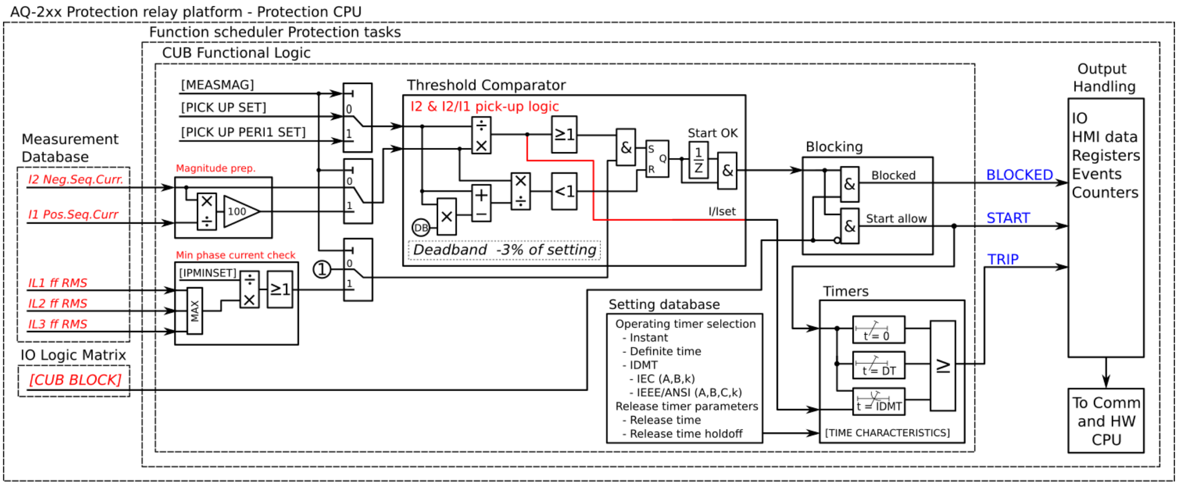
Register	Description
Event	Event name
Date and time	dd.mm.yyyy hh:mm:ss.mss
I_0 pre-triggering current	Start/Trip -20ms current
I_0 fault current	Start/Trip current
Fault capacitive I_0	Start/Trip capacitive current
Fault resistive I_0	Start/Trip resistive current
Fault U_0 (%)	Start/Trip voltage (percentage of nominal)
Fault U_0 (V)	Start/Trip voltage (in Volts)
I_0 fault angle	0...360°
Trip time remaining	0 ms...1800s
Setting group in use	Setting group 1...8 active
Network GND	Unearthed, Petersen coil earthed, Earthed network
I_0 pre-fault current	Start -200ms current

4.4.6 Negative sequence overcurrent/ phase current reversal/ current unbalance protection (I2>; 46/46R/46L)

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 device 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 device 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.

Figure. 4.4.6 - 42. Simplified function block diagram of the I2> function.



Measured input

The function block uses positive and negative sequence currents calculated from the phase current measurement channels. In the broken conductor mode (I2/I1) the function also uses fundamental frequency component 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.

Table. 4.4.6 - 81. 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
I_{L1}RMS	Fundamental frequency component of phase L1 (A) current measurement	5 ms
I_{L2}RMS	Fundamental frequency component of phase L2 (B) current measurement	5 ms
I_{L3}RMS	Fundamental frequency component of phase L3 (C) current measurement	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 editing the setting group.

Table. 4.4.6 - 82. General settings of the function.

Name	Range	Default	Description
I2> LN mode	• On • Blocked • Test • Test/ Blocked • Off	On	Set mode of CUB block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
I2> force status to	• Normal • Start • Trip • Blocked	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.
Measurement side	• Side 1 • Side 2	Side 1	Defines which current measurement module is used by the function. Visible if the unit has more than one current measurement module.
Measured magnitude	• I2pu • I2/I1	I2pu	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.

Pick-up settings

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.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.4.6 - 83. Pick-up settings.

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

Read-only parameters

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

Table. 4.4.6 - 84. Information displayed by the function.

Name	Range	Description
I2> LN behaviour	On Blocked Test Test/ Blocked Off	Displays the mode of CUB block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
I2> condition	Normal Start Trip Blocked	Displays the status of the protection function.

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 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.

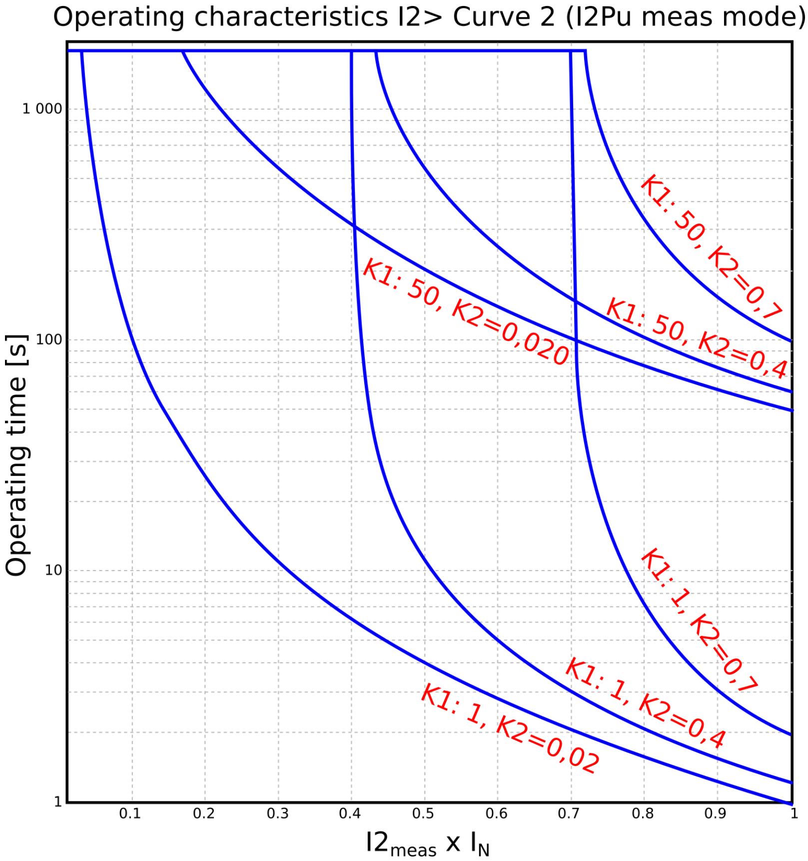
Unique to the current unbalance protection is the availability of the “Curve2” delay which follows the formula below:

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

- 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. 4.4.6 - 43. Operation characteristics curve for I2> Curve2.



For a more detailed description on the time characteristics and their setting parameters, please refer to the "General properties of a protection function" chapter and its "Operating time characteristics for trip and reset" section.

Events and registers

The current unbalance function (abbreviated "CUB" in event block names) generates events and registers from the status changes in the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The function offers four (4) independent stages; the events are segregated for each stage operation.

Table. 4.4.6 - 85. Event messages.

Event block name	Event names
CUB1...CUB4	Start ON
CUB1...CUB4	Start OFF
CUB1...CUB4	Trip ON

Event block name	Event names
CUB1...CUB4	Trip OFF
CUB1...CUB4	Block ON
CUB1...CUB4	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.

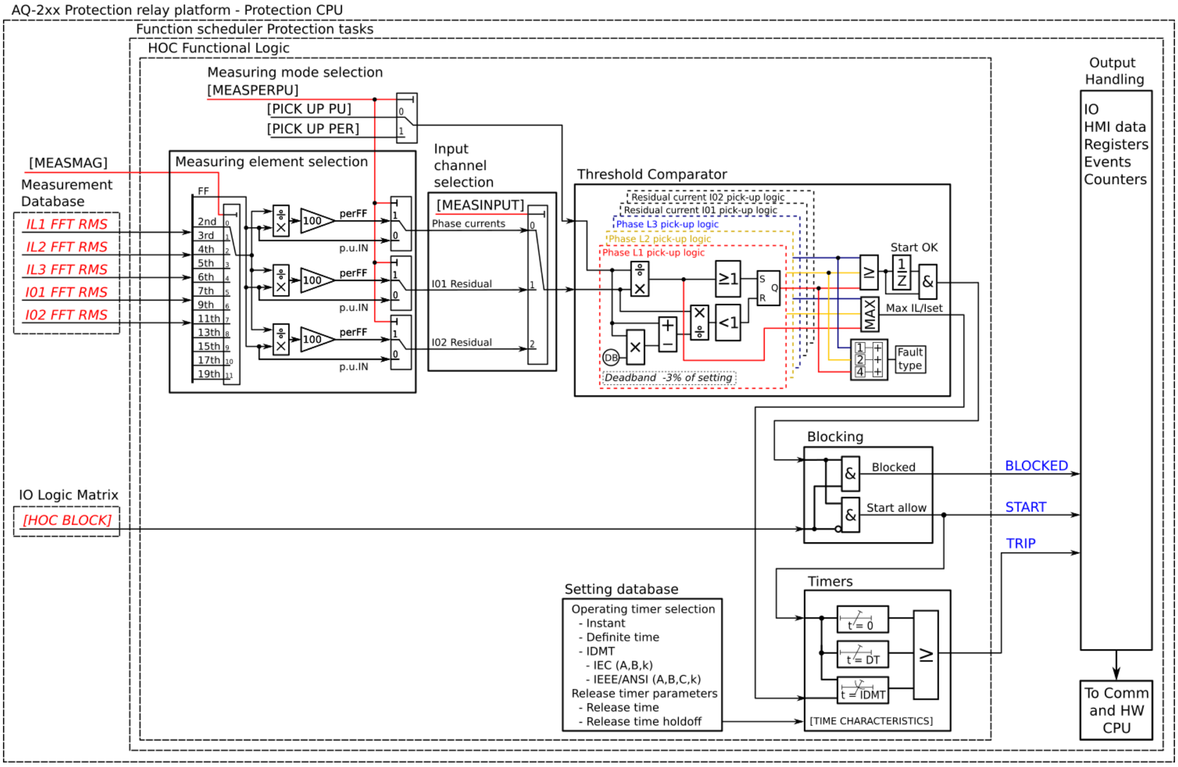
Table. 4.4.6 - 86. Register content.

Register	Description
Event	Event name
Date and time	dd.mm.yyyy hh:mm:ss.mss
Pre-trigger current	Start/Trip -20ms current
Fault current	Start/Trip current
Pre-fault current	Start -200ms current
Fault currents	I1, I2, IZ mag. and ang.
Trip time remaining	0 ms...1800s
Setting group in use	Setting group 1...8 active

4.4.7 Harmonic overcurrent protection (Ih>; 50H/51H/68H)

The harmonic overcurrent function is used for non-directional instant and time-delayed overcurrent detection and clearing. The number of stages in the function depends on the device model. The function constantly measures the selected harmonic component of the selected measurement channels, the value being either absolute value or relative to the RMS value.

Figure. 4.4.7 - 44. Simplified function block diagram of the Ih> function.



Measured input

The function block uses analog current measurement values from phase or residual currents. Each measurement input of the function block uses RMS (fundamental frequency component) values and harmonic components of the selected current input. The user can select the monitored magnitude to be equal to the per-unit RMS values of the harmonic component, or to the harmonic component percentage content compared to the RMS values.

Table. 4.4.7 - 87. Measurement inputs of the Ih> function.

Signal	Description	Time base
I_{L1}FFT	The magnitudes (RMS) of phase L1 (A) current components: - Fundamental - 2nd harmonic - 3rd harmonic - 4th harmonic - 5th harmonic - 6th harmonic - 7th harmonic - 9th harmonic - 11th harmonic - 13th harmonic - 15th harmonic - 17th harmonic - 19th harmonic.	5 ms

Signal	Description	Time base
I_{L2}FFT	The magnitudes (RMS) of phase L2 (B) current components: - Fundamental - 2nd harmonic - 3rd harmonic - 4th harmonic - 5th harmonic - 6th harmonic - 7th harmonic - 9th harmonic - 11th harmonic - 13th harmonic - 15th harmonic - 17th harmonic - 19th harmonic.	5 ms
I_{L3}FFT	The magnitudes (RMS) of phase L3 (C) current components: - Fundamental - 2nd harmonic - 3rd harmonic - 4th harmonic - 5th harmonic - 6th harmonic - 7th harmonic - 9th harmonic - 11th harmonic - 13th harmonic - 15th harmonic - 17th harmonic - 19th harmonic.	5 ms
I_{01}FFT	The magnitudes (RMS) of residual $I0_1$ current components: - Fundamental - 2nd harmonic - 3rd harmonic - 4th harmonic - 5th harmonic - 6th harmonic - 7th harmonic - 9th harmonic - 11th harmonic - 13th harmonic - 15th harmonic - 17th harmonic - 19th harmonic.	5 ms

Signal	Description	Time base
$I0_2$FFT	The magnitudes (RMS) of residual $I0_2$ current components: - Fundamental - 2nd harmonic - 3rd harmonic - 4th harmonic - 5th harmonic - 6th harmonic - 7th harmonic - 9th harmonic - 11th harmonic - 13th harmonic - 15th harmonic - 17th harmonic - 19th harmonic.	5 ms

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. 4.4.7 - 88. Operating mode selection settings.

Name	Range	Default	Description
Ih> LN mode	• On • Blocked • Test • Test/ Blocked • Off	On	Set mode of HOC block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
Ih> force status to	• Normal • Start • Trip • Blocked	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.
Ih> measurement side	• Side 1 • Side 2	Side 1	Defines which current measurement module is used by the function. Visible if the unit has more than one current measurement module.

Name	Range	Default	Description
Harmonic selection	• 2^{nd} harmonic • 3^{rd} harmonic • 4^{th} harmonic • 5^{th} harmonic • 6^{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	• $\times I_n$ • Ih/IL	$\times I_n$	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).

Pick-up settings

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.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.4.7 - 89. Pick-up settings.

Name	Range	Step	Default	Description
Ih_{set} pu	$0.05…2.00 \times I_n$	$0.01 \times I_n$	$0.20 \times I_n$	Pick-up setting (per unit monitoring)

Name	Range	Step	Default	Description
Ih/IL	5.00…200.00%	0.01%	20.00%	Pick-up setting (percentage monitoring)

Read-only parameters

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

Table. 4.4.7 - 90. Information displayed by the function.

Name	Range	Step	Description
Ih> behaviour	• On • Blocked • Test • Test/Blocked • Off	-	Displays the mode of HOC block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
Ih> condition	• Normal • Start • Trip • Blocked	-	Displays the status of the protection function.
Ih meas/ Ih set now	0.00...100000.00I_m/I_{set}	0.01I_m/I_{set}	The ratio between the monitored residual current and the pick-up value.
Expected operating time	0.000...1800.000s	0.005s	Displays the expected operating time when a fault occurs. When IDMT mode is used, the expected operating time depends on the measured voltage value. If the measured voltage changes during a fault, the expected operating time changes accordingly.
Time remaining to trip	-1800.000...1800.000s	0.005s	When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs.

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 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 the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs can be used for direct I/O controlling and user logic programming. 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 function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The function offers four (4) independent stages; the events are segregated for each stage operation.

Table. 4.4.7 - 91. Event description.

Event block name	Event names
HOC1...HOC4	Start ON
HOC1...HOC4	Start OFF
HOC1...HOC4	Trip ON
HOC1...HOC4	Trip OFF
HOC1...HOC4	Block ON
HOC1...HOC4	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. 4.4.7 - 92. Register content.

Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
Fault type	L1-G…L1-L2-L3
Pre-trigger current	Start/Trip -20ms current
Fault current	Start/Trip current
Pre-fault current	Start -200ms current
Trip time remaining	0 ms...1800s

Register	Description
Setting group in use	Setting group 1...8 active

4.4.8 Circuit breaker failure protection (CBFP; 50BF/52BF)

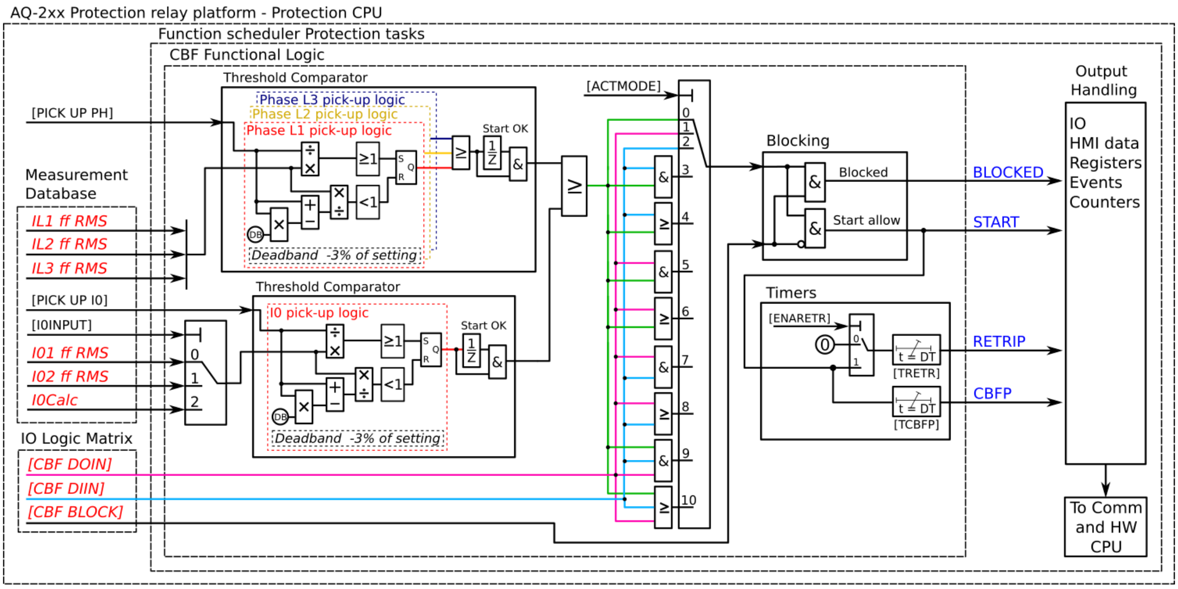
The circuit breaker failure protection function is used for monitoring the circuit breaker operation after it has received a TRIP signal. The function can also be used to retrip a failing breaker; if the retrip fails, an incoming feeder circuit breaker can be tripped by using the function's CBFP output. The retrip functionality can be disabled if the breaker does not have two trip 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 (trips, starts, logical signals etc.) 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.

Figure. 4.4.8 - 45. Simplified function block diagram of the CBFP function.



Measured input

The function block uses fundamental frequency component of phase current and residual current measurement values. The user can select I01, I02 or the calculated I0 for the residual current measurement.

Table. 4.4.8 - 93. Measurement inputs of the CBFP function.

Signal	Description	Time base
I_{L1}RMS	Fundamental frequency component of phase L1 (A) current measurement	5ms

Signal	Description	Time base
I_{L2}RMS	Fundamental frequency component of phase L2 (B) current measurement	5ms
I_{L3}RMS	Fundamental frequency component of phase L3 (C) current measurement	5ms
I_{01}RMS	Fundamental frequency component of residual input I_{01} measurement	5ms
I_{02}RMS	Fundamental frequency component of residual input I_{02} measurement	5ms
I_{0Calc}	Calculated residual current from the phase current inputs	5ms

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. 4.4.8 - 94. CBFP monitoring signal definitions.

Name	Description
Signal in monitor	Defines which TRIP events of the used protection functions trigger the CBFP countdown. For the CBFP function to monitor the signals selected here, the "Operation mode selection" parameter must be set to a mode that includes signals (e.g. "Signals only", "Signals or DO", "Current and signals and DO").
Trip monitor	Defines which output relay of the used protection functions trigger the CBFP countdown. For the CBFP function to monitor the output relays selected here, the "Operation mode selection" parameter must be set to a mode that includes digital outputs (e.g. "DO only", "Current and DO", "Current or signals or DO").

Table. 4.4.8 - 95. General settings of the function.

Name	Range	Default	Description
CBFP LN mode	• On • Blocked • Test • Test/ Blocked • Off	On	Set mode of CBF block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
CBFP force status to	• Normal • Start • ReTrip • CBFP • Blocked	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.
Measurement side	• Side 1 • Side 2	Side 1	Defines which current measurement module is used by the function.

Pick-up settings

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.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.4.8 - 96. Operating mode and input signals selection.

Name	Range	Step	Default	Description
I0Input	• Not in use • I01 • I02 • I0Calc	-	Not in use	Selects the residual current monitoring source, which can be either from the two separate residual measurements (I01 and I02) or from the phase current's calculated residual current.
Actmode	• Current only • DO only • Signals only • Current and DO • Current or DO • Current and signals • Current or signals • Signals and DO • Signals or DO • Current or DO or signals • Current and DO and Signals	-	Current only	Selects the operating mode. The mode can be dependent on current measurement, binary signal status, output relay status ("DO"), or a combination of the three.

Table. 4.4.8 - 97. 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.

Read-only parameters

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

Table. 4.4.8 - 98. Information displayed by the function.

Name	Range	Description
CBFP LN behaviour	• On • Blocked • Test • Test/ Blocked • Off	Displays the mode of CBF block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
CBFP condition	• Normal • Start • ReTrip • CBFP On • Blocked	Displays status of the protection function.

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 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.

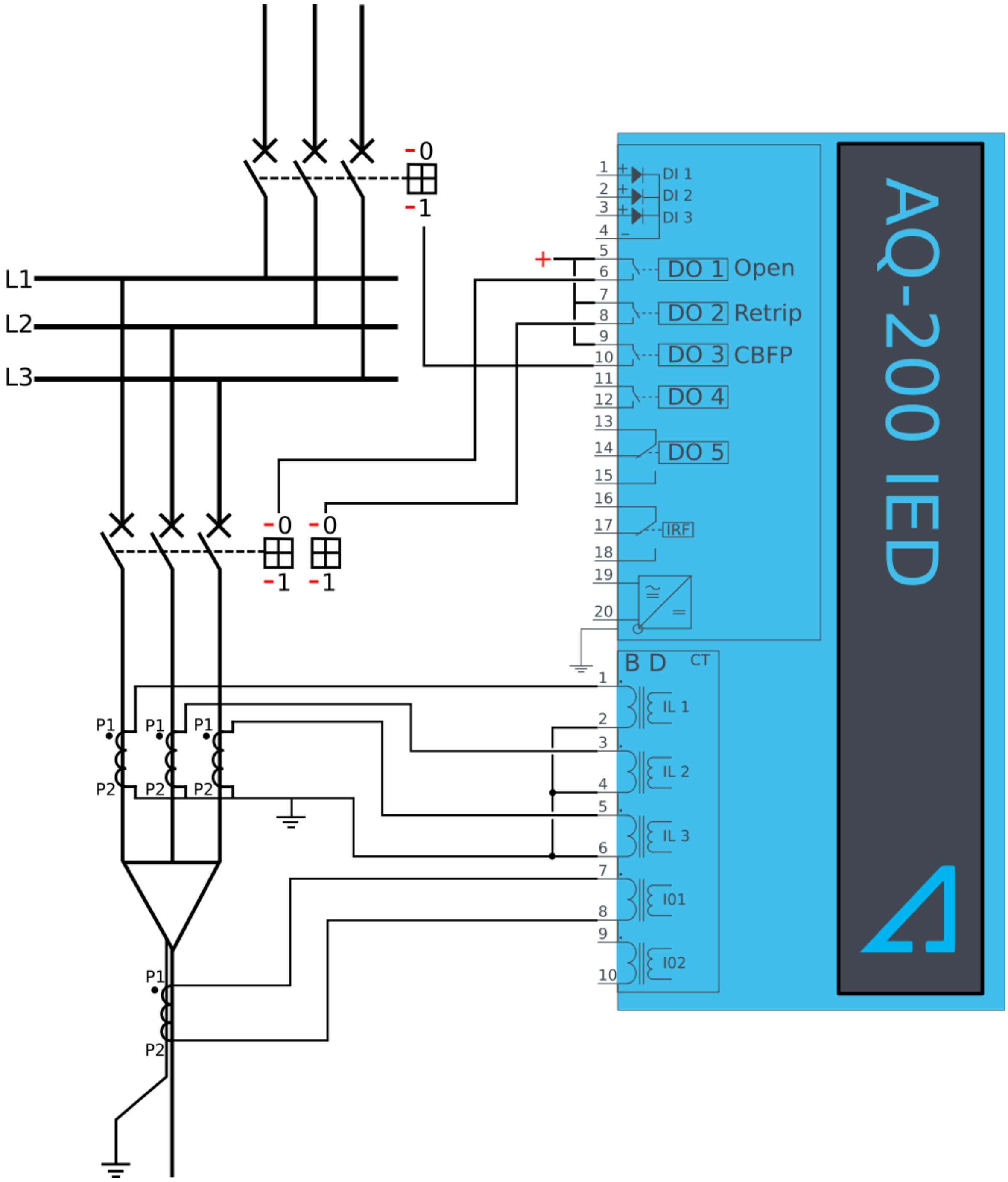
Table. 4.4.8 - 99. Setting parameters for operating time characteristics.

Name	Range	Step	Default	Description
Retrip	• No • Yes	-	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…1800.000s	0.005s	0.100s	Retrip start the timer. This setting defines how long the starting condition has to last before a RETRIP signal is activated.
CBFP	0.000…1800.000s	0.005s	0.200s	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.

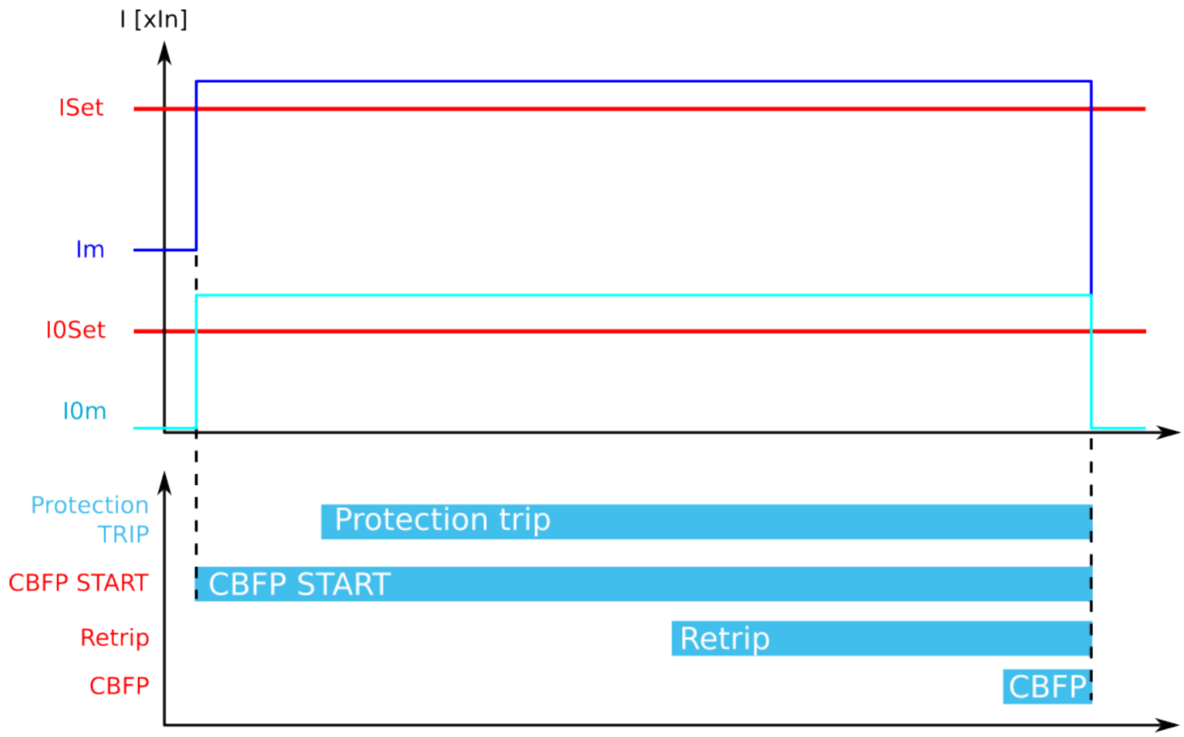
Trip, Retrip and CBFP in the device configuration

Figure. 4.4.8 - 46. Wiring diagram when Trip, Retrip and CBFP are configured to the device.



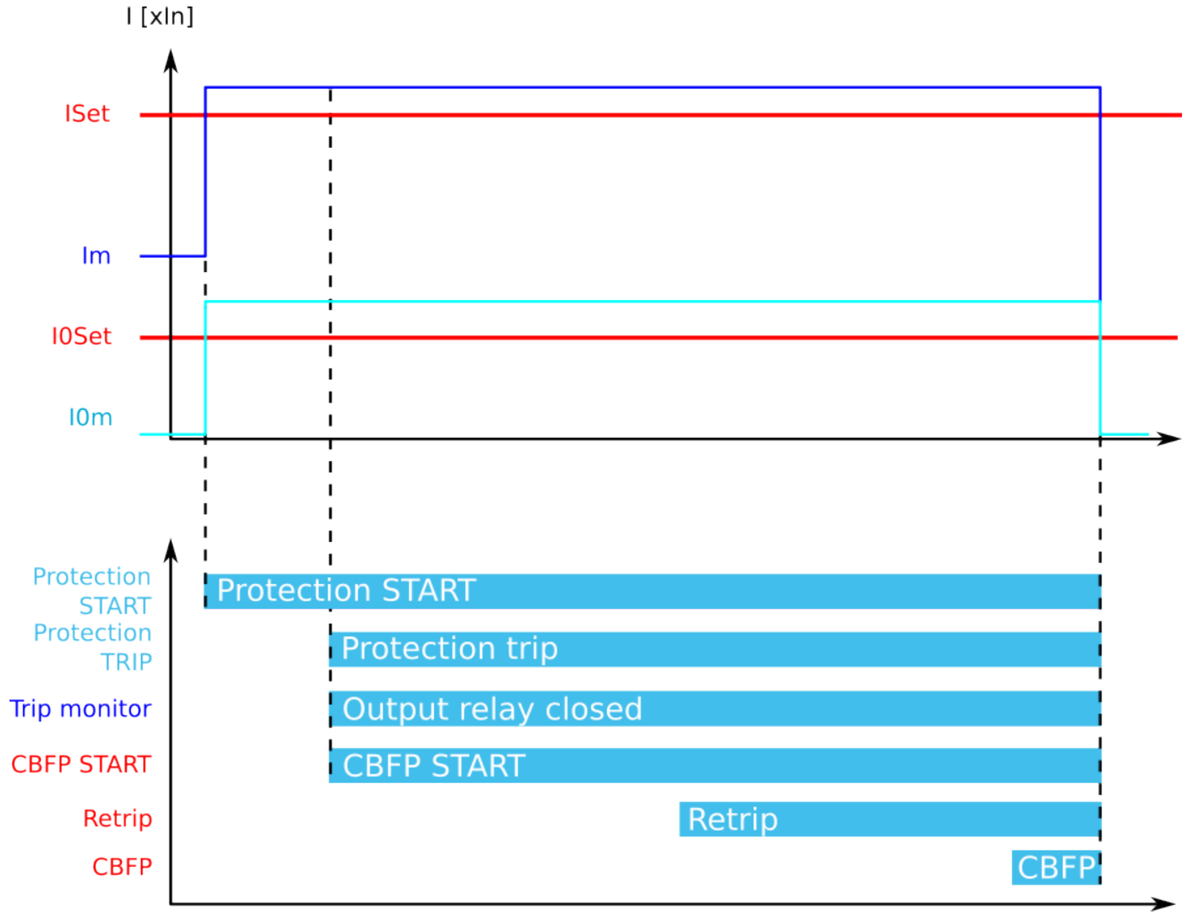
The retrip functionality can be used in applications whose circuit breaker has a retrip or a redundant trip coil available. The TRIP signal is normally wired to the breaker's trip coil from the device's trip output. The retrip is wired from its own device output contact in parallel with the circuit breaker's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

Figure. 4.4.8 - 47. Retrip and CBFP when "Current" is the selected criterion.



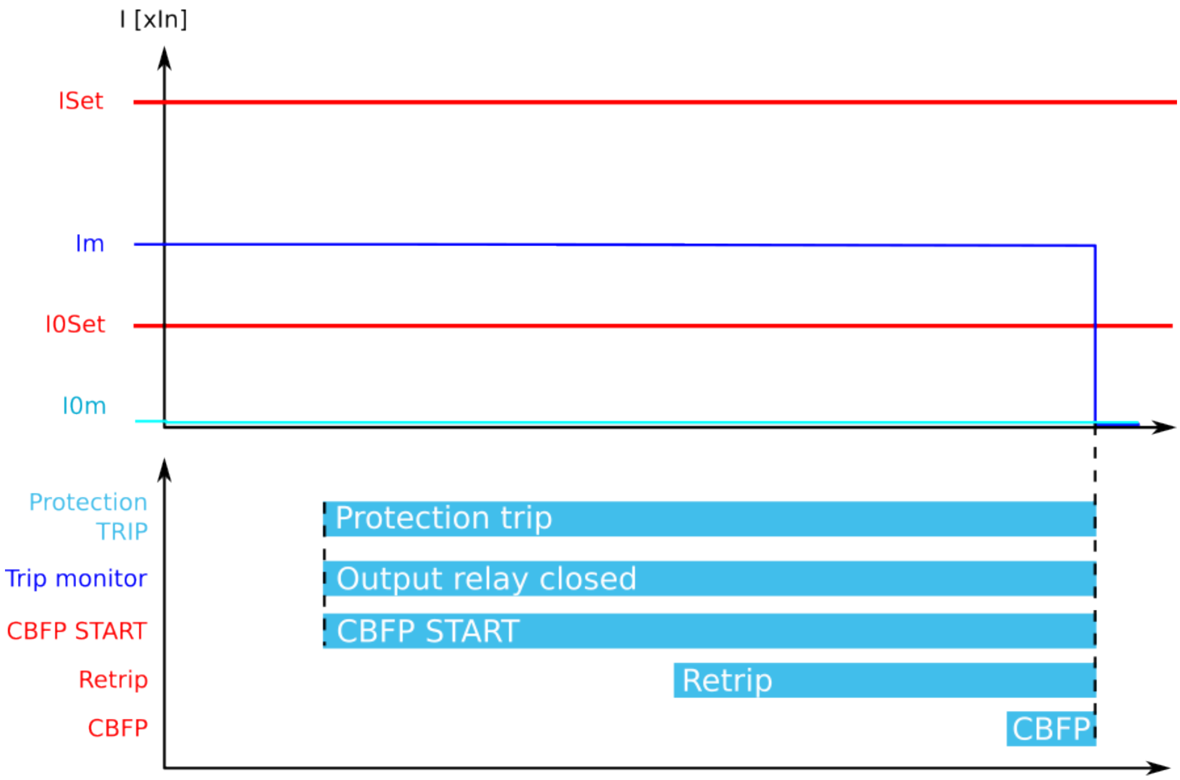
When the current threshold setting of I_{set} and/or $I0_{set}$ is exceeded, the current-based protection is activated and the counters for RETRIP and CBFP start calculating the set operating time. The tripping of the primary protection stage is not monitored in this configuration. Therefore, if the current is not reduced below the setting limit, a RETRIP signal is sent to the redundant trip coil. If the current is not reduced within the set time limit, the function also sends a CBFP signal to the incoming feeder 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. 4.4.8 - 48. Retrip and CBFP when "Current and DO" is the selected criterion.



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, until the primary protection operates). When the tripping signal reaches the primary protection stage, the RETRIP and CBFP counters start calculating 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 or the primary stage tripping signal is not reset, a RETRIP signal is sent to the redundant trip coil. If the retripping fails and the current is not reduced below the setting limit or the primary stage tripping signal is not reset, the function also sends a CBFP signal to the incoming feeder circuit 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 with current-based functions alone, and other function trips can be excluded from the CBFP functionality.

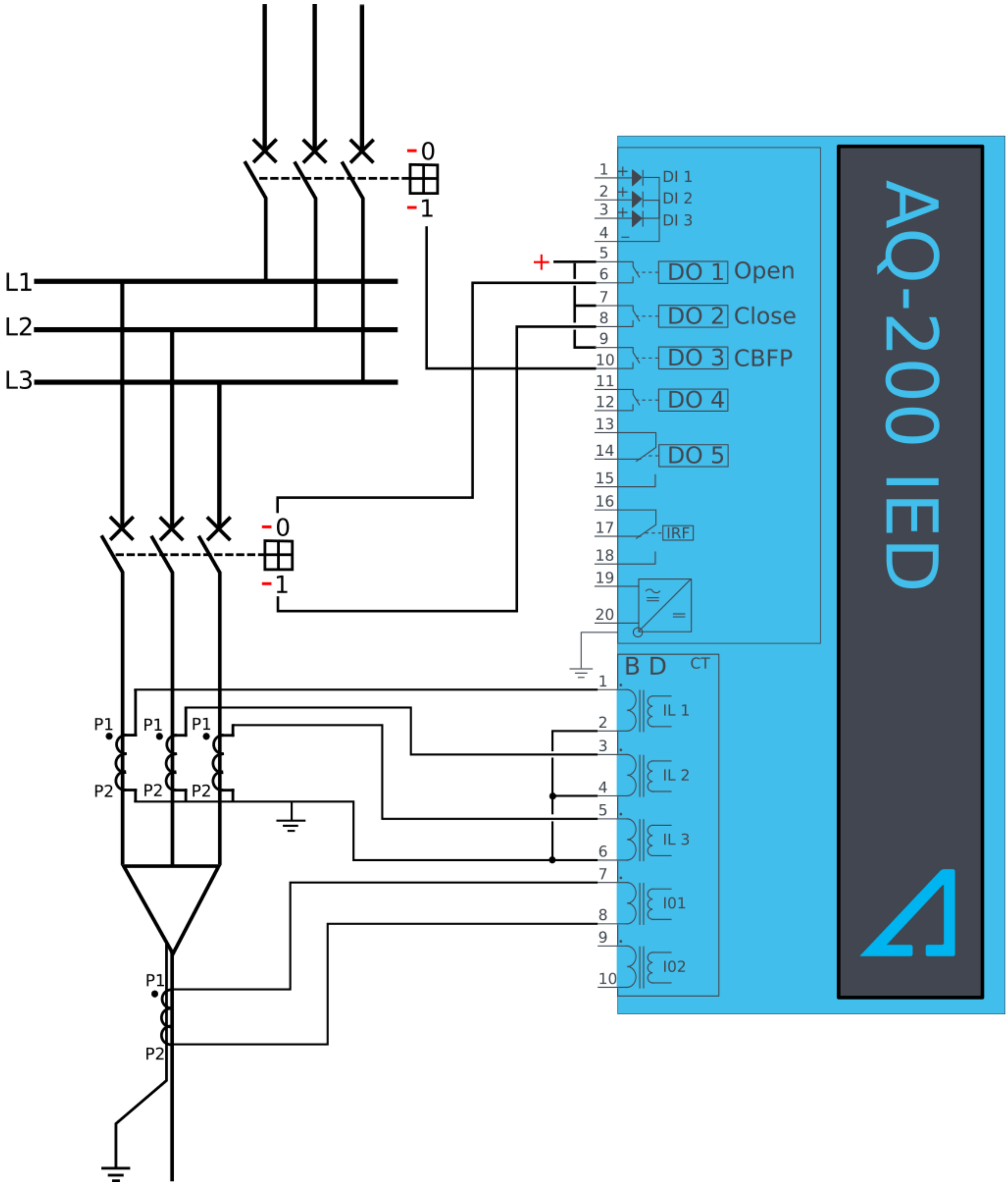
Figure. 4.4.8 - 49. Retrip and CBFP when "Current or DO" is the selected criterion.



When the current threshold setting of I_{set} and/or $I0_{set}$ is exceeded, or the TRIP signal reaches the primary protection stage, the function starts counting down towards the RETRIP and CBFP signals. The tripping of the primary protection stage is constantly monitored in this configuration regardless of the current's status. 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 above the limit or the signal is active) for the duration of the set RETRIP time delay, a RETRIP signal is sent to the redundant trip coil. If either of the conditions is active for the duration of the set CBFP time delay, a CBFP signal is sent to the incoming feeder circuit 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 with current-based functions alone, with added security from current monitoring. Other function trips can also be included in the CBFP functionality.

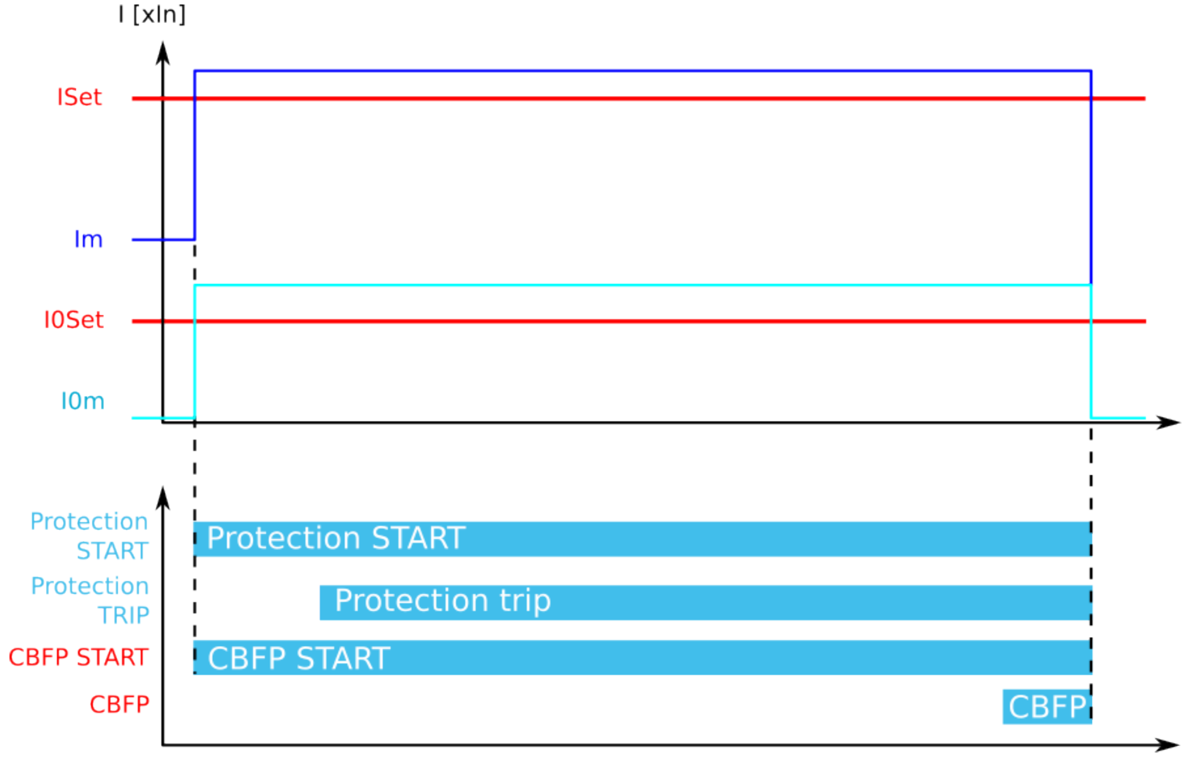
Trip and CBFP in the device configuration

Figure. 4.4.8 - 50. Wiring diagram when Trip and CBFP are configured to the device.



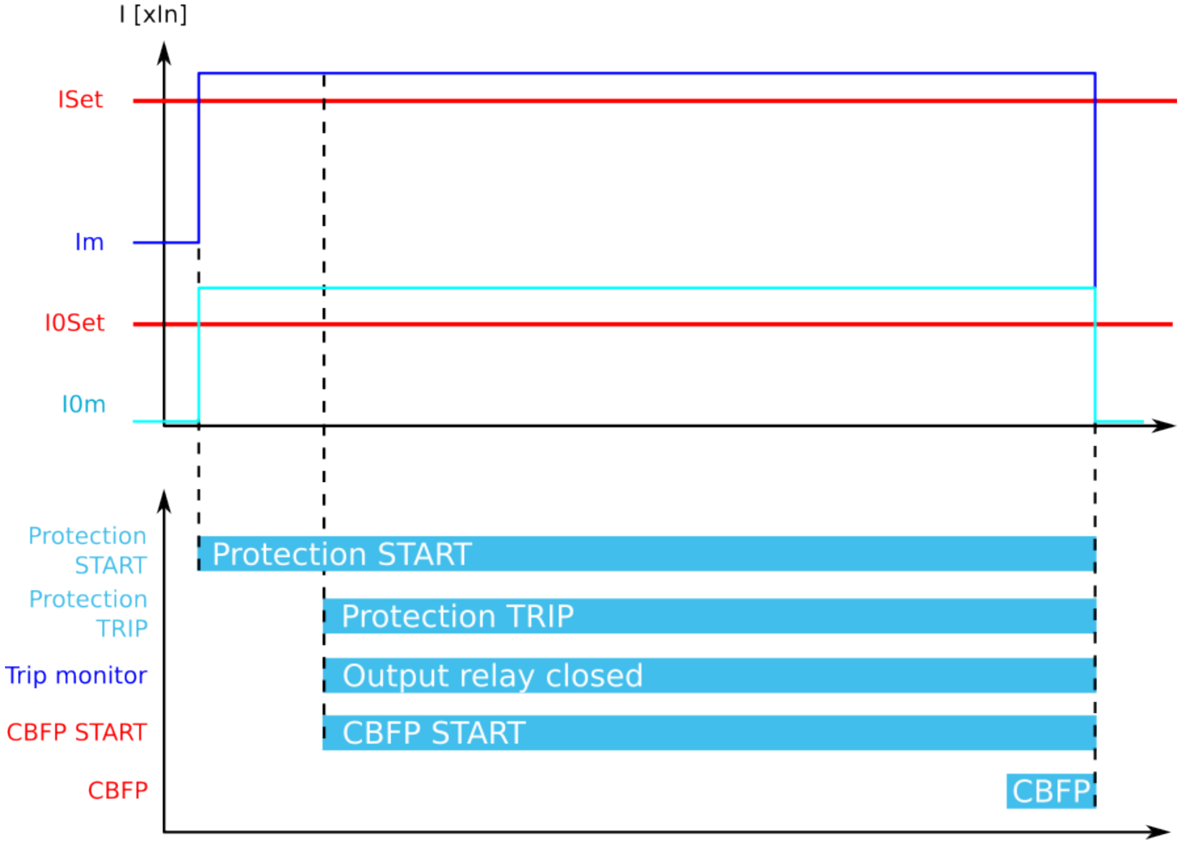
Probably the most common application is when the device's trip output controls the circuit breaker trip coil, while one dedicated CBFP contact controls the CBFP function. Below are a few operational cases regarding the various applications and settings of the CBFP function.

Figure. 4.4.8 - 51. CBFP when "Current" is the selected criterion.



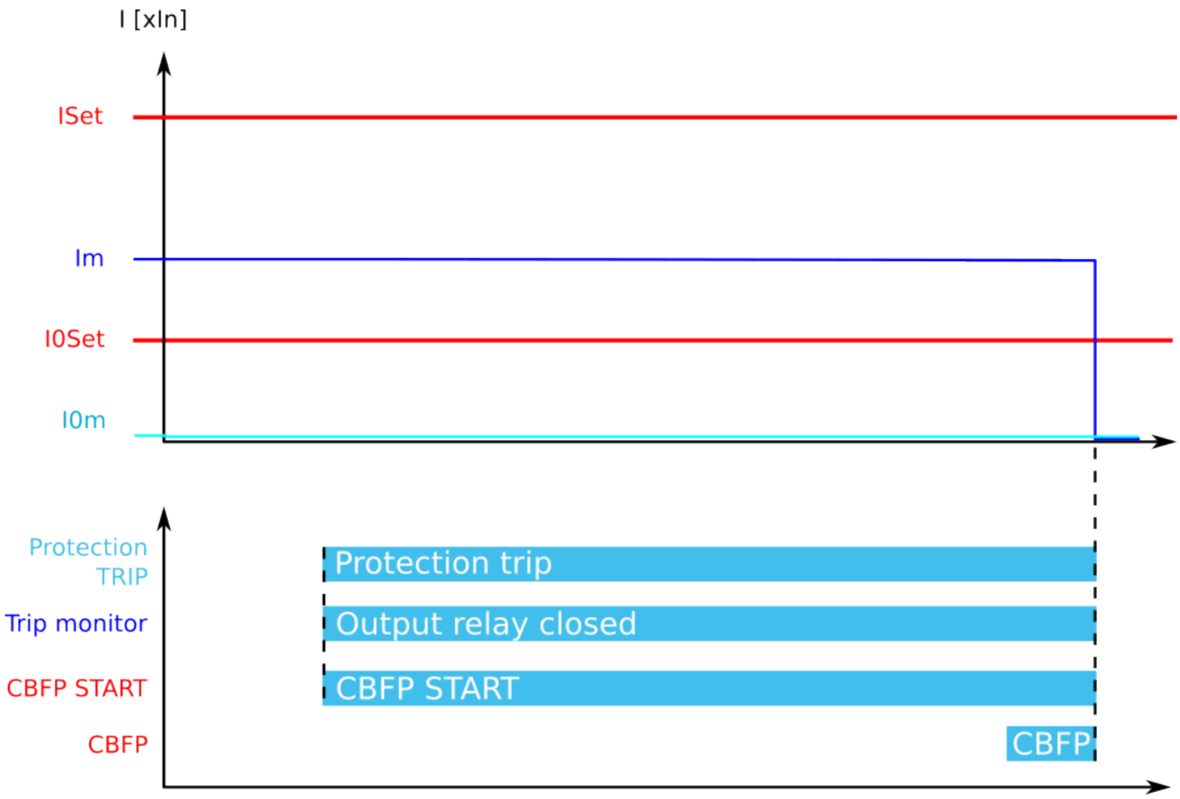
When the current threshold setting of I_{set} and/or $I0_{set}$ is exceeded, the current-based protection is activated and the counter for CBFP starts calculating the set operating time. The tripping of the primary protection stage is not monitored in this configuration. Therefore, if the current is not reduced below the setting limit, a CBFP signal is sent to the incoming feeder circuit 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. 4.4.8 - 52. CBFP when "Current and DO" is the selected criterion.



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 counter for CBFP is halted until the monitored output contact is controlled (that is, until the primary protection operates). When the tripping signal reaches the primary protection stage, the CBFP counter starts calculating 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 or the primary stage tripping signal is not reset, a CBFP signal is sent to the incoming feeder circuit breaker. The time delay counter for CBFP is 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 by current-based functions alone, and other function trips can be excluded from the CBFP functionality.

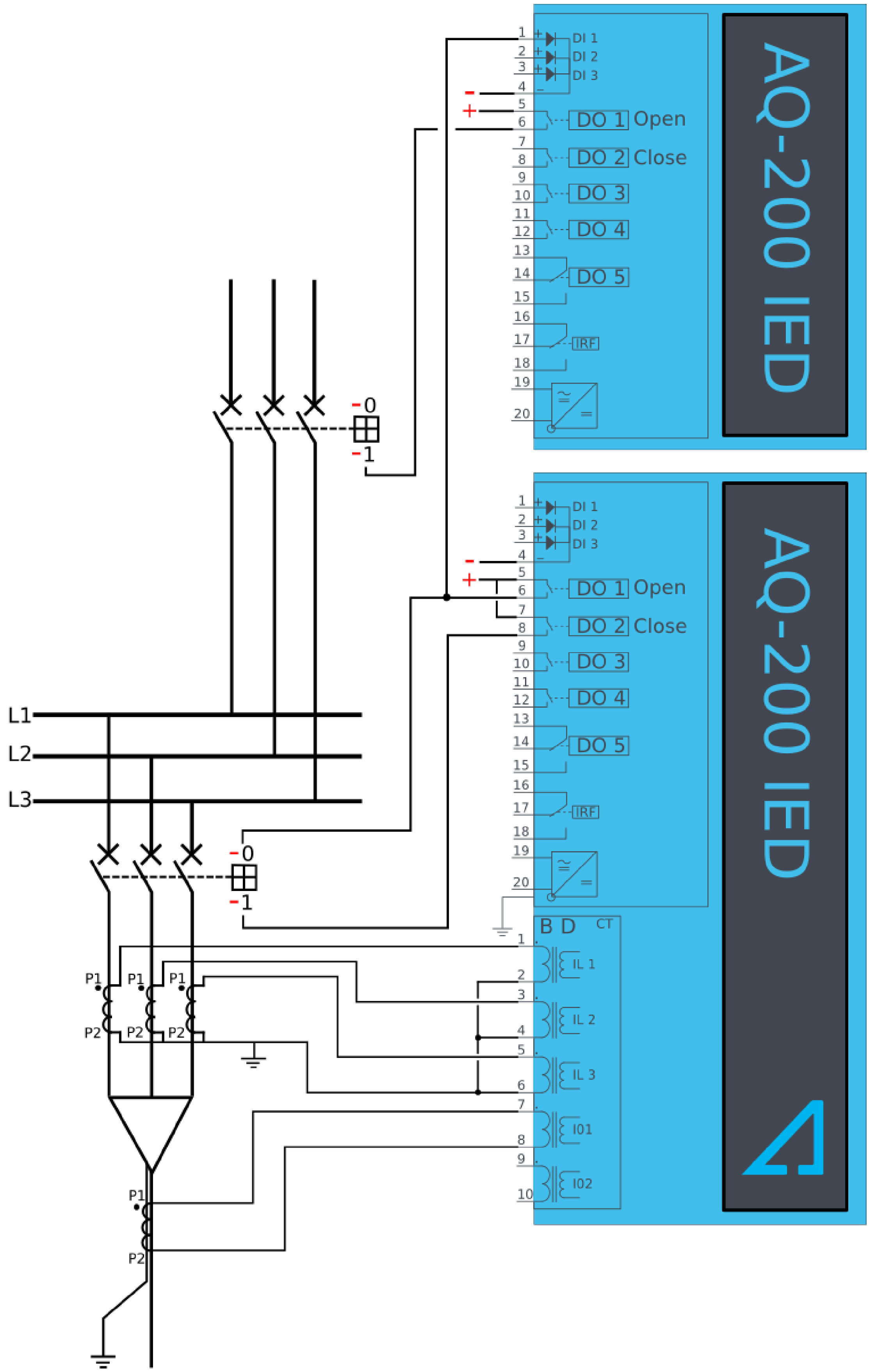
Figure. 4.4.8 - 53. CBFP when "Current or DO" is the selected criterion.



When the current threshold setting of I_{set} and/or $I0_{set}$ is exceeded, or the TRIP signal reaches the primary protection stage, the function starts counting down towards the CBFP signal. The tripping of the primary protection stage is constantly monitored in this configuration regardless of the current's status. 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 above the limit or the signal is active) for the duration of the set CBFP time delay, a CBFP signal is sent to the incoming feeder circuit breaker. The time delay counter for CBFP 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 by current-based functions alone, with added security from current monitoring. Other function trips can also be included to the CBFP functionality.

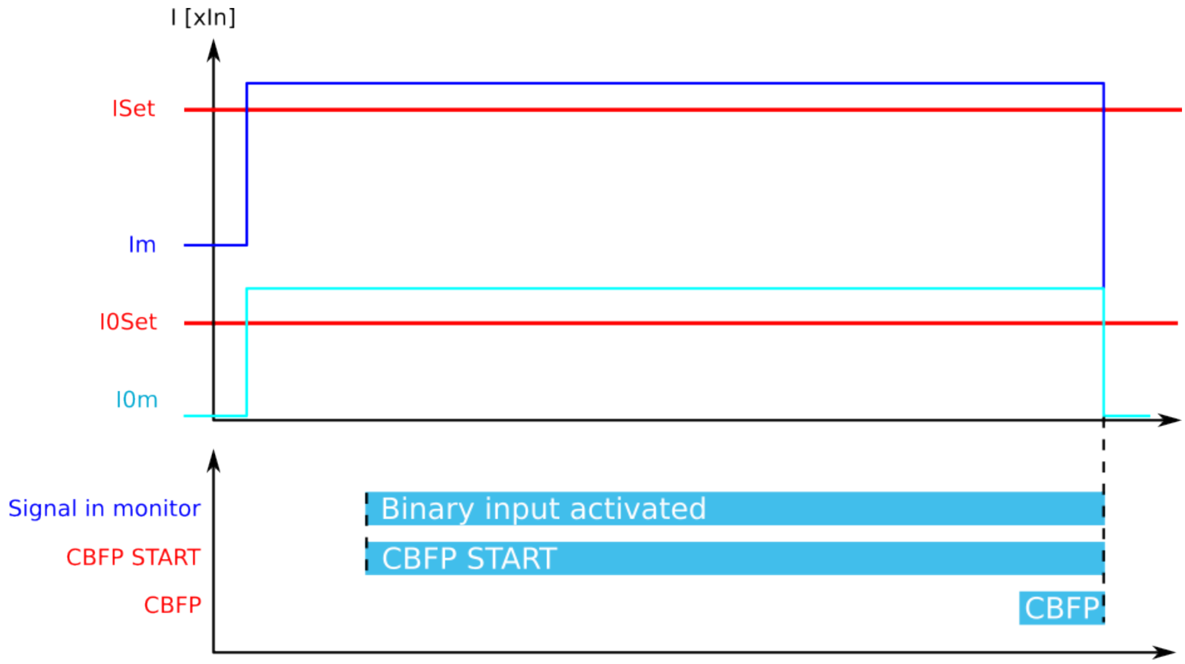
Device configuration as a dedicated CBFP unit

Figure. 4.4.8 - 54. Wiring diagram when the 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 a device is used for this purpose, the tripping signal is wired to the device's digital input and the device's own TRIP signal is used only for the CBFP purpose. In this application's incoming feeder 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 incoming feeder. The following example does not use retripping and the CBFP signal is used as the incoming feeder trip from the outgoing breaker trip signal. The TRIP signal can also be transported between different devices by using GOOSE messages.

Figure. 4.4.8 - 55. Dedicated CBFP operation from digital input signal.



In this mode the CBFP operates only from a digital input signal. Both current and output relay monitoring can be used. The counter for the CBFP signal begins 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 incoming feeder circuit 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 the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counters for RETRIP, CBFP, CBFP START and BLOCKED events.

Table. 4.4.8 - 100. Event messages.

Event block name	Event names
CBF1	Start ON
CBF1	Start OFF

Event block name	Event names
CBF1	Retrip ON
CBF1	Retrip OFF
CBF1	CBFP ON
CBF1	CBFP OFF
CBF1	Block ON
CBF1	Block OFF
CBF1	DO monitor ON
CBF1	DO monitor OFF
CBF1	Signal ON
CBF1	Signal OFF
CBF1	Phase current ON
CBF1	Phase current OFF
CBF1	Res current ON
CBF1	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.

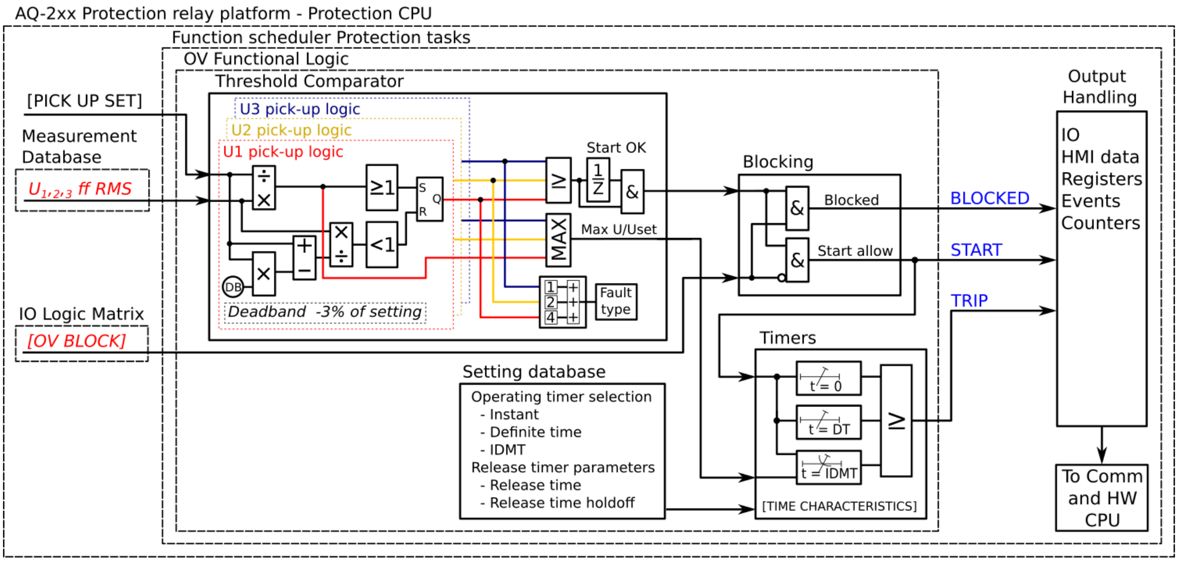
Table. 4.4.8 - 101. Register content.

Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
Max phase current	Highest phase current
Residual current	I01, I02 channel or calculated residual current
Time to RETR	Time remaining to retrip activation
Time to CBFP	Time remaining to CBFP activation
Setting group in use	Setting group 1...8 active

4.4.9 Overvoltage protection (U>; 59)

The overvoltage function is used for instant and time-delayed overvoltage protection. Devices 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.

Figure. 4.4.9 - 56. Simplified function block diagram of the U> function.



Measured input

The function block uses fundamental frequency component of line-to-line or line-to-neutral (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.

Table. 4.4.9 - 102. Measurement input of the U> function.

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

Table. 4.4.9 - 103. Measured magnitude selection settings.

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

Figure. 4.4.9 - 57. Selectable measurement magnitudes with 3LN+U4 VT connection.

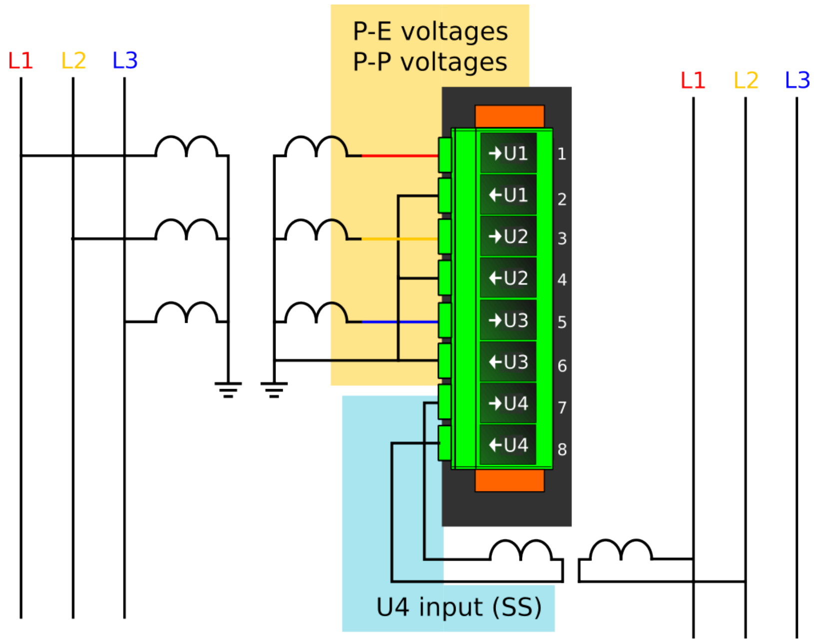


Figure. 4.4.9 - 58. Selectable measurement magnitudes with 3LL+U4 VT connection (P-E voltages not available without residual voltage).

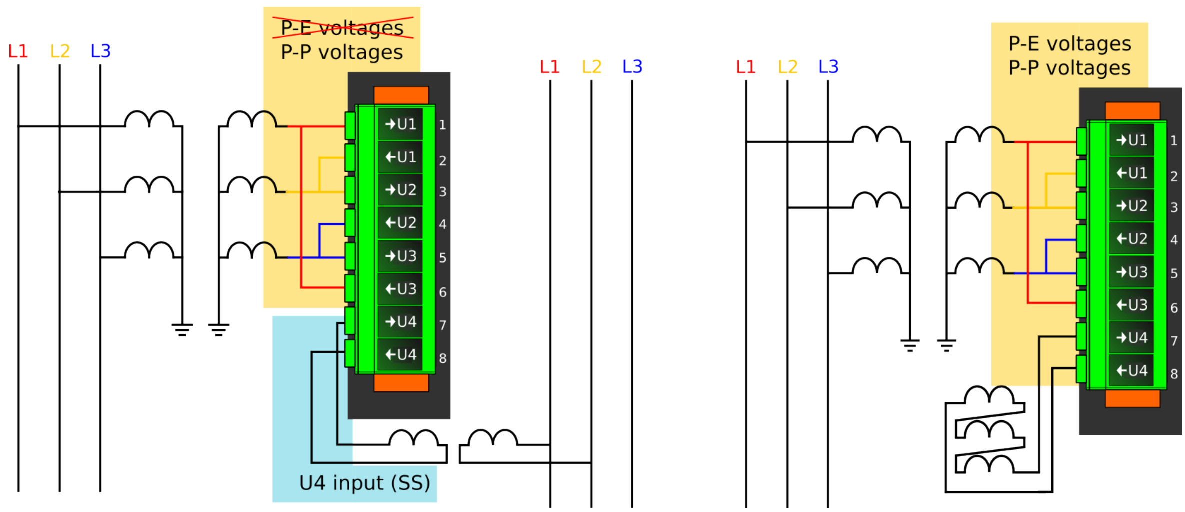
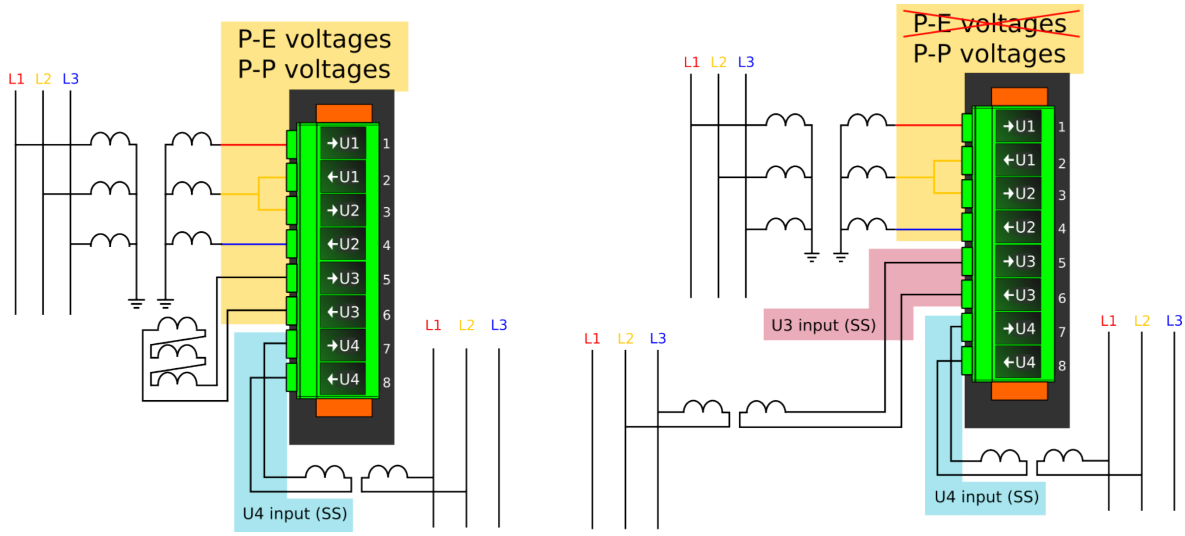


Figure. 4.4.9 - 59. Selectable measurement magnitudes with 2LL+U3+U4 VT connection (P-E voltages not available without residual voltage).



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.

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. 4.4.9 - 104. General settings of the function.

Name	Range	Default	Description
U> LN mode	• On • Blocked • Test • Test/ Blocked • Off	On	Set mode of OV block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
U> force status to	• Normal • Start • Trip • Blocked	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.

Pick-up settings

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.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.4.9 - 105. Pick-up settings.

Name	Range	Step	Default	Description
Operation mode	• 1 voltage • 2 voltages • 3 voltages	-	1 voltage	Pick-up criteria selection
U_{set}	50.00…150.00%U_n	0.01%U_n	105%U_n	Pick-up setting

Read-only parameters

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

Table. 4.4.9 - 106. Information displayed by the function.

Name	Range	Step	Description
U> LN behaviour	• On • Blocked • Test • Test/Blocked • Off	-	Displays the mode of OV block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
U< pick-up setting	0.0...1 000 000.0V	0.1V	The 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	0.000...1800.000s	0.005s	Displays the expected operating time when a fault occurs. When IDMT mode is used, the expected operating time depends on the measured voltage value. If the measured voltage changes during a fault, the expected operating time changes accordingly.
Time remaining to trip	-1800.000...1800.000s	0.005s	When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs.
$U_{A(B)}$ meas/U_{set} at the moment	0.00...1250.00U_m/U_{set}	0.01U_m/U_{set}	The ratio between U_A or U_{AB} voltage and the pick-up value.
$U_{B(C)}$ meas/U_{set} at the moment	0.00...1250.00U_m/U_{set}	0.01U_m/U_{set}	The ratio between U_B or U_{BC} voltage and the pick-up value.
$U_{C(A)}$ meas/U_{set} at the moment	0.00...1250.00U_m/U_{set}	0.01U_m/U_{set}	The ratio between U_C or U_{CA} voltage and the pick-up value.
U_{meas}/U_{set} at the moment	0.00...1250.00U_m/U_{set}	0.01U_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 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:

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

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. 4.4.9 - 107. 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.

Name	Range	Step	Default	Description
Definite operating time delay	0.000…800.000s	0.005s	0.040s	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 stage without added delay. When the parameter is set to 0.005...1800 s, the stage operates as independent delayed.
Time dial setting k	0.01…60.00s	0.01s	0.05s	This setting is active and visible when IDMT is the selected delay type. Time dial/multiplier setting for IDMT characteristics.
IDMT Multiplier	0.01…25.00s	0.01s	1.00s	This setting is active and visible when IDMT is the selected delay type. IDMT time multiplier in the U_m/U_{set} power.

Table. 4.4.9 - 108. Setting parameters for reset time characteristics.

Name	Range	Step	Default	Description
Release time delay	0.000…150.000s	0.005s	0.06s	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	• No • Yes	-	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	• No • Yes	-	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	• No • Yes	-	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.

Events and registers

The overvoltage function (abbreviated "OV" in event block names) generates events and registers from the status changes in the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The function offers four (4) independent stages; the events are segregated for each stage operation.

Table. 4.4.9 - 109. Event messages.

Event block name	Event names
OV1...OV4	Start ON
OV1...OV4	Start OFF
OV1...OV4	Trip ON
OV1...OV4	Trip OFF
OV1...OV4	Block ON
OV1...OV4	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.

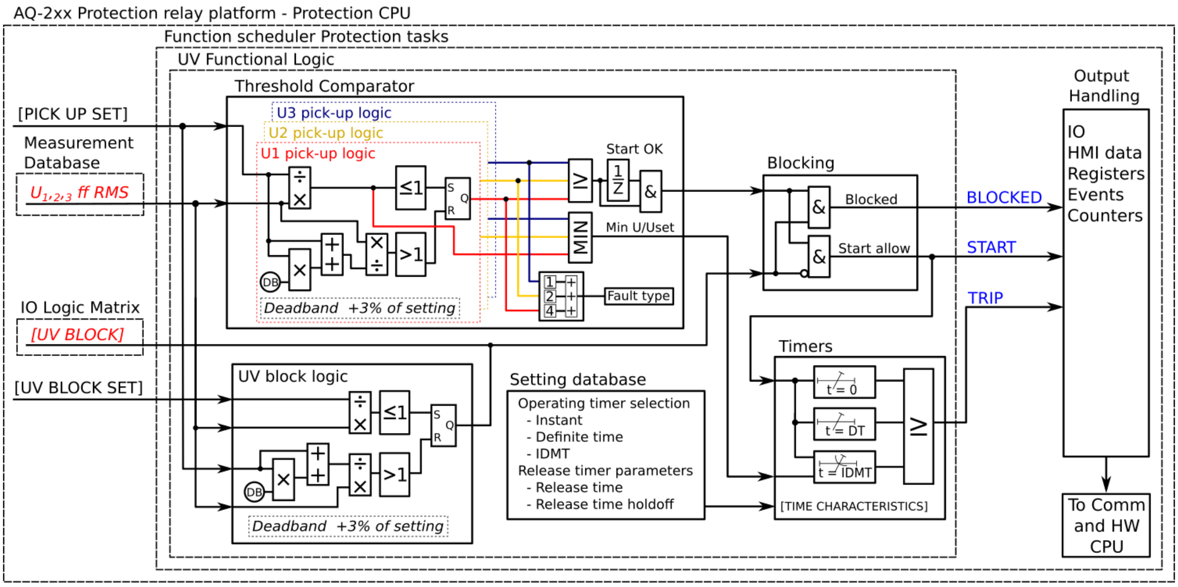
Table. 4.4.9 - 110. Register content.

Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
Fault type	L1-G…L1-L2-L3
Pre-trigger voltage	Start/Trip -20ms voltage
Pre-fault voltage	Start -200ms voltage
Trip time remaining	0 ms...1800s
Used SG	Setting group 1...8 active

4.4.10 Undervoltage protection (U<; 27)

The undervoltage function is used for instant and time-delayed undervoltage protection. Devices 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 has two blocking stages: internal blocking (based on voltage measurement and low voltage), or external blocking (e.g. during voltage transformer fuse failure).

Figure. 4.4.10 - 60. Simplified function block diagram of the U< function.



Measured input

The function block uses fundamental frequency component of line-to-line or line-to-neutral (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.

Table. 4.4.10 - 111. Measurement input of the U> function.

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

Table. 4.4.10 - 112. Measured magnitude selection settings.

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

Figure. 4.4.10 - 61. Selectable measurement magnitudes with 3LN+U4 VT connection.

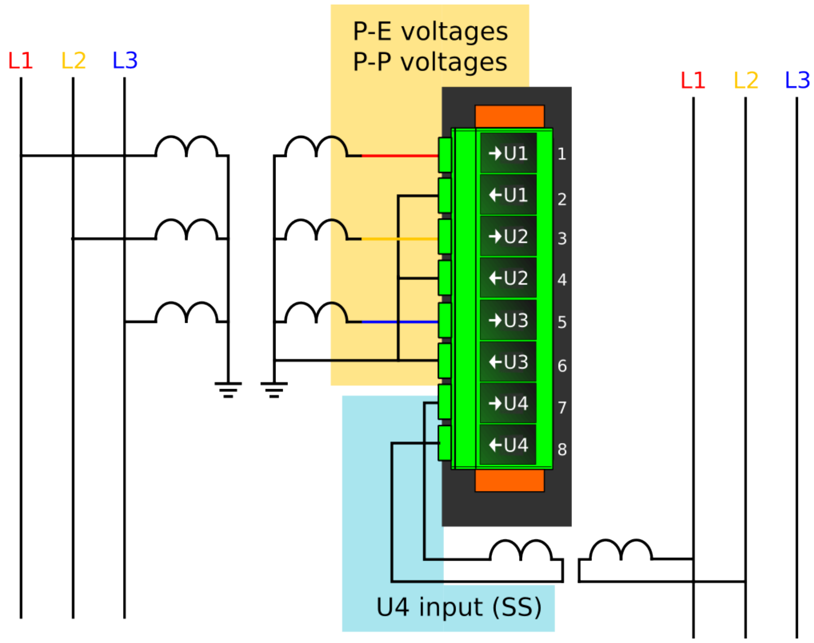


Figure. 4.4.10 - 62. Selectable measurement magnitudes with 3LL+U4 VT connection (P-E voltages not available without residual voltage).

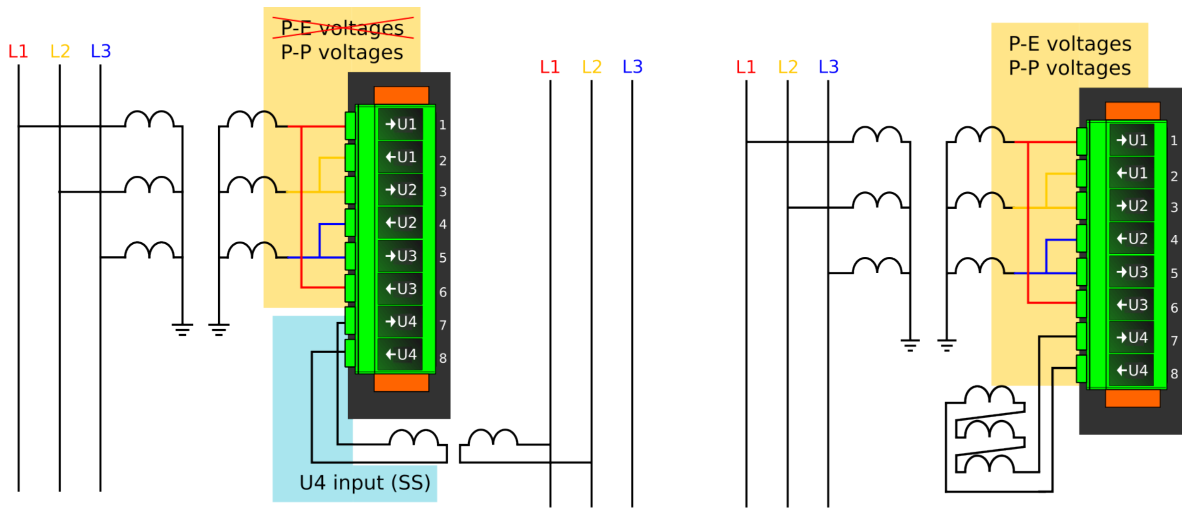
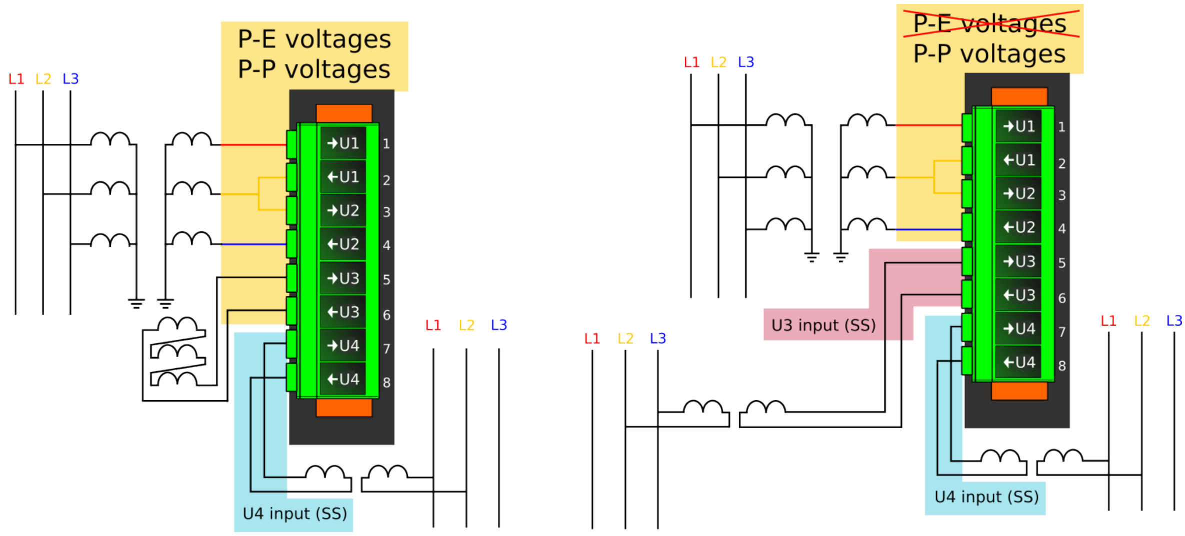


Figure. 4.4.10 - 63. Selectable measurement magnitudes with 2LL+U4 VT connection (P-E voltages not available without residual voltage).



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.

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. 4.4.10 - 113. General settings of the function.

Name	Range	Default	Description
U< LN mode	• On • Blocked • Test • Test/ Blocked • Off	On	Set mode of UV block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
U< force status to	• Normal • Start • Trip • Blocked	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.

Pick-up settings

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.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

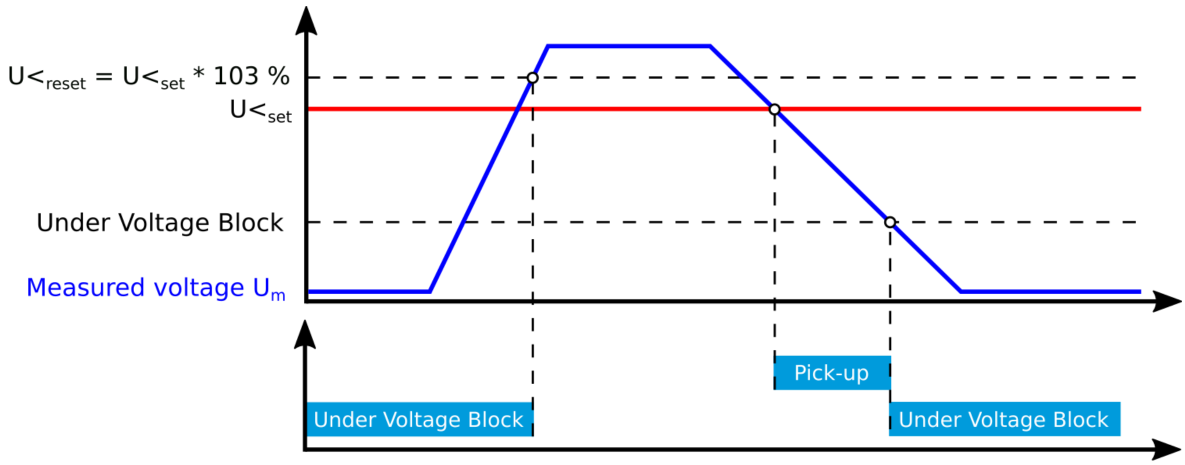
Table. 4.4.10 - 114. Pick-up settings.

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

Using *Block setting* to prevent nuisance trips

It is recommended to use the *Block setting* parameter to prevent the device from tripping in a situation where the network is de-energized. When the measured voltage drops below the set value, the device 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. 4.4.10 - 64. Example of the block setting operation.



Read-only parameters

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

Table. 4.4.10 - 115. Information displayed by the function.

Name	Range	Step	Description
U< LN behaviour	• On • Blocked • Test • Test/Blocked • Off	-	Displays the mode of UV block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
U< pick-up setting	0.0...1 000 000.0V	0.1V	The primary voltage required for tripping. The displayed pick-up voltage level depends on the pick-up setting and the voltage transformer settings.

Name	Range	Step	Description
U< block setting	0.0...1 000 000.0V	0.1V	The primary voltage level required 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 exceed the pick-up setting value.
Expected operating time	0.000...1800.000s	0.005s	Displays the expected operating time when a fault occurs. When IDMT mode is used, the expected operating time depends on the measured voltage value. If the measured voltage changes during a fault, the expected operating time changes accordingly.
Time remaining to trip	-1800.000...1800.000s	0.005s	When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs.
$U_{A(B)}$ meas/U_{set} at the moment	0.00...1250.00U_m/U_{set}	0.01U_m/U_{set}	The ratio between U_A or U_{AB} voltage and the pick-up value.
$U_{B(c)}$ meas/U_{set} at the moment	0.00...1250.00U_m/U_{set}	0.01U_m/U_{set}	The ratio between U_B or U_{BC} voltage and the pick-up value.
$U_{C(A)}$ meas/U_{set} at the moment	0.00...1250.00U_m/U_{set}	0.01U_m/U_{set}	The ratio between U_C or U_{CA} voltage and the pick-up value.
U_{meas}/U_{set} at the moment	0.00...1250.00U_m/U_{set}	0.01U_m/U_{set}	The ratio between the lowest measured phase or line 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 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:

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

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. 4.4.10 - 116. 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…1800.000s	0.005s	0.040s	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 stage without added delay. When the parameter is set to 0.005...1800 s, the stage operates as independent delayed.
Time dial setting k	0.01…60.00s	0.01s	0.05s	This setting is active and visible when IDMT is the selected delay type. Time dial/multiplier setting for IDMT characteristics.
IDMT Multiplier	0.01…25.00s	0.01s	1.00s	This setting is active and visible when IDMT is the selected delay type. IDMT time multiplier in the U_m/U_{set} power.

Table. 4.4.10 - 117. Setting parameters for reset time characteristics.

Name	Range	Step	Default	Description
Release time delay	0.000…150.000s	0.005s	0.06s	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.

Name	Range	Step	Default	Description
Delayed pick-up release	• No • Yes	-	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	• No • Yes	-	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	• No • Yes	-	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.

Events and registers

The undervoltage function (abbreviated "UV" in event block names) generates events and registers from the status changes in the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The function offers four (4) independent stages; the events are segregated for each stage operation.

Table. 4.4.10 - 118. Event messages.

Event block name	Event names
UV1...UV4	Start ON
UV1...UV4	Start OFF
UV1...UV4	Trip ON
UV1...UV4	Trip OFF
UV1...UV4	Block ON
UV1...UV4	Block OFF
UV1...UV4	Undervoltage Block ON
UV1...UV4	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. 4.4.10 - 119. Register content.

Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
Fault type	A…A-B-C
Pre-trigger voltage	Start/Trip -20ms voltage
Fault voltage	Start/Trip voltage
Pre-fault voltage	Start -200ms voltage
Trip time remaining	0 ms...1800s
Used SG	Setting group 1...8 active

4.4.11 Neutral overvoltage protection (U0>; 59N)

The neutral overvoltage function is used for non-directional instant and time-delayed earth fault protection.

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

$$U0 = 1/3(U_{L1} + U_{L2} + U_{L3})$$

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

Below are some examples of zero sequence calculation.

Figure. 4.4.11 - 65. Normal situation.

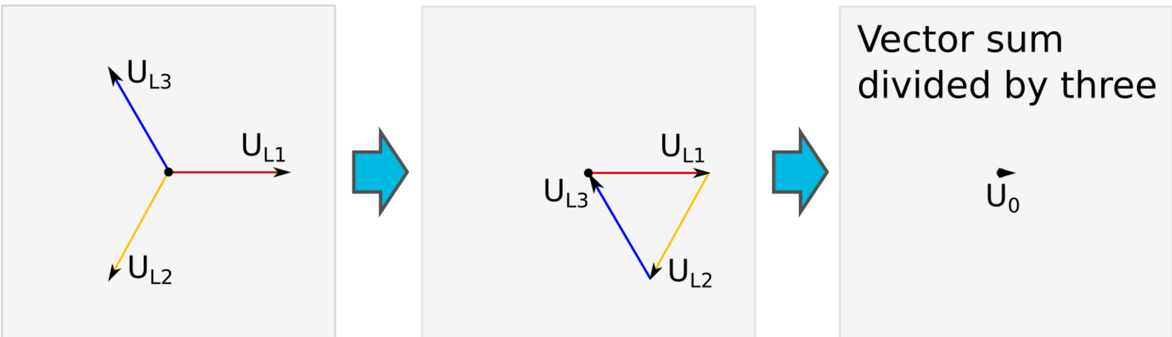


Figure. 4.4.11 - 66. Earth fault in isolated network.

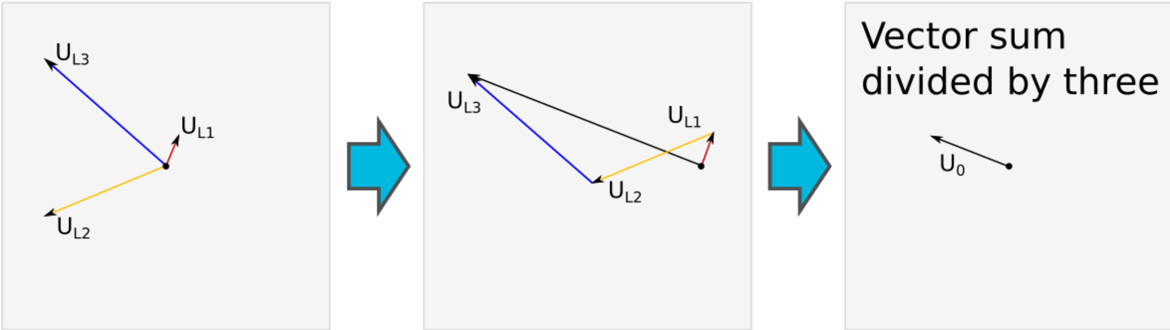


Figure. 4.4.11 - 67. Close-distance short-circuit between phases 1 and 3.

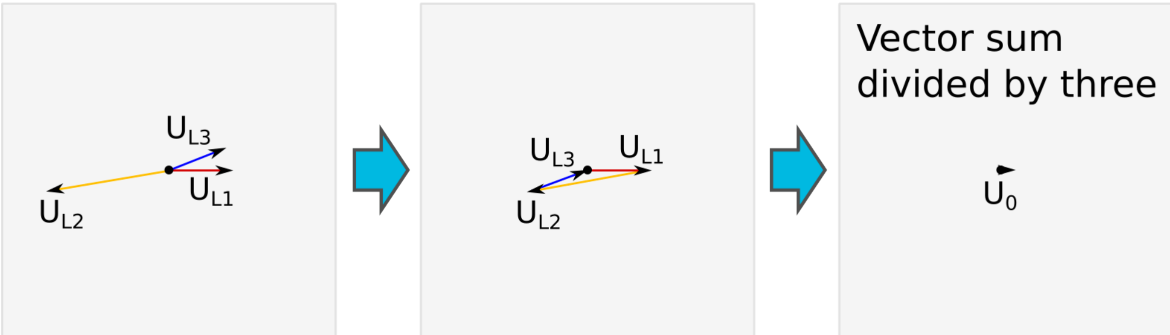
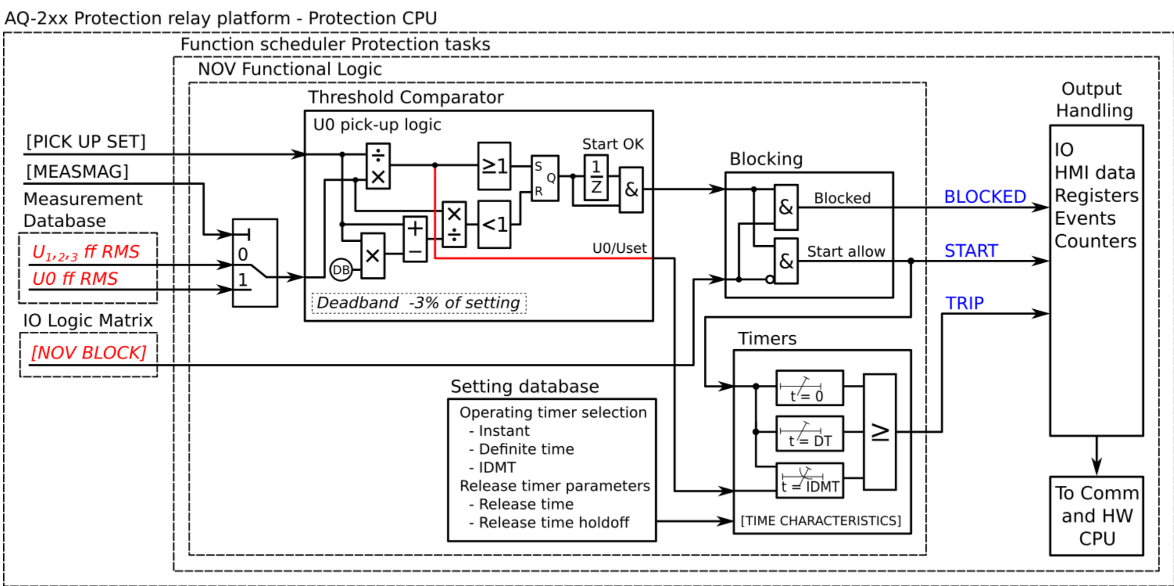


Figure. 4.4.11 - 68. Simplified function block diagram of the U0> function.



Measured input

The function block uses phase-to-neutral voltage magnitudes or calculated zero sequence component (as the user selects). Neutral overvoltage protection is scaled to line-to-line RMS 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.

The selection of the used measurement channel is made with a setting parameter.

Table. 4.4.11 - 120. Measurement inputs of the U0> function.

Signal	Description	Time base
U_0RMS	Fundamental frequency component of U0/V voltage measurement	5ms
U_{L1}RMS	Fundamental frequency component of U_{L1}/V voltage measurement	5ms
U_{L2}RMS	Fundamental frequency component of U_{L2}/V voltage measurement	5ms
U_{L3}RMS	Fundamental frequency component of U_{L3}/V voltage measurement	5ms

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. 4.4.11 - 121. General settings of the function.

Name	Range	Default	Description
U0> LN mode	• On • Blocked • Test • Test/ Blocked • Off	On	Set mode of NOV block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
U0> force status to	• Normal • Start • Trip • Blocked	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.
U0> meas input select	• Select • U0Calc • U3 Input • U4 Input	Select	Defines which available measured magnitude is used by the function. U0Calc calculates the voltage from phase voltages. Please note that U3 Input and U4 Input selections are available only if the channel has been set to U0 mode at *Measurements → Transformers → VT module.*

Pick-up settings

The U_{set} setting parameter controls the pick-up of the U0> 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 neutral voltage. 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 it triggers the pick-up operation of the function.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.4.11 - 122. Pick-up settings.

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

Read-only parameters

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

Name	Range	Step	Description
U0> LN mode behaviour	• On • Blocked • Test • Test/Blocked • Off	-	Displays the mode of NOV block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
U0> Measuring now	• No U0 avail! • U0Calc • U3 Input • U4 Input	-	Displays which voltage channel is used by the function. If no voltage channel has been selected the function defaults to calculated residual voltage if line-to-neutral voltages have been connected to device. If no channel is set to "U0" mode and line-to-line voltages are connected, no residual voltage is available and "No U0 avail!" will be displayed.
U0> Pick-up setting	0.0...1 000 000.0V	0.1V	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...1800.000s	0.005s	Displays the expected operating time when a fault occurs. When IDMT mode is used, the expected operating time depends on the measured voltage value. If the measured voltage changes during a fault, the expected operating time changes accordingly.
Time remaining to trip	-1800.000...1800.000s	0.005s	When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs.
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.

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 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:

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

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. 4.4.11 - 123. 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…1800.000s	0.005s	0.040s	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 without added delay. When the parameter is set to 0.005...1800 s, the stage operates as independent delayed.
Time dial setting k	0.01…60.00s	0.01s	0.05s	The setting is active and visible when IDMT is the selected delay type. Time dial/multiplier setting for IDMT characteristics.
IDMT Multiplier	0.01…25.00s	0.01s	1.00s	The setting is active and visible when IDMT is the selected delay type. IDMT time multiplier in the U_m/U_{set} power.

Table. 4.4.11 - 124. Setting parameters for reset time characteristics.

Name	Range	Step	Default	Description
Release time delay	0.000…150.000s	0.005s	0.06s	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	• No • Yes	-	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	• No • Yes	-	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	• No • Yes	-	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 the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a cumulative counter for the START, TRIP and BLOCKED events.

The function offers four (4) independent stages; the events are segregated for each stage operation.

Table. 4.4.11 - 125. Event messages.

Event block name	Event names
NOV1...NOV4	Start ON
NOV1...NOV4	Start OFF
NOV1...NOV4	Trip ON
NOV1...NOV4	Trip OFF
NOV1...NOV4	Block ON
NOV1...NOV4	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. 4.4.11 - 126. Register content.

Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
Fault type	L1-G…L1-L2-L3
Pre-trigger voltage	Start/Trip -20ms voltage
Fault voltage	Start/Trip voltage
Pre-fault voltage	Start -200ms voltage
Trip time remaining	0 ms...1800s
Setting group in use	Setting group 1...8 active

4.4.12 Sequence voltage protection (U1/U2>/<; 47/27P/59PN)

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). 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 either undervoltage or overvoltage.

Positive sequence voltage calculation

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

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

$$a = 1\angle 120°$$

$$a^2 = 1\angle 240°$$

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

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

Figure. 4.4.12 - 69. Normal situation.

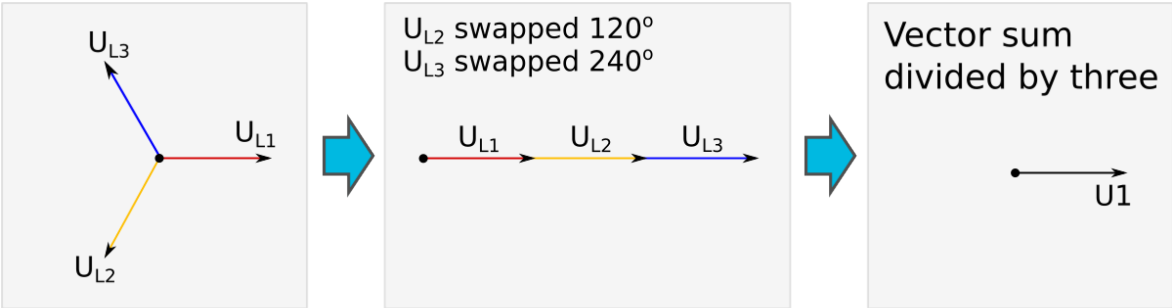


Figure. 4.4.12 - 70. Earth fault in an isolated network.

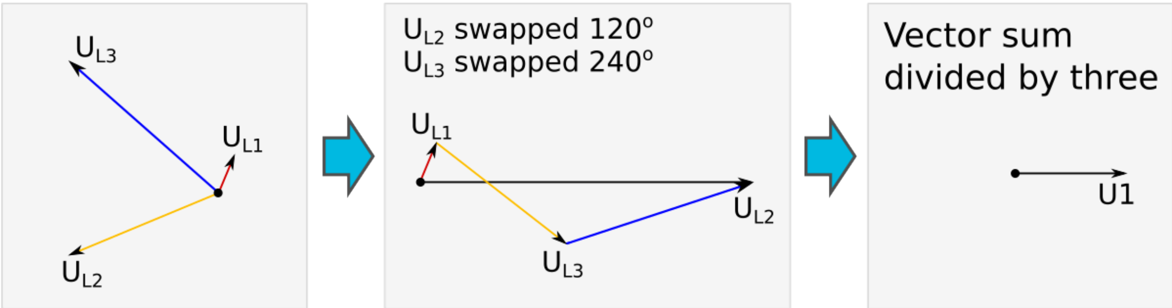
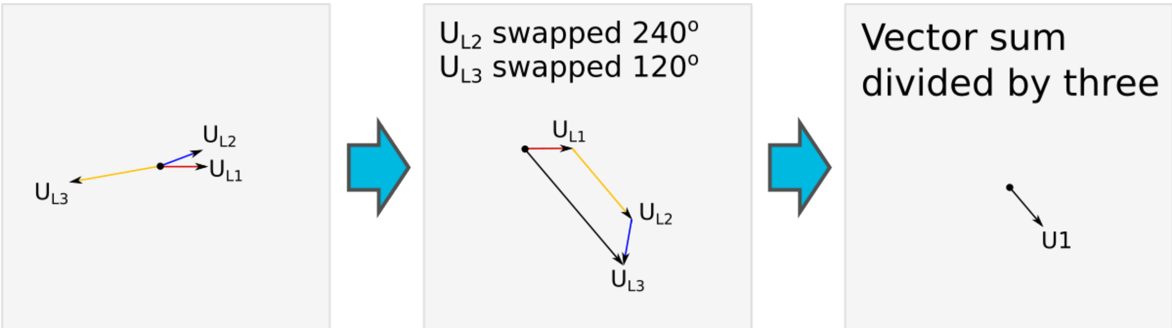


Figure. 4.4.12 - 71. Close-distance short-circuit between phases 1 and 3.



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. 4.4.12 - 72. Normal situation.

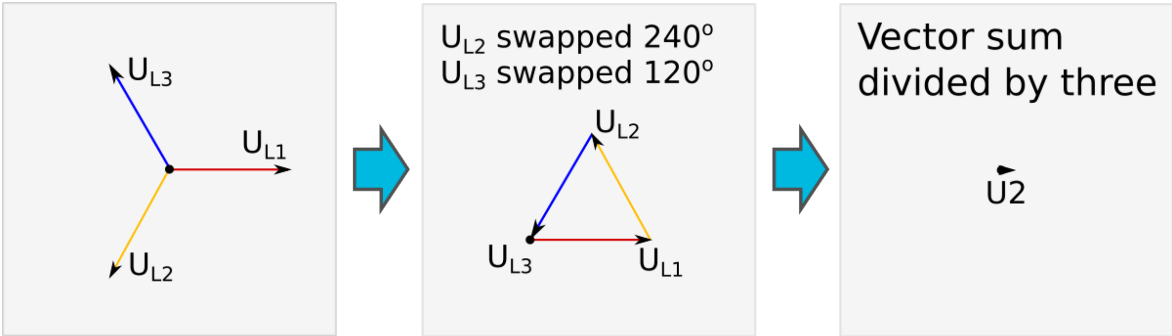


Figure. 4.4.12 - 73. Earth fault in isolated network.

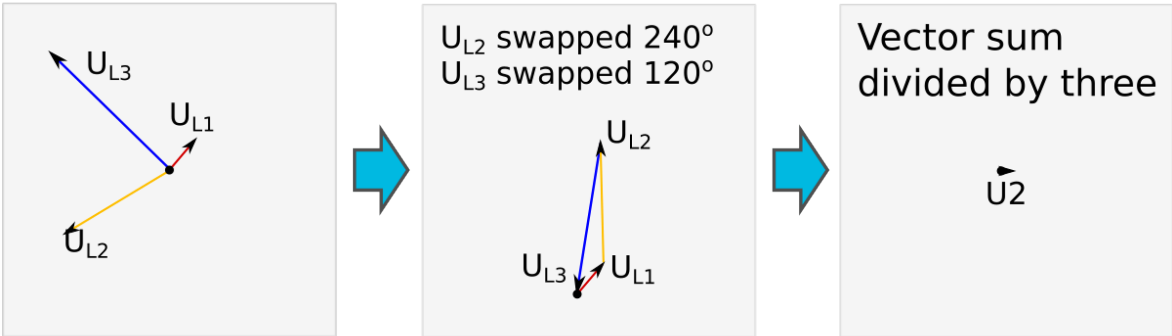


Figure. 4.4.12 - 74. Close-distance short-circuit between phases 1 and 3.

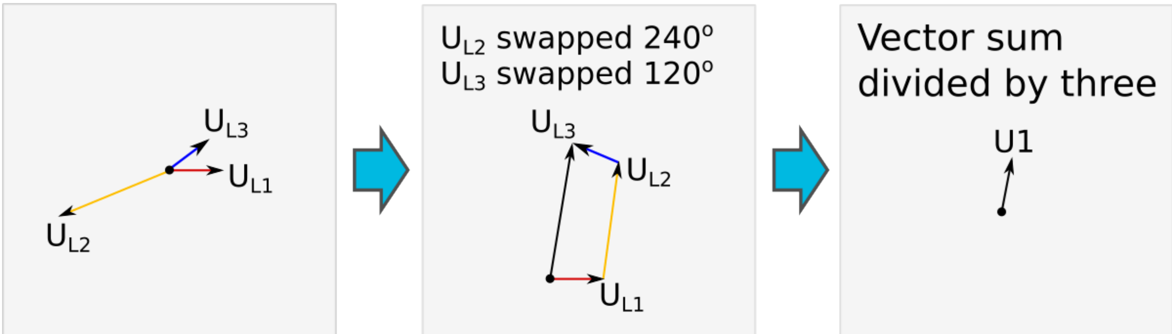
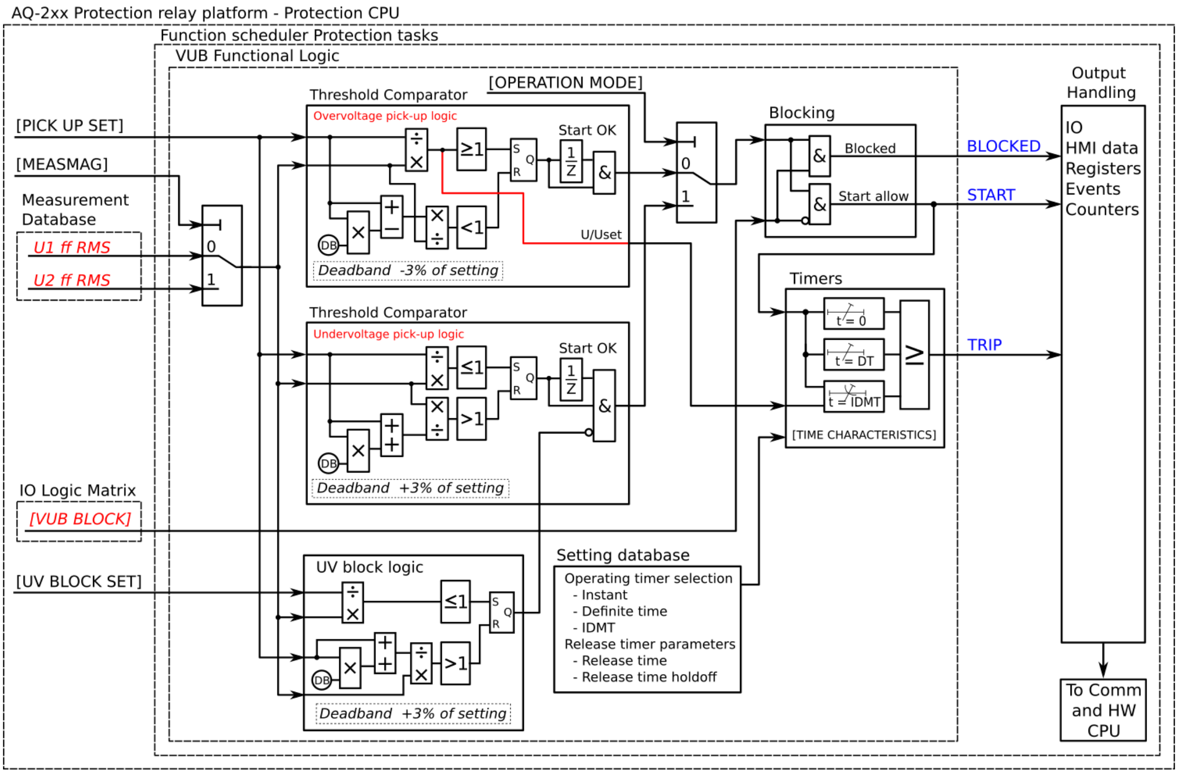


Figure. 4.4.12 - 75. Simplified function block diagram of the U1/U2>/< function.



Measured input

The function block uses fundamental frequency component of phase-to-phase, phase-to-neutral and zero sequence voltage measurements. The user can select the monitored magnitude to be either positive sequence voltage or negative sequence voltage values.

Table. 4.4.12 - 127. Measurement inputs of the U1/U2>/< function.

Signal	Description	Time base
U_1RMS	Fundamental frequency component of U_1/V voltage channel	5ms
U_2RMS	Fundamental frequency component of U_2/V voltage channel	5ms
U_3RMS	Fundamental frequency component of U_3/V voltage channel	5ms
U_4RMS	Fundamental frequency component of U_4/V voltage channel	5ms

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. 4.4.12 - 128. General settings of the function.

Name	Range	Default	Description
U1/2 >/< LN mode	• On • Blocked • Test • Test/Blocked • Off	On	Set mode of VUB block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
U1/2 >/< force status to	• Normal • Start • Trip • Blocked	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.
Measured magnitude	• U1 Positive sequence voltage • U2 Negative sequence voltage	U1 Positive sequence voltage	Selects which calculated voltage is supervised.

Pick-up settings

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.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

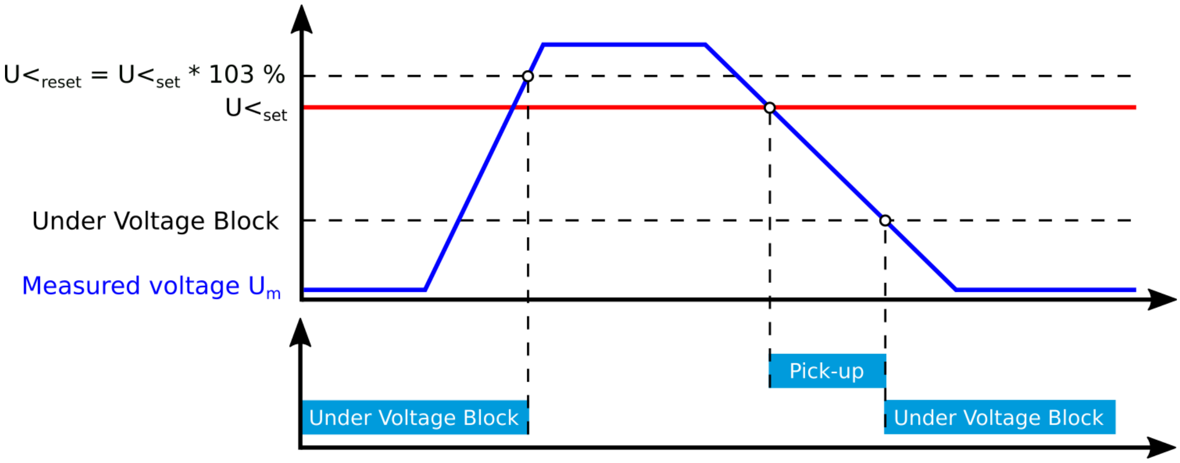
Table. 4.4.12 - 129. Pick-up settings.

Name	Range	Step	Default	Description
Pick-up terms	• Over > • Under<	-	Over>	Selects whether the function picks-up when the monitored voltage is under or over the set pick-up value.
U_{set}	5.00…150.00%U_n	0.01%U_n	105%U_n	Pick-up setting
U_{blk}	0.00…80.00%U_n	0.01%U_n	5%U_n	Undervoltage blocking (visible when the pick-up term is Under<)

Using *Block setting* to prevent nuisance trips

It is recommended to use the *Under block setting* U_{blk} parameter when Under< is the chosen tripping condition to prevent the function from tripping in a situation where the network is de-energized. When the measured voltage drops below the set value, the function 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. 4.4.12 - 76. Example of the block setting operation.



Read-only parameters

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

Table. 4.4.12 - 130. Information displayed by the function.

Name	Range	Step	Description
U1/2 >/< LN behaviour	• On • Blocked • Test • Test/Blocked • Off	-	Displays the mode of VUB block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
U1/2 >/< Pick-up setting	0.0...1 000 000.0V	0.1V	The 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	0.000...1800.000s	0.005s	Displays the expected operating time when a fault occurs. When IDMT mode is used, the expected operating time depends on the measured voltage value. If the measured voltage changes during a fault, the expected operating time changes accordingly.
Time remaining to trip	-1800.000...1800.000s	0.005s	When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs.
U_{meas}/U_{set} at the moment	$0.00...1250.00U_m/U_{set}$	$0.01U_m/U_{set}$	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 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 one of the following formulas:

Overvoltage

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

Undervoltage

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

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. 4.4.12 - 131. 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…1800.000s	0.005s	0.040s	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 without added delay. When the parameter is set to 0.005...1800 s, the stage operates as independent delayed.

Name	Range	Step	Default	Description
Time dial setting k	0.01…60.00s	0.01s	0.05s	The setting is active and visible when IDMT is the selected delay type. Time dial/multiplier setting for IDMT characteristics.
IDMT Multiplier	0.01…25.00s	0.01s	1.00s	The setting is active and visible when IDMT is the selected delay type. IDMT time multiplier in the U_m/U_{set} power.

Table. 4.4.12 - 132. Setting parameters for reset time characteristics.

Name	Range	Step	Default	Description
Release time delay	0.000…150.000s	0.005s	0.06s	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	• No • Yes	-	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	• No • Yes	-	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	• No • Yes	-	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 sequence voltage function (abbreviated "VUB" in event block names) generates events and registers from the status changes in the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also a resettable cumulative counter for the START, TRIP and BLOCKED events.

The function offers four (4) independent stages; the events are segregated for each stage operation.

Table. 4.4.12 - 133. Event messages.

Event block name	Event names
VUB1...VUB4	Start ON
VUB1...VUB4	Start OFF
VUB1...VUB4	Trip ON
VUB1...VUB4	Trip OFF
VUB1...VUB4	Block ON
VUB1...VUB4	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. 4.4.12 - 134. Register content.

Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
Pre-trigger voltage	Start/Trip -20ms voltage
Fault voltage	Start/Trip voltage
Pre-fault voltage	Start -200ms voltage
Trip time remaining	0 ms...1800s
Setting group in use	Setting group 1...8 active

4.4.13 Overfrequency and underfrequency protection (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*).

Figure. 4.4.13 - 77. Simplified function block diagram of the f> function.

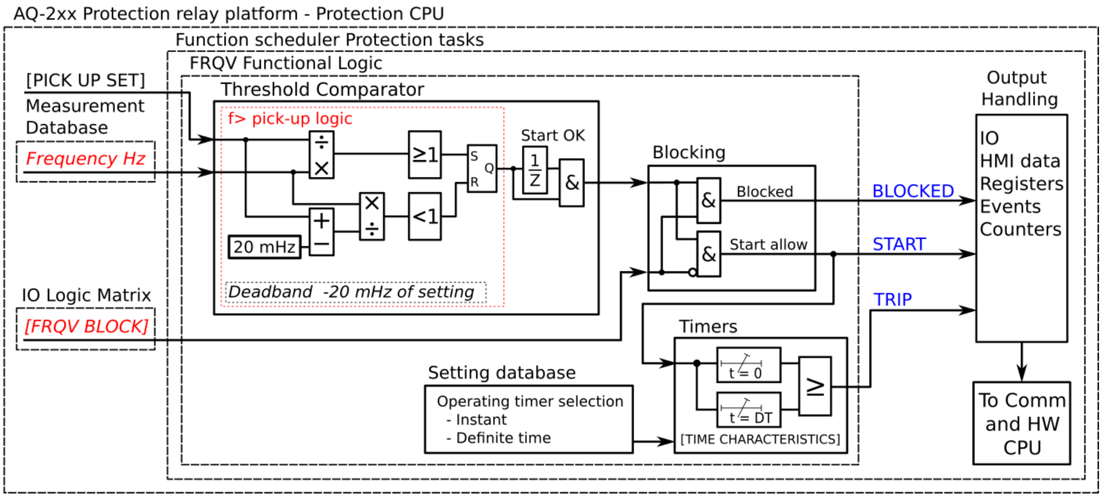
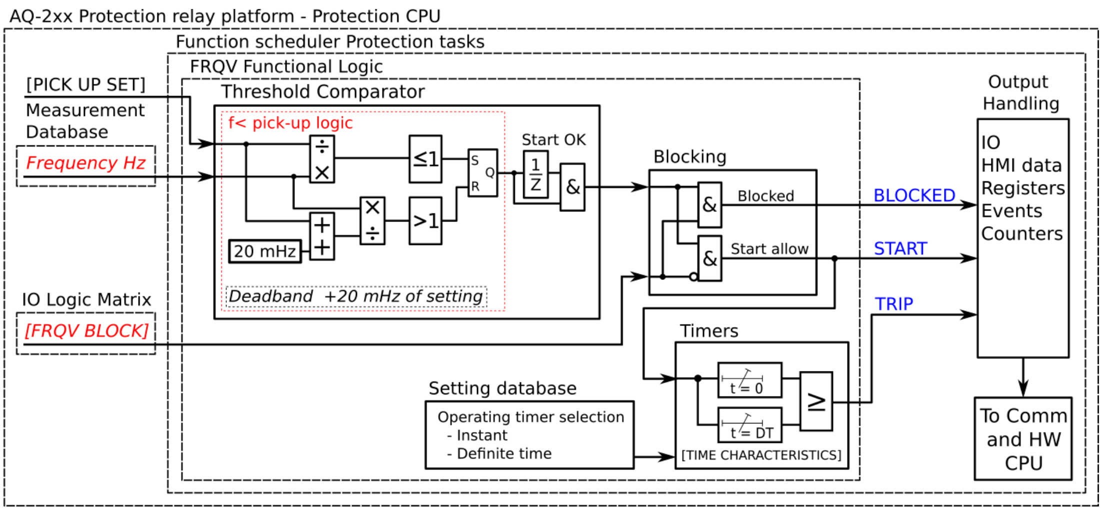


Figure. 4.4.13 - 78. Simplified function block diagram of the f< function.



Measured input

The frequency protection function compares the measured frequency to the pick-up setting (given in Hz). There are three (3) frequency references available. Please refer to "Frequency tracking and scaling" chapter for a detailed description of frequency tracking.

Table. 4.4.13 - 135. Measurement inputs of the f>/< function.

Signals	Description	Time base
Frequency reference 1	Primary frequency reference	5ms
Frequency reference 2	Secondary frequency reference	5ms
Frequency reference 3	Tertiary frequency reference	5ms

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. 4.4.13 - 136. General settings of the function.

Name	Range	Default	Description
f</> LN mode	• On • Blocked • Test • Test/ Blocked • Off	On	Set mode of FRQV block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
f> enable f>> enable f>>> enable f>>>> enable f< enable f<< enable f<<< enable f<<<< enable	• No • Yes	No	Enables or disables the stage.
f> force status to f>> force status to f>>> force status to f>>>> force status to f< force status to f<< force status to f<<< force status to f<<<< force status to	• Normal • Start • Trip • Blocked	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.

Pick-up settings

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 20mHz is built into the function and is always relative to the pick-up value.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.4.13 - 137. Pick-up settings.

Name	Range	Step	Default	Description
f> used in setting group	• No • Yes	-	No	Enables or disables the protection stage in the setting group.
fset>	10.00…80.00Hz	0.01Hz	51Hz	Pick-up setting
fset<	5.00…75.00Hz	0.01Hz	49Hz	Pick-up setting
f< undervoltage block	0.00...120.00%Un	0.01%Un	0.00%Un	Block setting. If set to zero, blocking is not in use. When the measured voltage drops below the set value, the operation of the functions is blocked.

Operating time characteristics for trip and reset

This function supports definite time delay (DT). 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".

Read-only parameters

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

Table. 4.4.13 - 138. Information displayed by the function.

Name	Range	Step	Description
f</> LN behaviour	• On • Blocked • Test • Test/Blocked • Off	-	Displays the mode of FRQV block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
f</> condition	• Normal • Start • Trip • Blocked	-	Displays the status of the protection function.
f meas / f set	0.000..20.000f_m/f_{set}	0.001f_m/f_{set}	The ratio between the measured frequency and the pick-up value.
Expected operating time	0.000...1800.000s	0.005s	Displays the expected operating time when a fault occurs.
Time remaining to trip	-1800.000...1800.000s	0.005s	When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs.

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 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 the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

Table. 4.4.13 - 139. Event messages.

Event block name	Event names
FRQV1	f>/< Start ON
FRQV1	f>/< Start OFF
FRQV1	f>/< Trip ON
FRQV1	f>/< Trip OFF
FRQV1	f>/< Blocked ON
FRQV1	f>/< Blocked 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. 4.4.13 - 140. Register content.

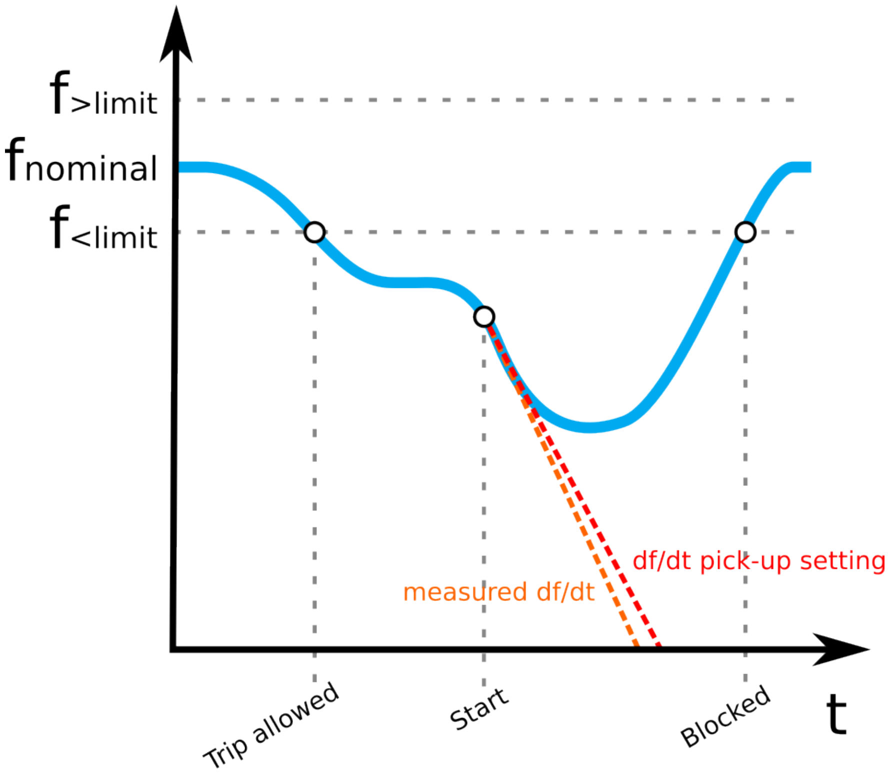
Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
f Pre-trig (Hz)	Start/Trip -20ms frequency
f Fault (Hz)	Fault frequency
Setting group in use	Setting group 1...8 active

4.4.14 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.

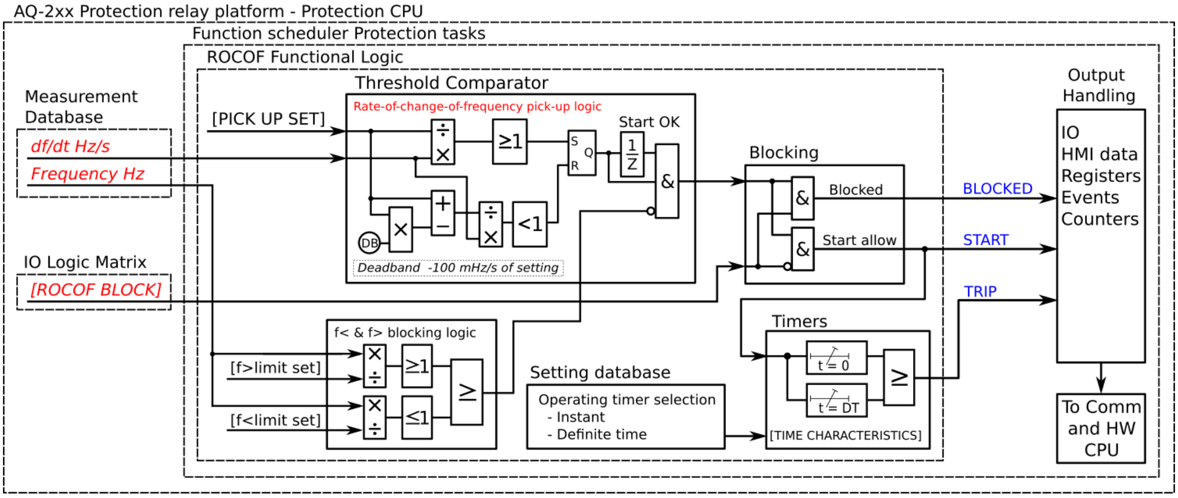
Figure. 4.4.14 - 79. Operation of the df/dt>/< function when the frequency starts but doesn't trip.



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 function 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*).

Figure. 4.4.14 - 80. 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). There are three (3) frequency references available. Please refer to "Frequency tracking and scaling" chapter for a detailed description of frequency tracking.

Table. 4.4.14 - 141. Measurement inputs of the df/dt>/< function.

Signals	Description	Time base
Frequency reference 1	Primary frequency reference	5ms
Frequency reference 2	Secondary frequency reference	5ms
Frequency reference 3	Tertiary frequency reference	5ms

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. 4.4.14 - 142. General settings of the function.

Name	Range	Step	Default	Description
df/dt >/< LN mode	• On • Blocked • Test • Test/Blocked • Off	-	On	Set mode of DFT block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
Max allowed df/dt rate	0.10...50.00 Hz/s	0.10 Hz/s	20 Hz/s	If df/dt rate exceeds this setting, the function is blocked.
df/dt >/< (1...8) enable	• No • Yes	-	No	Enables or disables the stage.

Name	Range	Step	Default	Description
df/dt >/< (1...8) force status to	• Normal • Start • Trip • Blocked	-	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.

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 +/- 100 mHz/s 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.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.4.14 - 143. Pick-up settings.

Name	Range	Step	Default	Description
df/dt>/< (1...8) used in setting group	• No • Yes	-	No	Enables the protection stage in setting group.
df/dt>/< (1...8) operating mode	• Rising • Falling • Both	-	Rising	Defines the operation mode of the protection stage. In "Rising" mode df/dt function can trip only from increasing frequency. In "Falling" mode df/dt function can trip only from decreasing frequency. "Both" allows df/dt to trip from both.
df/dt>/< (1...8) frequency limit	• Not used • Use f limit	-	Not used	Displays if frequency limits are used or not.
df/dt>/< (1...8) pick-up	0.01...10.00Hz/s	0.01Hz/s	0.2Hz/s	Pick-up setting.
df/dt>/< (1...8) f< limit	7.00...65.00Hz/s	0.01Hz/s	49.95Hz/s	Underfrequency limit. Tripping is permitted when measured frequency is under this value. This parameter is visible only when operation mode is set to "Falling" or "Both".
df/dt>/< (1...8) f> limit	10.00...70.00Hz/s	0.01Hz/s	51Hz/s	Overfrequency limit. Tripping is permitted if measured frequency is above this value. This parameter is visible only when operation mode is set to "Rising" or "Both".

Operating time characteristics for trip and reset

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

Read-only parameters

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

Table. 4.4.14 - 144. Information displayed by the function.

Name	Range	Step	Description
df/dt >/< LN behaviour	• On • Blocked • Test • Test/Blocked • Off	-	Displays the mode of DFT block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
Measured df/dt	0.000...20.000Hz/s	0.001Hz/s	Rate-of-change-of-frequency at the moment.
df/dt >/< (1...8) condition	• Normal • Start • Trip • Blocked	-	Displays the status of the protection function.
df/dt >/< (1...8) df/dt meas / df/dt set	0.000...20.000p.u.	0.005p.u.	The ratio between the rate-of-change-of-frequency and the pick-up value.
Expected operating time	0.000...1800.000s	0.005s	Displays the expected operating time when a fault occurs.
Time remaining to trip	-1800.000...1800.000s	0.005s	When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs.

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 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 the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs are can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

Table. 4.4.14 - 145. Event messages.

Event block name	Event names
DFT1	df/dt>/< (1...8) Start ON
DFT1	df/dt>/< (1...8) Start OFF
DFT1	df/dt>/< (1...8) Trip ON
DFT1	df/dt>/< (1...8) Trip OFF
DFT1	df/dt>/< (1...8) Blocked ON
DFT1	df/dt>/< (1...8) Blocked 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. 4.4.14 - 146. Register content.

Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
df/dt>/< Pre-trig (Hz/s)	Start/Trip –20ms df/dt>/<
f Pre-trig (Hz)	Start/Trip –20ms frequency
df/dt>/< Fault (Hz/s)	Fault df/dt>/<
f Fault (Hz)	Fault frequency
Setting group in use	Setting group 1...8 active

4.4.15 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.

Figure. 4.4.15 - 81. PQ diagram of the pick-up areas in various modes.

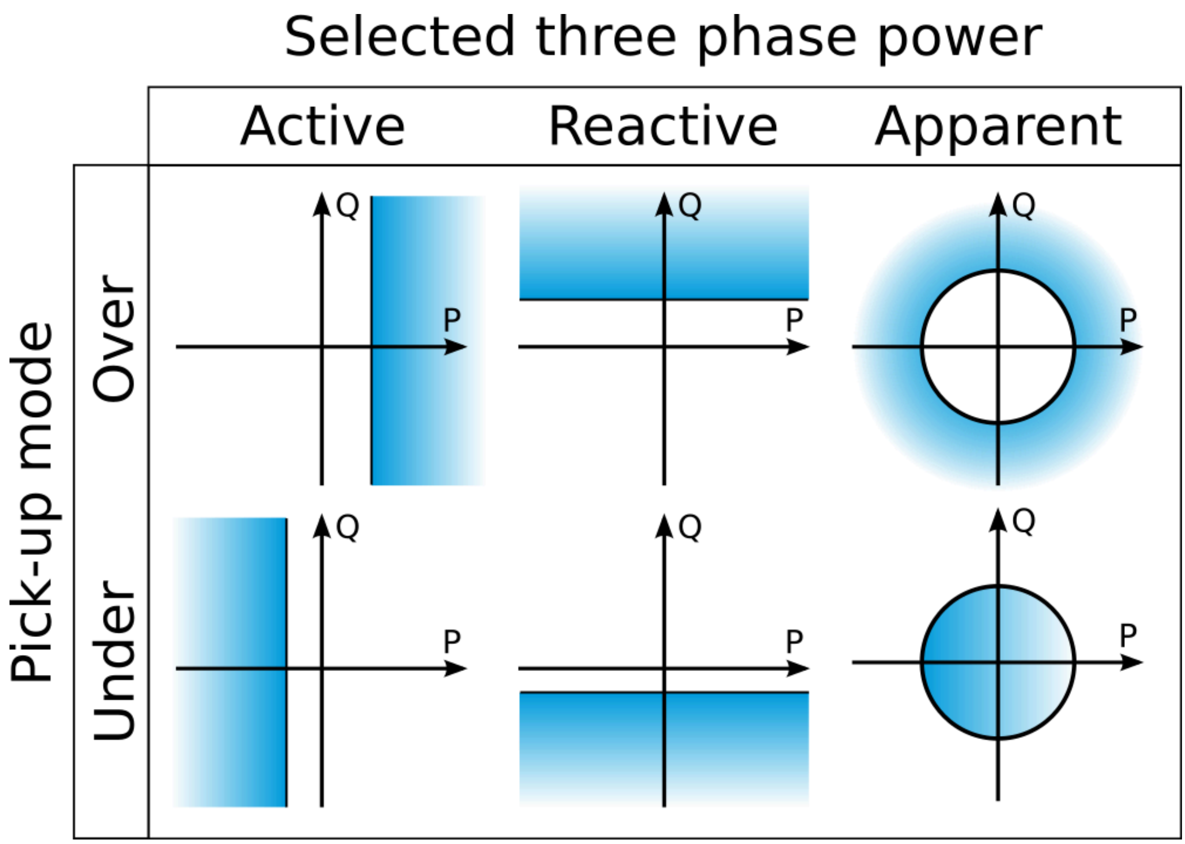
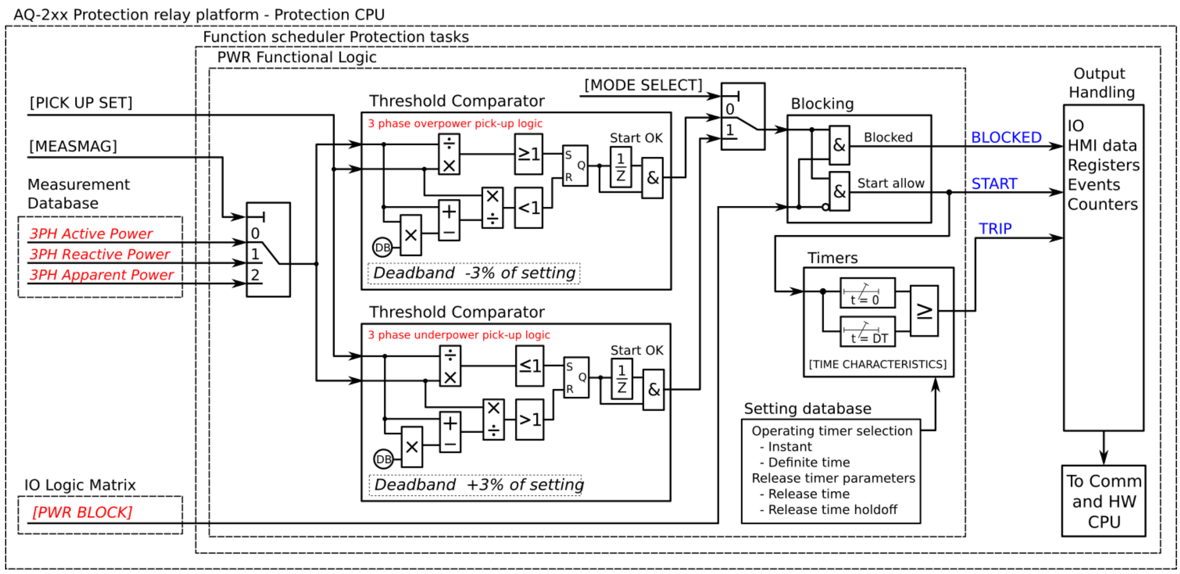


Figure. 4.4.15 - 82. Simplified function block diagram of the power protection function.



Measured input

The function block uses three phase currents and line-to-neutral or line-to-line voltages to calculate active, reactive or apparent power (as the uset chooses). Please refer to "Power and energy calculation" chapter for a detailed description of power calculation.

Table. 4.4.15 - 147. Measurement inputs of the P> function.

Signal	Description	Time base
I_{L1}RMS	Fundamental frequency component of phase L1 (A) current measurement	5ms
I_{L2}RMS	Fundamental frequency component of phase L2 (B) current measurement	5ms
I_{L3}RMS	Fundamental frequency component of phase L3 (C) current measurement	5ms
U_1RMS	Fundamental frequency component of U_1/V voltage measurement	5ms
U_2RMS	Fundamental frequency component of U_2/V voltage measurement	5ms
U_3RMS	Fundamental frequency component of U_3/V voltage measurement	5ms
U_4RMS	Fundamental frequency component of U_4/V voltage measurement	5ms

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. 4.4.15 - 148. General settings of the function.

Name	Range	Default	Description
PQS>/< LN mode	• On • Blocked • Test • Test/ Blocked • Off	On	Set mode of PWR block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
PQS>/< force status to	• Normal • Start • Trip • Blocked	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.
PQS>/< measurement side	• POW1 • POW2	POW1	Defines which side of power measurement is used. POW1 and POW2 can be set up at *Measurements → Power and energy measurements.*

Pick-up settings

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.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.4.15 - 149. Pick-up settings.

Name	Range	Step	Default	Description
Measured magnitude	• P3PH • Q3PH • S3PH	-	P3PH	Defines which three phase power is used: Active, reactive or apparent power.
Nominal MVA reference	• Set manually • Use Gen nom MVA • Use Trafo nom MVA	-	Set manually	Defines whether the used nominal power is set manually or if transformer or generator status monitoring function defines the nominal power automatically.
Set nominal MVA	0.0001...1000.0000MVA	0.0001MVA	10MVA	Nominal MVA used by the function. This parameter is visible only when "Nominal MVA reference" parameter is set to "Set manually"
Pick-up mode	• > Over • < Under	-	Over	Defines whether the function operates in underpower or overpower protection mode.
Pick-up	-500.000…500.000%	0.005%	0%	Pick-up setting. Related to the nominal power set by the user.

Read-only parameters

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

Table. 4.4.15 - 150. Information displayed by the function.

Name	Range	Step	Description
PQS>/< LN behaviour	On Blocked Test Test/Blocked Off	-	Displays the mode of PWR block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
PQS>/< condition	Normal Start Trip Blocked	-	Displays the status of the protection function.
PQS>/< selected measurement	POW1CT1 POW1CT2 POW2CT1 POW2CT2 Undefined	-	Displays the selected power measurement. This indication is visible if the device has more than one current measurement unit.
Nominal MVA used	0.000...1800.000MVA	0.001MVA	Displays the nominal power used by the function. This parameter is displayed if "Nominal MVA reference" parameter has been set to "Use Gen nom MVA" or "Use Trafo nom MVA".
Pick-up setting	-1800.000...1800.000MVA	0.001MVA	Pick-up setting used at the moment by the function. Value of this parameter can change if setting group has been changed.

Name	Range	Step	Description
Measurement now	-1800.000...1800.000MVA	0.001MVA	Measured active, reactive or apparent power at the moment.
Meas/Set at the moment	-1250.00...1250.00p.u.	0.01p.u.	Ratio between the measured power and pick-up setting.
Meas/Nom at the moment	-1250.00...1250.00p.u.	0.01p.u.	Ratio between the measured power and used nominal power value.
Expected operating time	0.000...1800.000s	0.005s	Displays the expected operating time when a fault occurs.
Time remaining to trip	-1800.000...1800.000s	0.005s	When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs.

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 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 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 power protection function (abbreviated "PWR" in event block names) generates events and registers from the status changes in the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's output can be used for direct I/O controlling and user logic programming. The function also a resettable cumulative counter for the START, TRIP and BLOCKED events.

The function offers four (4) independent stages; the events are segregated for each stage operation.

Table. 4.4.15 - 151. Event messages.

Event block name	Event names
PWR1...PWR4	Start ON

Event block name	Event names
PWR1...PWR4	Start OFF
PWR1...PWR4	Trip ON
PWR1...PWR4	Trip OFF
PWR1...PWR4	Block ON
PWR1...PWR4	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.

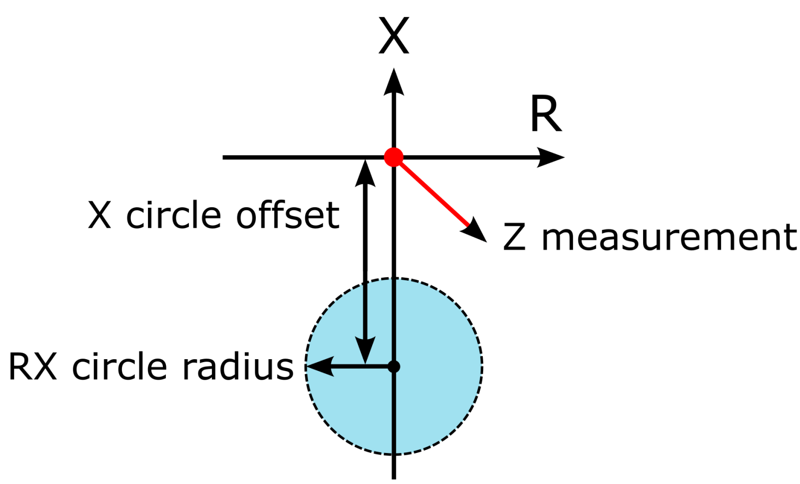
Table. 4.4.15 - 152. Register content.

Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
Pre-trigger power	Start/Trip -20ms power
Fault power	Start/Trip power
Pre-fault power	Start -200ms power
Trip time remaining	0 ms...1800s
Setting group in use	Setting group 1...8 active

4.4.16 Underexcitation protection (X<; 40)

Synchronous machines require a certain amount of excitation to stay stable. If the excitation drops too low a synchronous machine can drop out of step. One way for the protection relay to sense underexcitation is by measuring the impedance. When the measured impedance enters the defined circle, the function will trip.

Figure. 4.4.16 - 83. Underexcitation protection with impedance measurement.



Measured input

The function block uses phase currents and line-to-line or line-to-neutral voltages to calculate phase-to-phase impedance values, phase-to-neutral impedance values or positive sequence impedance values.

Table. 4.4.16 - 153. Measurement inputs of the X< function.

Signal	Description	Time base
Z1 Impedance loop	Phase-to-neutral impedance loop	5 ms
Z2 Impedance loop	Phase-to-neutral impedance loop	5 ms
Z3 Impedance loop	Phase-to-neutral impedance loop	5 ms
Z12 Impedance loop	Phase-to-phase impedance loop	5 ms
Z23 Impedance loop	Phase-to-phase impedance loop	5 ms
Z31 Impedance loop	Phase-to-phase impedance loop	5 ms
Positive sequence impedance	Pos.seq. impedance calculated from three phases	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 editing the setting group.

Table. 4.4.16 - 154. General settings of the function.

Name	Range	Default	Description
X< LN mode	• On • Blocked • Test • Test/ Blocked • Off	On	Set mode of URX block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
X< force status to	• Normal • Start • Trip • Blocked	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.
Operation mode	• P-E impedances • Pos. Seq. impedances • P-P impedances	P-E impedances	Defines which available measurement is used by the function.

Pick-up settings

The *X circle offset* and *RX circle radius* setting parameters control the pick-up of the X< function. This defines the tripping area of the function. The function constantly monitors the distance between the defined circle and the measured impedance. The reset ratio of 103 % is built into the function and is always relative to the RX circle radius.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.4.16 - 155. Pick-up settings.

Name	Range	Step	Default	Description
X circle offset (pri)	-50 000...50 000 Ohm	0.01 Ohm	-50.00 Ohm	Sets the distance from origo to the edge of tripping area.
RX circle radius (pri)	0.01...50 000 Ohm	0.01 Ohm	50.00 Ohm	Sets the radius of tripping area.

Read-only parameters

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

Table. 4.4.16 - 156. Information displayed by the function.

Name	Range	Step	Description
X< LN behaviour	• On • Blocked • Test • Test/Blocked • Off	-	Displays the mode of URX block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
X< condition	• Normal • Start • Trip • Blocked	-	Displays the status of the protection function.
Expected operating time	0.000...1800.000s	0.005s	Displays the expected operating time when a fault occurs.
Time remaining to trip	-1800.000...1800.000s	0.005s	When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs.
Z_{meas}/Z_{set} at the moment	-1250.00...1250.00 Z_m/Z_{set}	$0.01Z_m/Z_{set}$	The ratio between the measured impedance 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 processes the release time characteristics similarly to when the pick-up signal is reset.

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 underexcitation function (abbreviated "URX" in event block names) generates events and registers from the status changes in the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

Table. 4.4.16 - 157. Event messages.

Event block name	Event names
URX1...URX2	Start ON
URX1...URX2	Start OFF
URX1...URX2	Trip ON
URX1...URX2	Trip OFF
URX1...URX2	Block ON

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. 4.4.16 - 158. Register content.

Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
Pre-trigger impedance (Z)	Start/Trip -20ms impedance
Fault impedance (Z)	Start/Trip impedance
Pre-fault impedance (Z)	Start -200ms impedance
Trip time remaining	0 ms...1800s
Setting group in use	Setting group 1...8 active

4.4.17 Volts-per-hertz overexcitation protection (V/Hz>; 24)

Generators, transformers, and motors have their own, specific volts-per-hertz ratios under which these machines are expected to operate. Exceeding the V/Hz ratio results in machine overexcitation which causes iron core saturation in generators and transformers. This causes a breakdown of the insulation in the core's interlamination due to excessive voltage and eddy current heating. Additionally, stray flux is induced into non-laminated components which are not designed to carry flux-caused currents. In generators overexcitation typically occurs if the V/Hz ratio goes five percent above the nominal V/Hz ratio, with any possible damage happening within seconds. The most common situation for overexcitation is when a machine is off-line prior to synchronization.

The figure below shows how the pick-up settings and the measured frequency affect the pick-up level of the volts-per-hertz protection function.

Figure. 4.4.17 - 84. Effect of pick-up settings and the measured frequency to the overvoltage function's pick-up level.

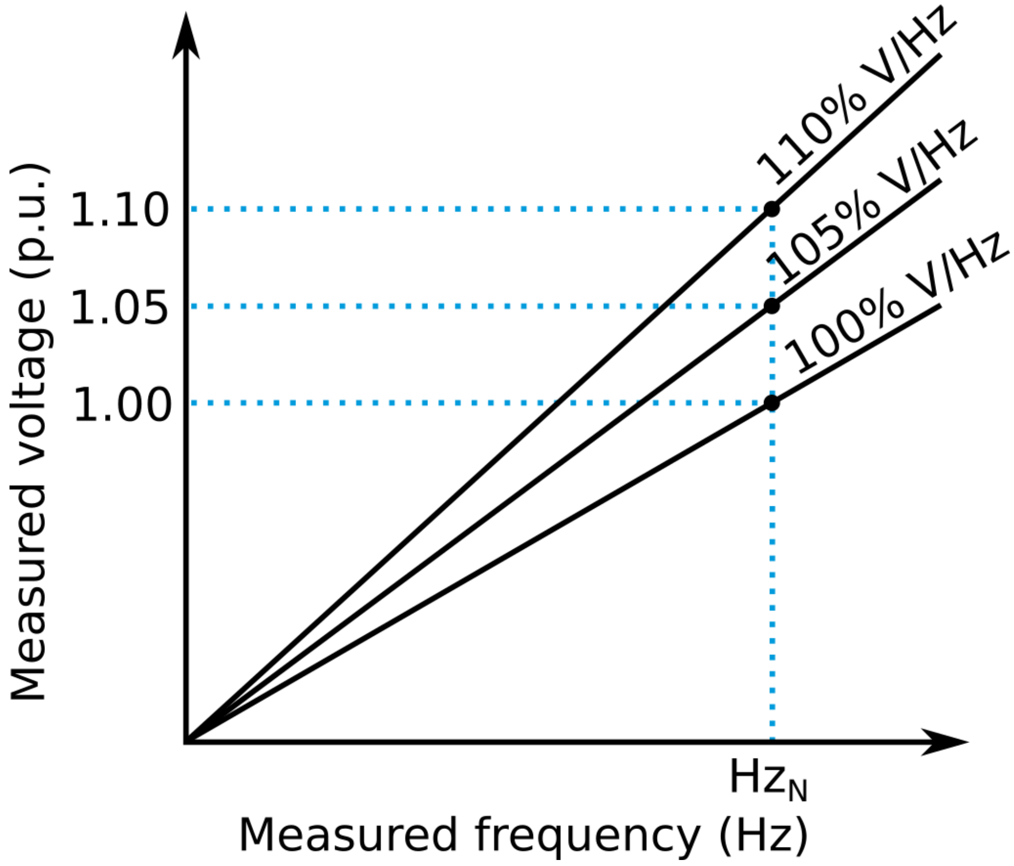
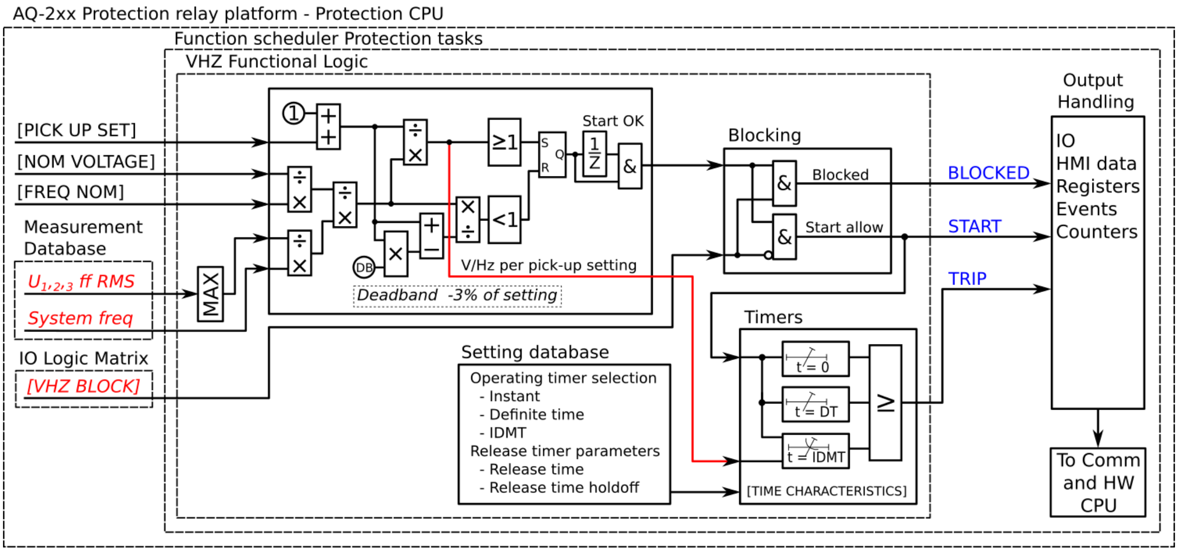


Figure. 4.4.17 - 85. Simplified function block diagram of the V/Hz> function.



Measured input

The function block uses fundamental frequency component of phase-to-phase voltage measurements. Frequency measurement values is used for determining the overvoltage pick-up level. Please refer to "Frequency tracking and scaling" chapter for a detailed description of frequency tracking.

> **NOTICE!**
> The used sampling mode for frequency must be "Tracking".

Table. 4.4.17 - 159. Measurement inputs of the volts-per-hertz function.

Signal	Description	Time base
U_1RMS	Fundamental frequency component of U_1/V voltage channel	5ms
U_2RMS	Fundamental frequency component of U_1/V voltage channel	5ms
U_3RMS	Fundamental frequency component of U_1/V voltage channel	5ms
U_4RMS	Fundamental frequency component of U_1/V voltage channel	5ms
Frequency reference 1	Primary frequency reference	5ms
Frequency reference 2	Secondary frequency reference	5ms
Frequency reference 3	Tertiary frequency reference	5ms

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. 4.4.17 - 160. General settings of the function.

Name	Range	Default	Description
V/Hz> LN mode	• On • Blocked • Test • Test/ Blocked • Off	On	Set mode of VHZ block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
V/Hz > force status to	• Normal • Start • Trip • Blocked	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.

Pick-up settings

Volts-per-hertz protection is based on the ratio between the maximum phase-to-phase voltage and the measured system frequency. The *Pick-up V/Hz > (% of nominal)* setting parameter controls the pick-up of the volts-per-hertz function. This defines the maximum measured voltage allowed in relation to the measured frequency before action from the function. The function constantly calculates the ratio between the *Pick-up V/Hz (% of nominal)*and the calculated U_{meas}/f_{meas} ratio. The reset ratio of 97 % is built into the function and is always relative to the *Pick-up V/Hz (% of nominal)*value.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.4.17 - 161. Pick-up settings.

Name	Range	Step	Default	Description
Pick-up V/Hz > (% of nominal)	0.01…30.00%	0.01%	5.00%	The maximum allowed increase in the measured V/Hz ratio in relation to the nominal V/Hz ratio.
Alarm delay (DT)	0.000...1800.000s	0.005s	0.040s	The definite operation time delay for alarm event.
Delay type	• DT • Inverse • DT and inverse	-	DT	Selects the delay type(s) for the time counter.
Time dial setting k	0.01...65.00	0.01	0.01	Defines the time dial/multiplier setting for inverse curve characteristics. This setting is active and visible when the "Delay type" parameter is set to "Inverse" or "DT and inverse".
Definite operating time delay	0.000…1800.000s	0.005s	0.040s	The definite operating time delay which is applied no matter how much the V/Hz ratio is exceeded. This setting is only visible, when the selected delay type is "DT" or "DT and inverse".

Inverse operating time characteristics are calculated according to the following equation:

$$t_{inverse} = DT_{set} + \frac{0.18 \times TimeDial\ k}{\left(\frac{V}{Hz_{measured}} - 1\right)^{IDMT_{multiplier}}}$$

Figure. 4.4.17 - 86. Inverse (above) and inverse and DT (below) time characteristics with the TimeDial k setting effect.

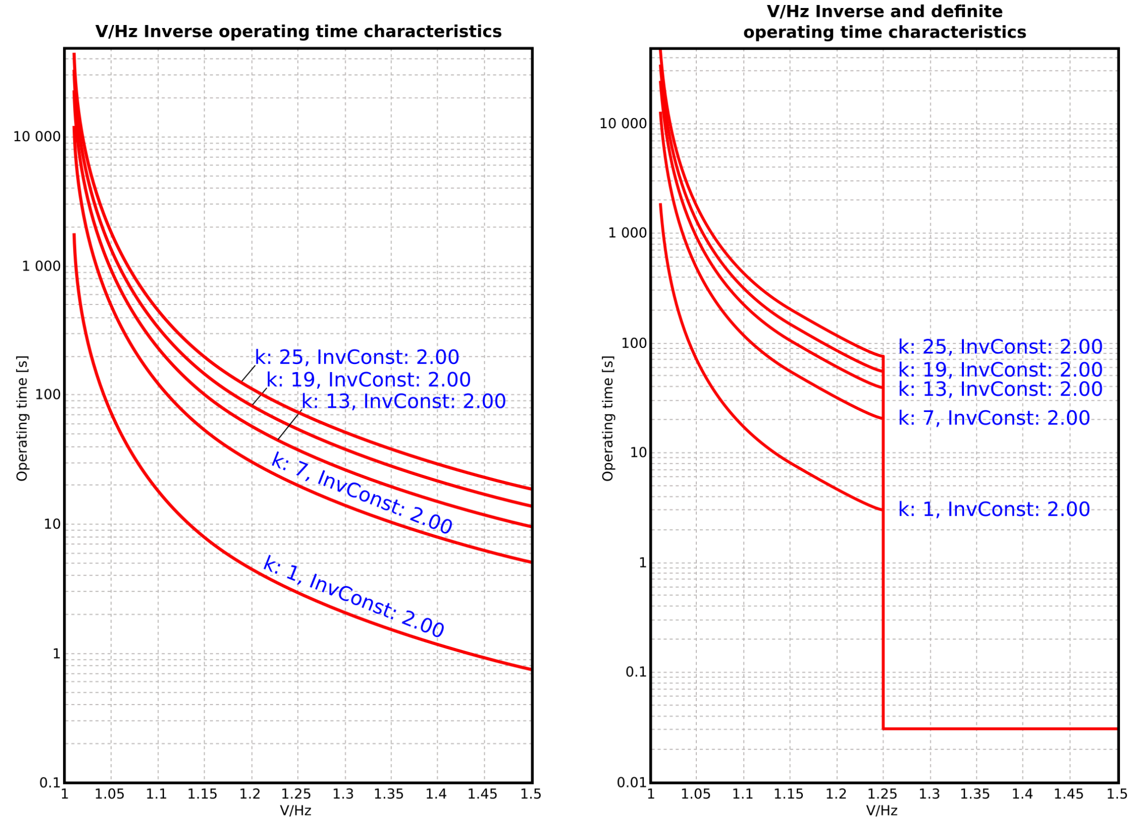
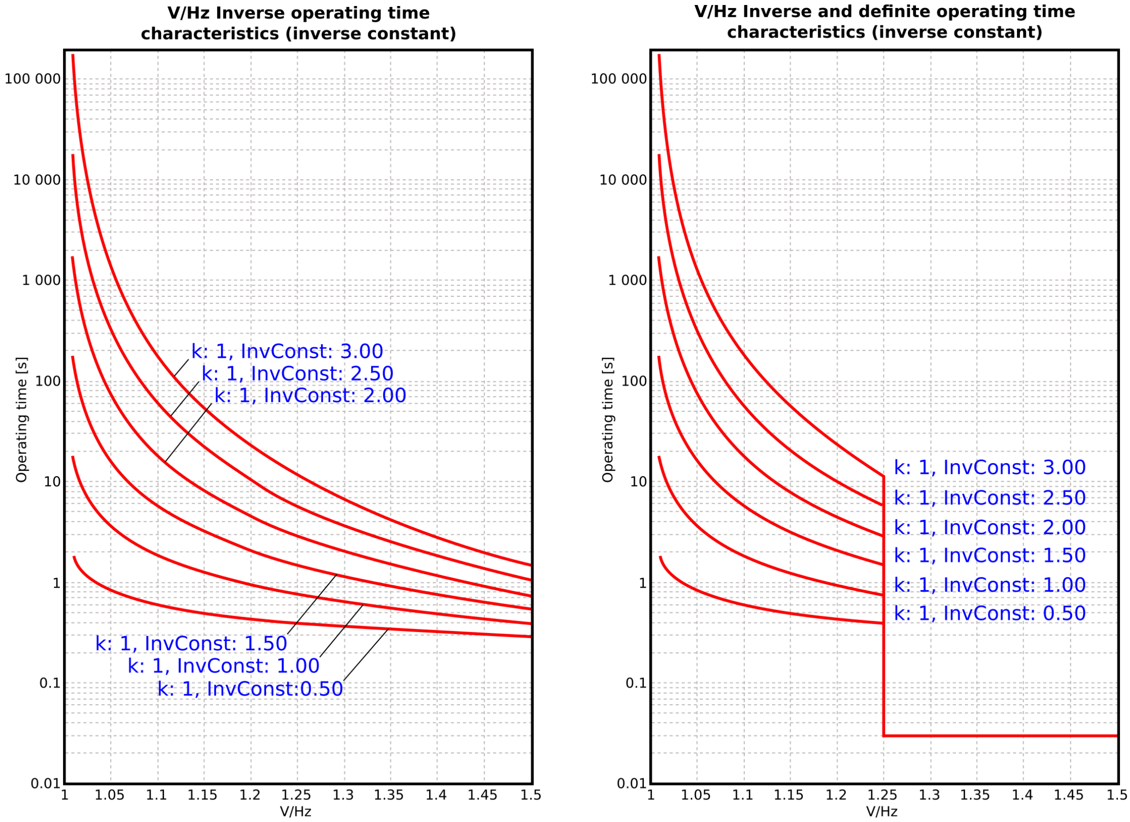


Figure. 4.4.17 - 87. Inverse (above) and inverse and DT (below) time characteristics with the inverse constant setting effect.



Read-only parameters

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

Table. 4.4.17 - 162. Information displayed by the function.

Name	Range	Step	Description
V/Hz> LN behaviour	• On • Blocked • Test • Test/Blocked • Off	-	Displays the mode of VHZ block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
V/ Hz> condition	• Normal • Start • Alarm • Trip • Blocked	-	Displays the status of the protection function.
Expected operating time	0.000...1800.000s	0.005s	Displays the expected operating time when a fault occurs.
Time remaining to trip	-1800.000...1800.000s	0.005s	When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs.
U/f atm to pick-up U/f ratio	-100.00...100.00%	$0.01P_m/P_{set}$	The ratio between the measured power and the pick-up value.
Nominal U/f	-100.000...100.000V/ Hz	0.001V/Hz	Nominal volts-per-hertz ratio (voltage in per-unit value divided by nominal frequency). When 50Hz is used nominal U/f
U/f at the moment	-100.000...100.000V/ Hz	0.001V/Hz	Volts-per-hertz at the moment.
U/f atm to nominal U/f ratio	-100.000...100.000V/ Hz	0.001V/Hz	Measured volts-per-hertz ratio divided by nominal volts-per-hertz ratio.

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 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 volts-per-hertz overexcitation protection function (abbreviated "VHZ" in event block names) generates events and registers from the status changes in the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The function offers one (1) stage

Table. 4.4.17 - 163. Event messages.

Event block name	Event names
VHZ1	V/Hz (1...2) Start ON
VHZ1	V/Hz (1...2) Start OFF
VHZ1	V/Hz (1...2) Alarm ON
VHZ1	V/Hz (1...2) Alarm OFF
VHZ1	V/Hz (1...2) Trip ON
VHZ1	V/Hz (1...2) Trip OFF
VHZ1	V/Hz (1...2) Block ON
VHZ1	V/Hz (1...2) 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. 4.4.17 - 164. Register content.

Name	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
Voltages (AB/BC/CA) pre-trig	Start/Trip -20ms voltages
Frequency pre-trig	Start/Trip -20ms frequency
Voltages (AB/BC/AC) fault	Start/Trip voltages
Frequency fault	Start/Trip frequency
Voltages (AB/BC/AC) pre-fault	Start -200ms voltages
Frequency pre-fault	Start -200ms frequency
Trip time remaining	0 ms...1800 s
Setting group in use	Setting group 1...8 active

4.4.18 Underimpedance protection (Z<; 21U)

Underimpedance protection is an alternative for voltage-restrained overcurrent protection. It can be used to detect short-circuit faults near the generator even when the short-circuit current is small. Additionally, under impedance protection can be used as backup protection for transformer protection.

Figure. 4.4.18 - 88. Operating characteristics of underimpedance protection.

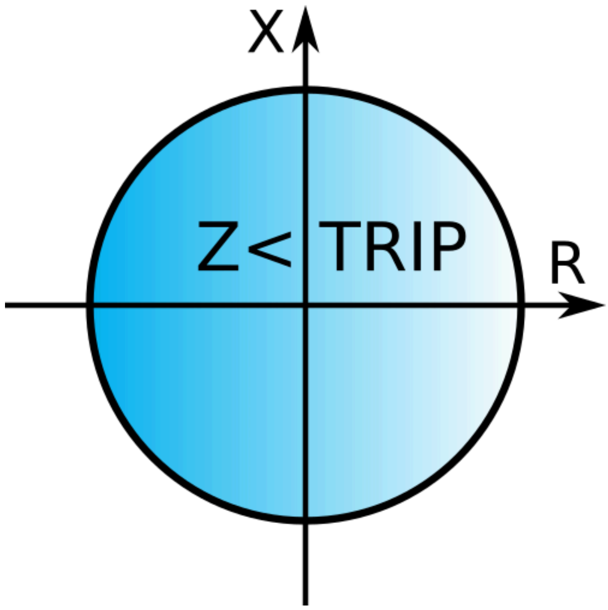
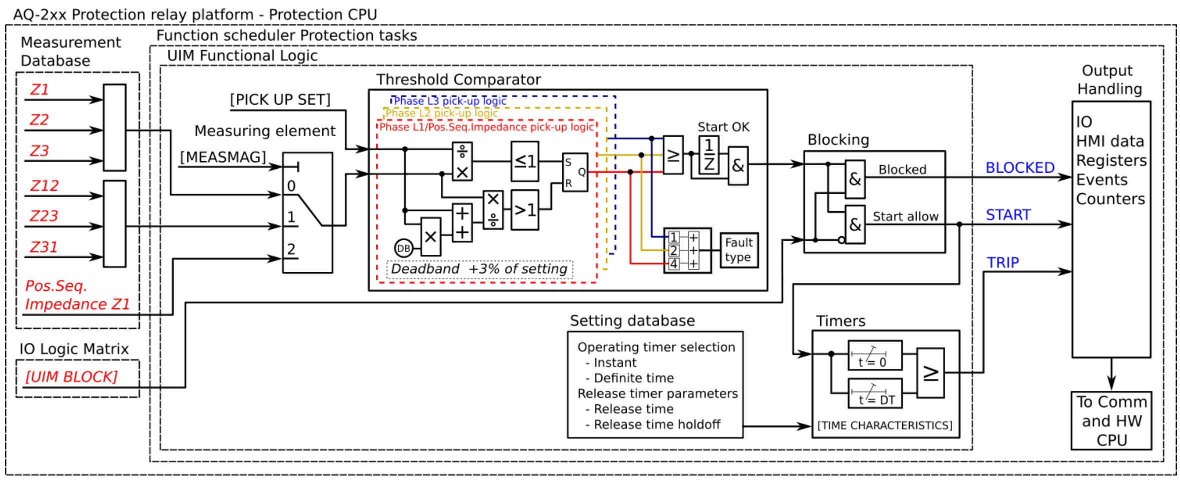


Figure. 4.4.18 - 89. Simplified function block diagram of the Z< function.



Measured input

The function block uses phase currents and phase-to-phase or phase-to-neutral voltage measurement values. These values are used for calculating impedance.

Table. 4.4.18 - 165. Measurement inputs of the Z< function.

Signal	Description	Time base
I_{L1}RMS	Fundamental frequency component of phase L1 (A) current	5ms

Signal	Description	Time base
I_{L2}RMS	Fundamental frequency component of phase L2 (B) current	5ms
I_{L3}RMS	Fundamental frequency component of phase L3 (C) current	5ms
U_1RMS	Fundamental frequency component of voltage channel U_1/V	5ms
U_2RMS	Fundamental frequency component of voltage channel U_2/V	5ms
U_3RMS	Fundamental frequency component of voltage channel U_3/V	5ms
U_4RMS	Fundamental frequency component of voltage channel U_4/V	5ms

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. 4.4.18 - 166. General settings of the function.

Name	Range	Default	Description
Z< LN mode	• On • Blocked • Test • Test/ Blocked • Off	On	Set mode of UIM block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
Z< force status to	• Normal • Start • Trip • Blocked	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.
Operation mode	• P-E Impedances • P-P Impedances • Pos. seq. Impedance	P-E Impedance	Selects the used impedances.

Pick-up settings

The Z_{set} *(pri)<* setting parameter controls the the pick-up of the Z< function. This defines the minimum allowed measured impedance before action from the function. The function constantly calculates the ratio between the impedance pick-up leveland the calculated impedance for each of the three stages or the positive sequence impedance. The reset ratio of 103 % is built into the function and is always relative to the current pick-up value.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.4.18 - 167. Pick-up settings.

Name	Range	Step	Default	Description
Z_{set} (pri)<	0.10…150.00Ω	0.01Ω	10Ω	Pick-up setting as primary side impedance

Read-only parameters

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

Table. 4.4.18 - 168. Information displayed by the function.

Name	Range	Step	Description
Z< LN behaviour	• On • Blocked • Test • Test/Blocked • Off	-	Displays the mode of UIM block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
Z< condition	• Normal • Start • Trip • Blocked	-	Displays status of the protection function.
Expected operating time	0.000...1800.000s	0.005s	Displays the expected operating time when a fault occurs.
Time remaining to trip	-1800.000...1800.000s	0.005s	When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs.
Z_{meas}/Z_{set} at the moment	0.00...1250.00	0.01	The ratio between the lowest measured impedance 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 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 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 underimpedance protection function (abbreviated "UIM" in event block names) generates events and registers from the status changes in the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The function offers two (2) independent stages; the events are segregated for each stage operation.

Table. 4.4.18 - 169. Event messages.

Event block name	Event names
UIM1...UIM2	Start ON
UIM1...UIM2	Start OFF
UIM1...UIM2	Trip ON
UIM1...UIM2	Trip OFF
UIM1...UIM2	Block ON
UIM1...UIM2	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.

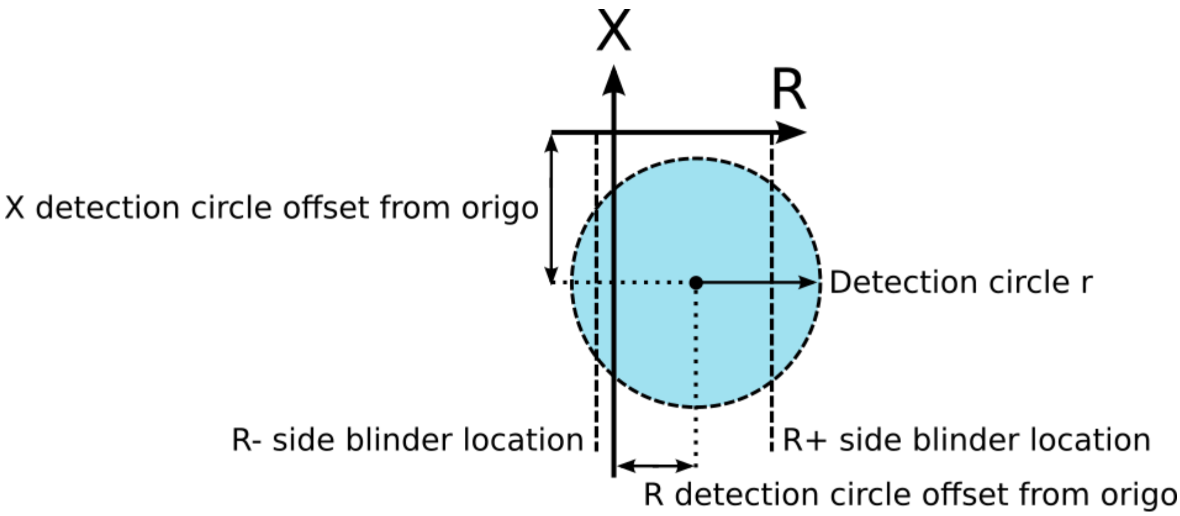
Table. 4.4.18 - 170. Register content.

Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
Fault type	A-E...A-B-C
Pre-trigger impedance	Start/Trip -20ms impedance
Fault impedance	Start/Trip impedance
Pre-fault impedance	Start -200ms impedance
Trip time remaining	0 ms...1800s
Setting group in use	Setting group 1...8 active

4.4.19 Pole slip protection (78)

Pole slipping is a phenomena when synchronism is lost due to power swings. This can happen in extreme fault conditions which cause a transient torque on the machine. Generators might experience this if it has low excitation, because it produces a weak magnetic field. The "slip" occurs when rotor electrically and physically shifts in relation to the stator, after which the field returns the rotor back in sync with the stator. This causes high acceleration and deceleration causes stress on the generator and prime mover, which can cause winding movement, shaft fracture or worse.

Figure. 4.4.19 - 90. Operating characteristics of pole slip protection.



Measured input

The function block uses phase currents and phase-to-phase or phase-to-neutral voltage measurement values. These values are used for calculating impedance.

Table. 4.4.19 - 171. Measurement inputs of the pole slip protection function.

Signal	Description	Time base
I_{L1}RMS	Fundamental frequency component of phase L1 (A) current	5ms
I_{L2}RMS	Fundamental frequency component of phase L2 (B) current	5ms
I_{L3}RMS	Fundamental frequency component of phase L3 (C) current	5ms
U_1RMS	Fundamental frequency component of voltage channel U_1/V	5ms
U_2RMS	Fundamental frequency component of voltage channel U_2/V	5ms
U_3RMS	Fundamental frequency component of voltage channel U_3/V	5ms
U_4RMS	Fundamental frequency component of voltage channel U_4/V	5ms

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. 4.4.19 - 172. General settings of the function.

Name	Range	Default	Description
Pole slip [78] LN mode	• On • Blocked • Test • Test/ Blocked • Off	On	Set mode of OOS block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
Pole slip force status to	• Normal • Start • Trip • Blocked	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.

Pick-up settings

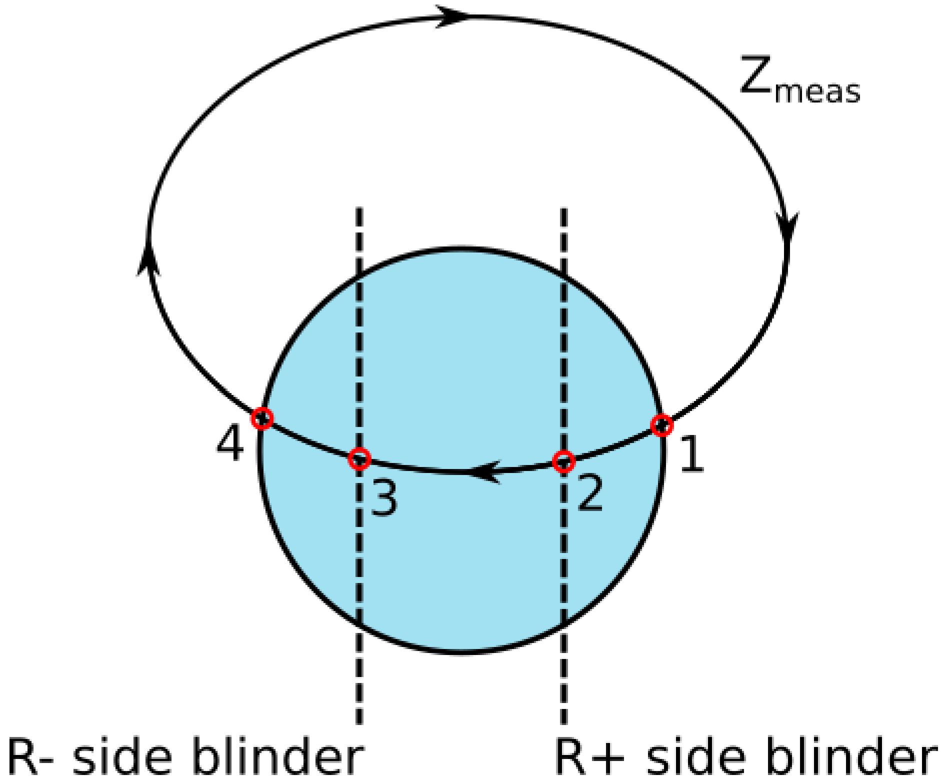
Parameters listed below determine the slip detection area. Slip detection area consists of detection circle and two side blinders. For a slip to be counted the impedance must first enter the circle, then while inside the circle the impedance must cross the blinders and then exit the circle. Keep in mind that the impedance must stay between the blinders longer than what is set to *Minimum locust traverse time between blinders* for the function to count the slip. If more than one slips are required for the function to trip the measured impedance must enter the circle from the same side each cycle. If time set to *Reset slip detection after last detected slip* has passed between slips the slip counter is reset.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.4.19 - 173. Pick-up settings.

Name	Range	Step	Default	Description
X detection circle offset from origin (pri)	-50 000.00...50 000.00 Ohm	0.01 Ohm	-50.00 Ohm	Moves the midpoint of circle in the X-axis (reactance).
R detection circle offset from origo (pri)	-50 000.00...50 000.00 Ohm	0.01 Ohm	0.00 Ohm	Moves the midpoint of circle in the R-axis (resistance).
Detection circle r (pri)	0.01...50 000.00 Ohm	0.01 Ohm	50.00 Ohm	Sets the radius of the detection circle.
R+ side blinder location (pri)	0.00...50 000.00 Ohm	0.01 Ohm	20.00 Ohm	R+ side blinder. Impedance must cross this level after entering the circle for the function to count a slip.
R- side blinder location (pri)	-50 000.00...0.00 Ohm	0.01 Ohm	-20.00 Ohm	R- side blinder. Impedance must cross this level after entering the circle for the function to count a slip.
Minimum locus traverse time between blinders	0.000...1800.00 s	0.005 s	0.050 s	Minimum time impedance must stay between the blinders so that the function will count a slip.
Pole slip detection limit to trip	1...5 slips	1 slips	1 slips	How many slips need to be detected for the function to trip.
Reset slip detection after last detected slip	0.000...1800.000 s	0.005 s	1.000 s	Maximum time between slips before the function resets the slip counter to zero.

Figure. 4.4.19 - 91. Impedance must enter the circle first then cross the blinders and lastly exit the circle for the function to count a slip. Impedance can enter the circle from either side but it must keep entering the circle from the same side for the function to keep counting the slips.



Read-only parameters

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

Table. 4.4.19 - 174. Information displayed by the function.

Name	Range	Description
Pole slip [78] LN behaviour	• On • Blocked • Test • Test/ Blocked • Off	Displays the mode of OOS block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
Pole slip condition	• Normal • Start • Trip • Blocked	Displays status of the protection function.
Configuration status	• Ok • Incorrect VT set • Incorrect char. Set	Displays the status of settings currently in use.

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 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 pole slip protection function (abbreviated "OOS" in event block names) generates events and registers from the status changes in the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

Table. 4.4.19 - 175. Event messages.

Event block name	Event names
OOS1	Poleslip Detection START ON
OOS1	Poleslip Detection START OFF
OOS1	Poleslipt Trip ON
OOS1	Poleslip Trip OFF
OOS1	Poleslip Detection BLOCKED ON
OOS1	Poleslip Detection 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 START, TRIP or BLOCKED. The table below presents the structure of the function's register content.

Table. 4.4.19 - 176. Register content.

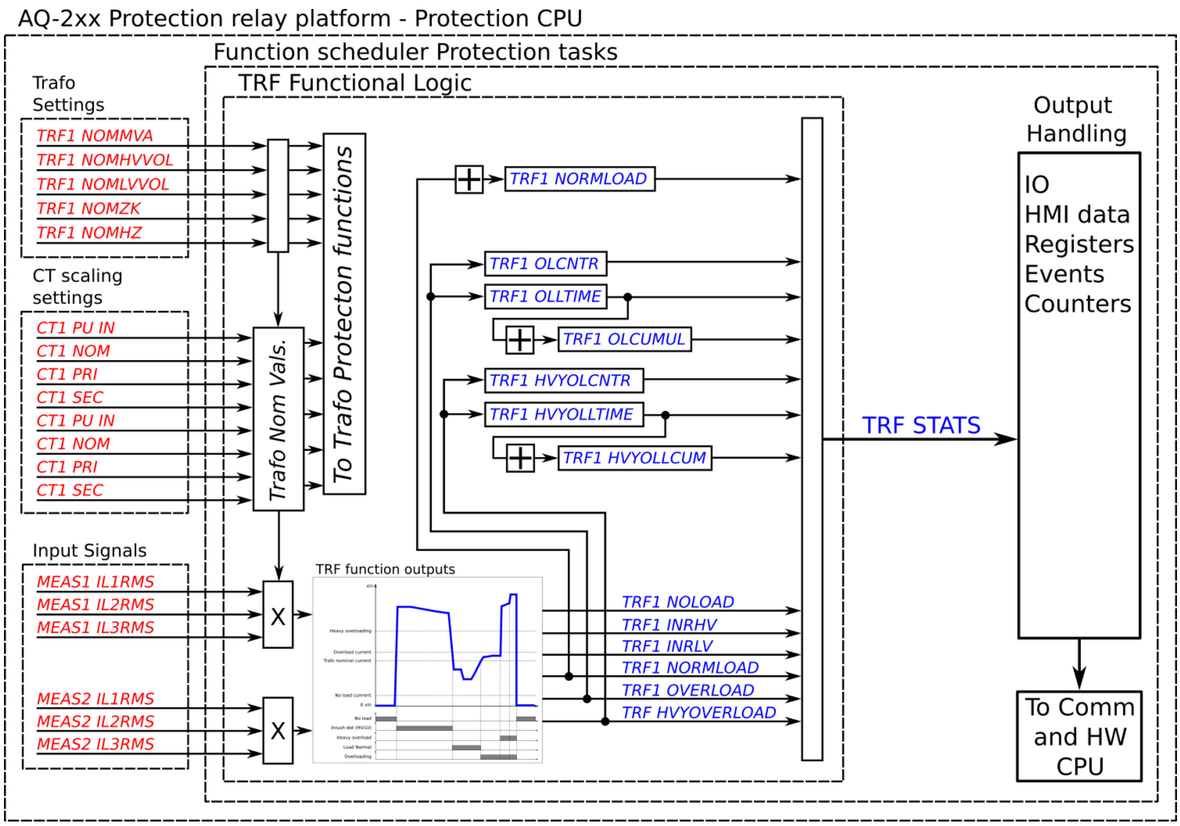
Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
In blinder time	Duration of reactance being between the blinders.
Setting group in use	Setting group 1...8 active

4.4.20 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 protection device to 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.

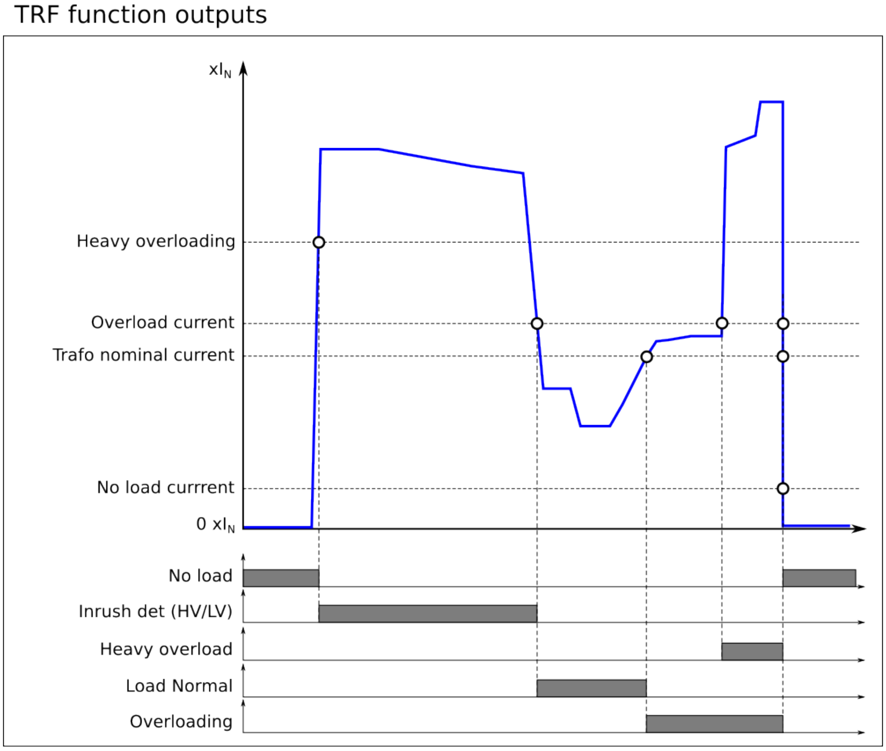
These signals can be used in indication or in logic programming, and they are the basis for the events the function generates (if so chosen).

Figure. 4.4.20 - 92. 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. 4.4.20 - 93. 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. 4.4.20 - 177. Settings of the transformer status monitoring function and how they are shared by other protection functions.

Name	Range	Step	Default	Description
TRF LN mode	• On • Blocked • Test • Test/ Blocked • Off	-	On	Set mode of MST block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.

Name	Range	Step	Default	Description
TRF LN behaviour	• On • Blocked • Test • Test/ Blocked • Off	-	-	Displays the mode of MST block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
Transformer parameters controlled by SG	• No • Yes	-	No	If this parameter is set to "Yes" it is possible to change transformer nameplate values instantly by switching between up to eight (8) setting groups. See "Transformer setting groups" section below.
TRF force status to	• NoForce • Light/ Noload • HV inrush • LV inrush • Normload • Overload • High Overload	-	NoForce	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.
Transformer nominal	0.1...500.0MVA	0.1MVA	1.0MVA	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…500.0kV	0.1kV	110.0kV	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…500.0kV	0.1kV	110.0kV	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%	The transformer's short-circuit impedance in percentages. Used for calculating short-circuit current.
Transformer nom. freq.	10…75Hz	1Hz	50Hz	The transformer's nominal frequency. Used for calculating the transformer's nominal short-circuit inductance.

Name	Range	Step	Default	Description
Transf. vect. group	• Manual set • Yy0 • Yyn0 • YNy0 • YNyn0 • Yy6 • Yyn6 • YNy6 • YNyn6 • Yd1 • YNd1 • Yd7 • YNd7 • Yd11 • YNd11 • Yd5 • YNd5 • Dy1 • Dyn1 • Dy7 • Dyn7 • Dy11 • Dyn11 • Dy5 • Dyn5 • Dd0 • Dd6	-	Yy0	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 protection device 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 "Manual set".
HV side Star or Zigzag / Delta	• Star/Zigzag • Delta	-	Star/ Zigzag	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	• Not earthed • Earthed	-	Not earthed	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	• Lead • Lag	-	Lead	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	• Star/Zigzag • Delta	-	Star/ Zigzag	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	• Not earthed • Earthed	-	Not earthed	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	• Lead • Lag	-	Lead	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...360.00deg	0.1deg	0.0deg	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.

Name	Range	Step	Default	Description
HV-LV side mag correction	0.0…100.0xI$_n$	0.1xI$_n$	0.0xI$_n$	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	• - • Check	-	-	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. 4.4.20 - 178. Calculations of the transformer status monitoring function.

Name	Range	Step	Default	Description
HV side nominal current (pri)	0.01...50 000.00A	0.01A	0.00A	The calculated primary current of the transformer's HV side primary current.
HV side nominal current (sec)	0.01…250.00A	0.01A	0.00A	The calculated primary current of the transformer's HV side secondary current.
HV CT nom. to TR nom. factor	0.01…250.00p.u.	0.01p.u.	0.00p.u.	The transformer's HV side calculated nominal to the CT primary rate.
LV side nominal current (pri)	0.01…50 000.00A	0.01A	0.00A	The calculated primary current of the transformer's LV side primary current.
LV side nominal current (sec)	0.01…250.00A	0.01A	0.00A	The calculated primary current of the transformer's LV side secondary current.
LV CT nom. to TR nom. factor	0.01…250.00p.u.	0.01p.u.	0.00p.u.	The transformer's LV side calculated nominal to the CT primary rate.
Transformer nom. impedance	0.01…250.00Ω	0.01Ω	0.00Ω	The calculated nominal impedance of the transformer.
Transformer nom. Zk	0.01…250.00Ω	0.01Ω	0.00Ω	The calculated nominal short-circuit impedance of the transformer.
Transformer nom. SC inductance	0.001…250.000µH	0.01µH	0.000µH	The calculated nominal short-circuit inductance of the transformer.
Transformer ratio	0.01…250.00	0.01	0.00	The transformer's calculated ratio (= HV/LV).
LV side max. 3ph SC curr.	0.001…500.000kA	0.001kA	0.000kA	The calculated maximum three-phase short-circuit current in the LV poles of the transformer.
LV side 3ph SC to HV side	0.001…500.000kA	0.001kA	0.000kA	Shows how the calculated maximum three-phase short-circuit current in the LV side is seen in the HV side.

Name	Range	Step	Default	Description
LV side max. 2ph SC curr.	0.001…500.000kA	0.001kA	0.000kA	The calculated maximum two-phase short-circuit current in the LV poles of the transformer.
LV side 2ph SC to HV side	0.001...500.000kA	0.001kA	0.000kA	Shows how the calculated maximum two-phase short-circuit current in the LV side is seen in the HV side.

Table. 4.4.20 - 179. Output signals of the transformer status monitoring function.

Name	Description
No/Light load	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	The signal is active, when the detected current rises above the "High overcurrent" limit in the HV side.
LV side inrush detected	The signal is active, when the detected current rises above the "High overcurrent" limit in the LV side.
Load normal	The signal is active when the measured current is below the "Nominal current" but above the "No load current" limit.
Overloading	The signal is active, when the measured current is between the "Nominal current" and the "High overcurrent" limits.
Heavy overloading (HVY overloading)	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. 4.4.20 - 180. Event messages.

Event block name	Event names
TRF1	Light/No load ON
TRF1	Light/No load OFF
TRF1	HV side inrush ON
TRF1	HV side inrush OFF
TRF1	LV side inrush ON
TRF1	LV side inrush OFF
TRF1	Load normal ON
TRF1	Load normal OFF
TRF1	Overloading ON

Event block name	Event names
TRF1	Overloading OFF
TRF1	High overload ON
TRF1	High overload OFF
TRF1	Setting changes, calculating new transformer data
TRF1	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. 4.4.20 - 181. Register content.

Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
HV L1 current	HV side's Phase L1 current x I_n
HV L2 current	HV side's Phase L2 current x I_n
HV L3 current	HV side's Phase L3 current x I_n
LV L1 current	LV side's Phase L1 current x I_n
LV L2 current	LV side's Phase L2 current x I_n
LV L3 current	LV side's Phase L3 current x I_n

Transformer setting groups

If "Transformer parameters controlled by SG" parameter has been set to "Yes" it is possible to instantly change transformer parameters by changing the active setting group. Transformer parameter setting groups are controlled separately from the general setting group control. This allows for changing the following transformer nameplate values without changing the protection parameters:

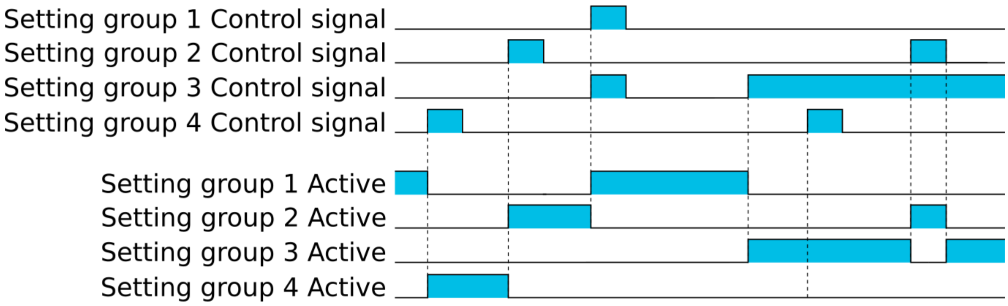
- Transformer nominal MVA
- HV side nominal voltage
- LV side nominal voltage
- Transformer vector group
- Transformer Zk %
- Transformer nominal frequency

Setting group selection can be applied to each of the setting groups individually by activating one of the various internal logic inputs or 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.

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.

Setting groups follow a hierarchy in which setting group 1 has the highest priority, setting group 2 has second highest priority etc. If a static activation signal is given for two setting groups, the setting group with higher priority will be active. If setting groups are controlled by pulses, the setting group activated by pulse will stay active until another setting groups receives and activation signal.

Figure. 4.4.20 - 94. Example sequences of group changing (control with pulse only, or with both pulses and static 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. 4.4.20 - 182. Settings of the setting group selection function.

Name	Range	Default	Description
Active setting group	• SG1 • SG2 • SG3 • SG4 • SG5 • SG6 • SG7 • SG8	SG1	Displays which setting group is active.
Force setting group	• None • SG1 • SG2 • SG3 • SG4 • SG5 • SG6 • SG7 • SG8	None	The selection of the overriding setting group. After "Force SG change" is enabled, any of the configured setting groups in the device 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 setting group change	• Disabled • Enabled	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.

Name	Range	Default	Description
Used setting groups	• SG1 • SG1...2 • SG1...3 • SG1...4 • SG1...5 • SG1...6 • SG1...7 • SG1...8	SG1	The selection of the activated setting groups in the application. Newly-enabled setting groups use default parameter values.
Remote setting group change	• None • SG1 • SG2 • SG3 • SG4 • SG5 • SG6 • SG7 • SG8	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. 4.4.20 - 183. Signals of the setting group selection function.

Name	Description
Setting group 1	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	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	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	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	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	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	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	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.

The setting group selection function block (abbreviated "SGS2" 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 events triggered by the function are recorded with a time stamp.

Table. 4.4.20 - 184. Event messages.

Event block name	Event names
SGS2	SG2...SG8 Enabled
SGS2	SG2...SG8 Disabled
SGS2	SG1...SG8 Request ON
SGS2	SG1...SG8 Request OFF
SGS2	Remote Change SG Request ON
SGS2	Remote Change SG Request OFF
SGS2	Local Change SG Request ON
SGS2	Local Change SG Request OFF
SGS2	Force Change SG ON
SGS2	Force Change SG OFF
SGS2	SG Request Fail Not configured SG ON
SGS2	SG Request Fail Not configured SG OFF
SGS2	Force Request Fail Force ON
SGS2	Force Request Fail Force OFF
SGS2	SG Req. Fail Lower priority Request ON
SGS2	SG Req. Fail Lower priority Request OFF
SGS2	SG1...SG8 Active ON
SGS2	SG1...SG8 Active OFF

4.4.21 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 31st) 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:

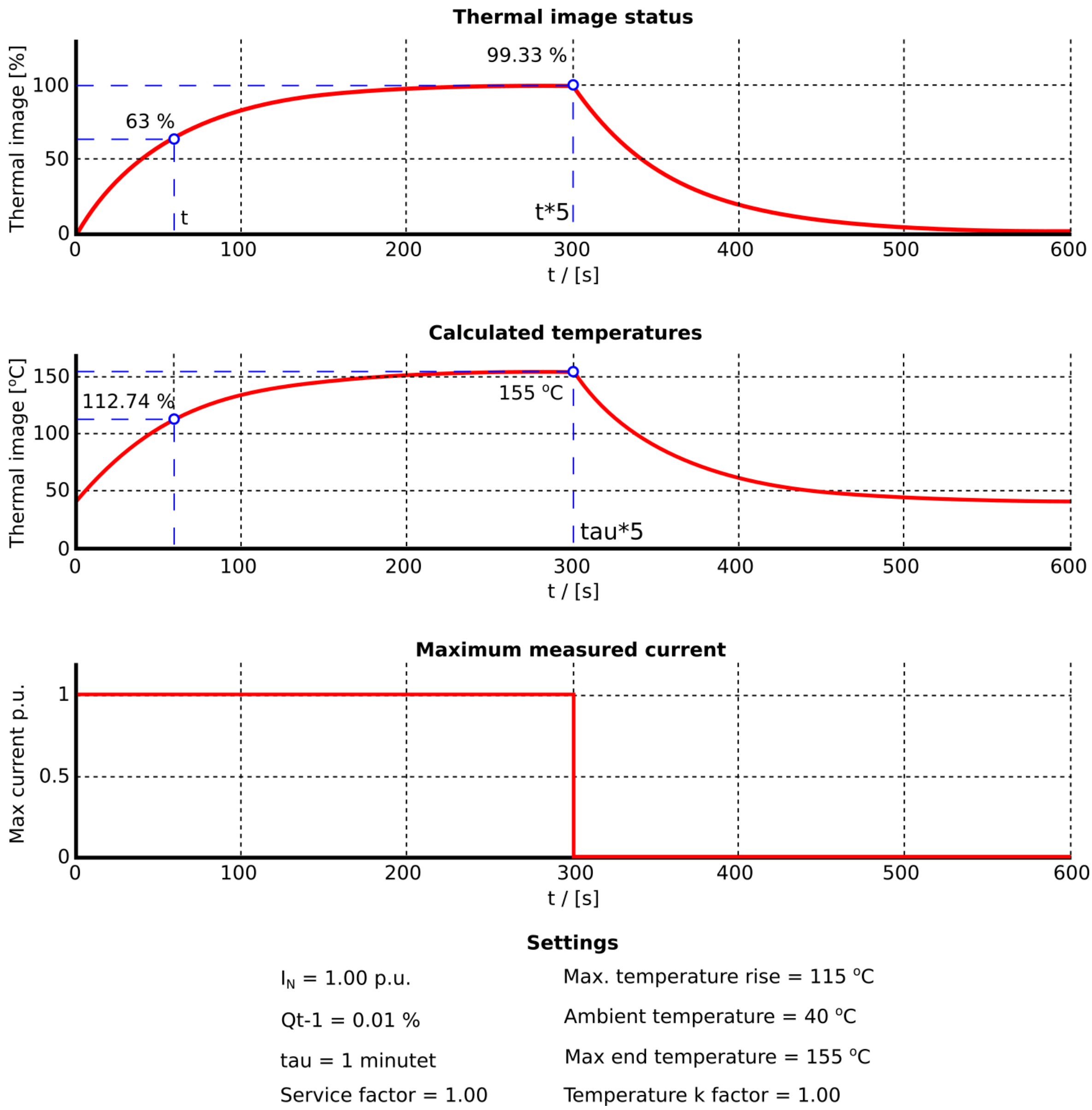
$$\theta_{t\%} = \left(\left(\theta_{t-1} - \left(\frac{I_{MAX}}{I_N \times k_{SF} \times k_{AMB}} \right)^2 \times e^{-\frac{t}{\tau_1/\tau_2}} \right) + \left(\frac{I_{MAX}}{I_N \times k_{SF} \times k_{AMB}} \right)^2 \right) \times 100\%$$

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. 4.4.21 - 95. 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:

$$t_{Amb<t_{min}} = k_{min}$$

$$t_{Amb<t_{ref}} = \left(\frac{1-k_{min}}{t_{ref}-t_{min}} \times (t_{AMB}-t_{min})\right) + k_{min}$$

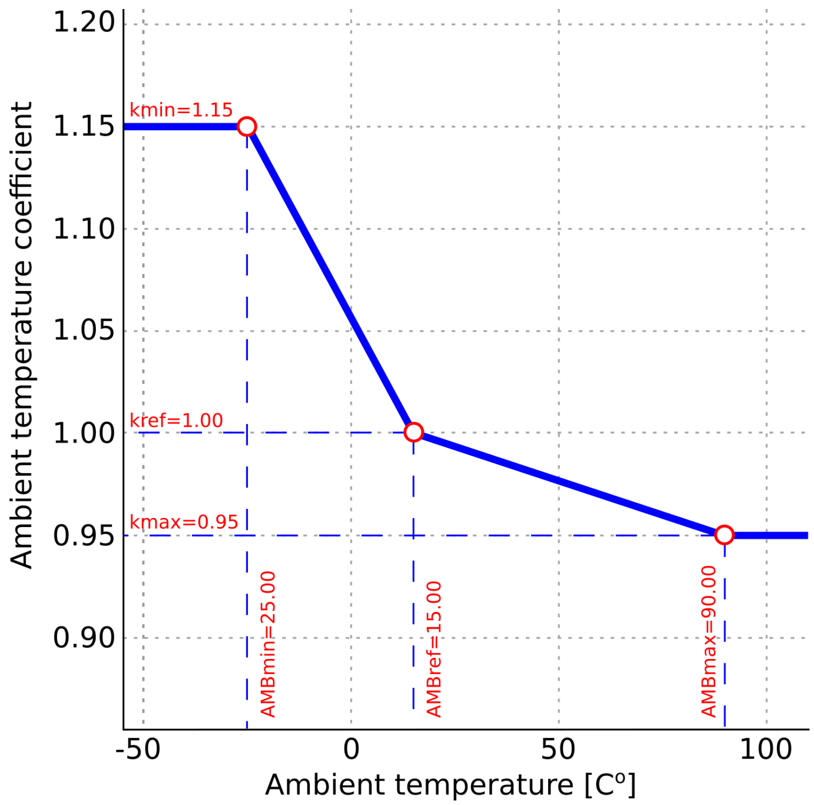
$$t_{Amb>t_{ref}} = \left(\frac{k_{max}-1}{t_{max}-t_{ref}} \times (t_{AMB}-t_{ref})\right) + 1.0$$

$$t_{Amb>t_{max}} = k_{max}$$

Where:

- t_{amb} = Measured (set) ambient temperature (can be set in ˚C or ˚F)
- t_{max} = Maximum temperature (can be set in ˚C or ˚F) for the protected object
- k_{max} = Ambient temperature correction factor for the maximum temperature
- t_{min} = Minimum temperature (can be set in ˚C or ˚F) for the protected object
- k_{min} = Ambient temperature correction factor for the minimum temperature
- t_{ref} = Ambient temperature reference (can be set in ˚C or ˚F, the temperature in which the manufacturer's temperature presumptions apply, the temperature correction factor is 1.0)

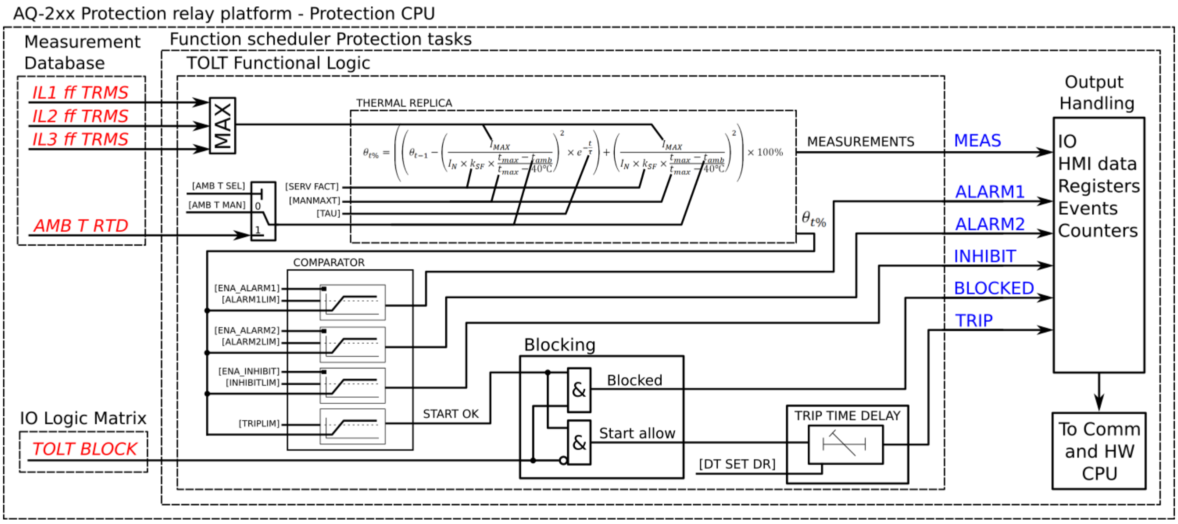
Figure. 4.4.21 - 96. Ambient temperature coefficient calculation (a three-point linear approximation and a settable correction curve).



Function inputs and outputs

The following figure presents a simplified function block diagram of the transformer thermal overload protection function.

Figure. 4.4.21 - 97. Simplified function block diagram of the TT> function.



Measured input

The function block uses phase current measurement values. The function block uses TRMS values from the whole harmonic specter of 32 components. RTD input can be used for measuring the ambient temperature.

Table. 4.4.21 - 185. Measurement inputs of the TT> function.

Signal	Description	Time base
I_{L1}TRMS	TRMS measurement of phase L1 (A) current	5 ms
I_{L2}TRMS	TRMS measurement of phase L2 (B) current	5 ms
I_{L3}TRMS	TRMS measurement of phase L3 (C) current	5 ms
RTD	Temperature measurement for the ambient correction	5 ms

Table. 4.4.21 - 186. General settings (not selectable under setting groups)

Name	Range	Default	Description
TT> LN mode	• On • Blocked • Test • Test/ Blocked • Off	On	Set mode of TOLT block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
TT> mode	• Disabled • Activated	Disabled	The selection of the function is activated or disabled in the configuration. By default it is not in use.

Name	Range	Default	Description
TT> force status to	• Normal • Blocked • Alarm1 On • Alarm2 On • Inhibit On • Trip On	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.
Temp C or F deg	• C • F	C	The selection of whether the temperature values of the thermal image and RTD compensation are shown in Celsius or in Fahrenheit.

Table. 4.4.21 - 187. Settings for thermal replica.

Name	Range	Step	Default	Description
IN thermal cap current	0.10…40.00xI_n	0.01xI_n	1.00xI_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…500.0min	0.1min	10.0min	The τ_h time constant setting. This time constant is used for the heating of the protected object.
tau c (t const)	0.1…500.0min	0.1min	10.0min	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. 4.4.21 - 188. Environmental settings

Name	Range	Step	Default	Description
Object max. temp. (t_{max} = 100%)	0…500deg	1deg	90deg	The maximum allowed temperature for the protected object. The default suits for Celsius range and for PEX-insulated cables.
Ambient temp. sel.	• Manual set • RTD	-	Manual set	The selection of whether fixed or measured ambient temperature is used for the thermal image biasing.
Man. amb. temp. set	0…500deg	1deg	15deg	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.

Name	Range	Step	Default	Description
RTD amb. temp. read.	0…500deg	1deg	15deg	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	• Linear est. • Set curve	-	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 "Linear est." which means the internally calculated correction for ambient temperature.
Temp. reference (t_{ref}) k_{amb}=1.0	-60…500deg	1deg	15deg	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 °C and for cables in the air it is usually 25 °C. This setting is visible if "Ambient lin. or curve" is set to "Linear est."
Max. ambient temp.	0…500deg	1deg	45deg	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…5.00xI_n	0.01xI_n	1.00xI_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…500deg	1deg	0deg	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…5.00xI_n	0.01xI_n	1.00xI_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…500.0deg	0.1deg	15deg	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	• Not used • Used	-	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".

Pick-up settings

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.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.4.21 - 189. Pick-up settings.

Name	Range	Step	Default	Description
Enable TT> Alarm 1	• Disabled • Enabled	-	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	• Disabled • Enabled	-	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	• Disabled • Enabled	-	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	• Disabled • Enabled	-	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…3600.000s	0.005s	0.000s	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 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. 4.4.21 - 190. General status codes.

Name	Range	Description
TT> LN behaviour	• On • Blocked • Test • Test/ Blocked • Off	Set mode of TOLT block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
TT> Condition	• Normal • Alarm 1 ON • Alarm 2 ON • Inhibit ON • Trip ON • 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	• Light/No load • High overload • Overloading • 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	• SF setting ok • 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	• Ambient setting ok • 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.

Name	Range	Description
TT> Setting alarm	• Nominal current calc ok • 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	• Ambient setting ok • Inconsistent setting of ambient k	Indicates if ambient k setting has been set wrong. Visible only when there is a setting fault.

Table. 4.4.21 - 191. Measurements.

Name	Range	Description/values
Currents	• Primary A • Secondary A • Per unit	The active phase current measurement from IL1 (A), IL2 (B) and IL3 (C) phases in given scalings.
Thermal image	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
	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
	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. 4.4.21 - 192. 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

Name	Description / values
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 the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the ALARM, INHIBIT, TRIP and BLOCKED events.

Table. 4.4.21 - 193. Event messages.

Event block name	Event names
TOLT1	Alarm1 ON
TOLT1	Alarm1 OFF
TOLT1	Alarm2 ON
TOLT1	Alarm2 OFF
TOLT1	Inhibit ON
TOLT1	Inhibit OFF
TOLT1	Trip ON
TOLT1	Trip OFF
TOLT1	Block ON
TOLT1	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. 4.4.21 - 194. Register content.

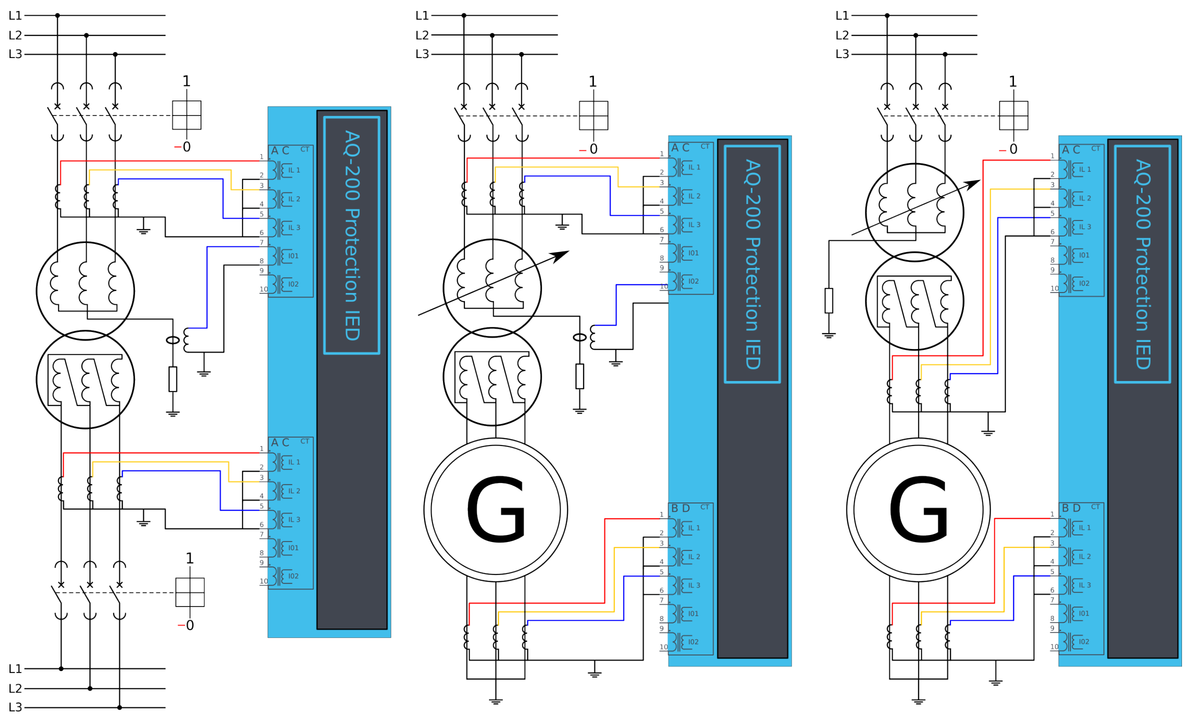
Name	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
Time to reach 100 % theta	seconds
Ref. T current	x I_n

Name	Description
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
Setting group in use	Setting group 1...8 active

4.4.22 Generator/transformer differential protection (Idb>/Idi>/I0dHV>/I0dLV>; 87T/87N/87G)

The generator/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. This function can also be used for protecting generators.

Figure. 4.4.22 - 98. Differential protection function can be used for protecting transformers, generators and both at the same time.



Power transformers are seen in electric power generation, transmission, and distribution. They are also part of application networks for a wide range of purposes (eg. power and voltage levels). 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 high-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	Risk level	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.

Transformer	Risk level	Protection
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, backup 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 protection relays require backup 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 backup 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 devices 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. Therefore, transformer protection should be set to delayed operation (not instant) so that the low-voltage side protection relays can operate before transformer protection. This is necessary 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 protection with instant operation causes problems with timing coordination or sensitivity, especially if the instant protection is set on high-current starting criteria. However, this is not a significant issue with smaller transformers as the installation and maintenance of various differential protections is considered more expensive than not having full 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. 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.

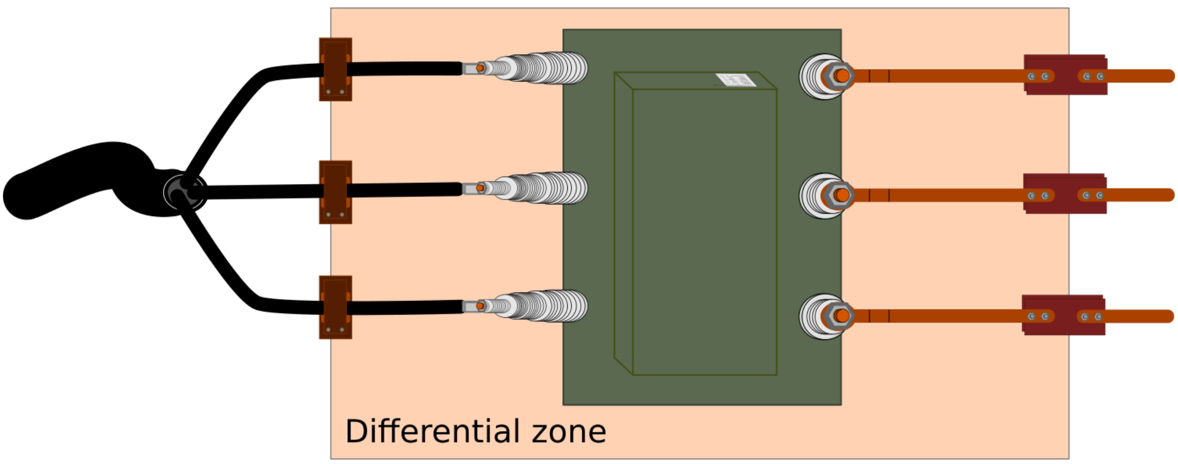
Transformer properties and basic concepts for differential protection

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.

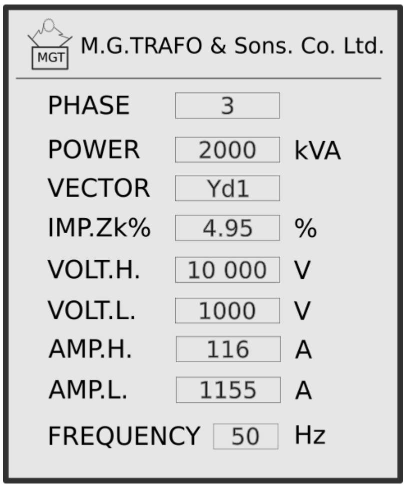
Figure. 4.4.22 - 99. Transformer and its components forming the differential zone.



The differential protection 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. 4.4.22 - 100. 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:

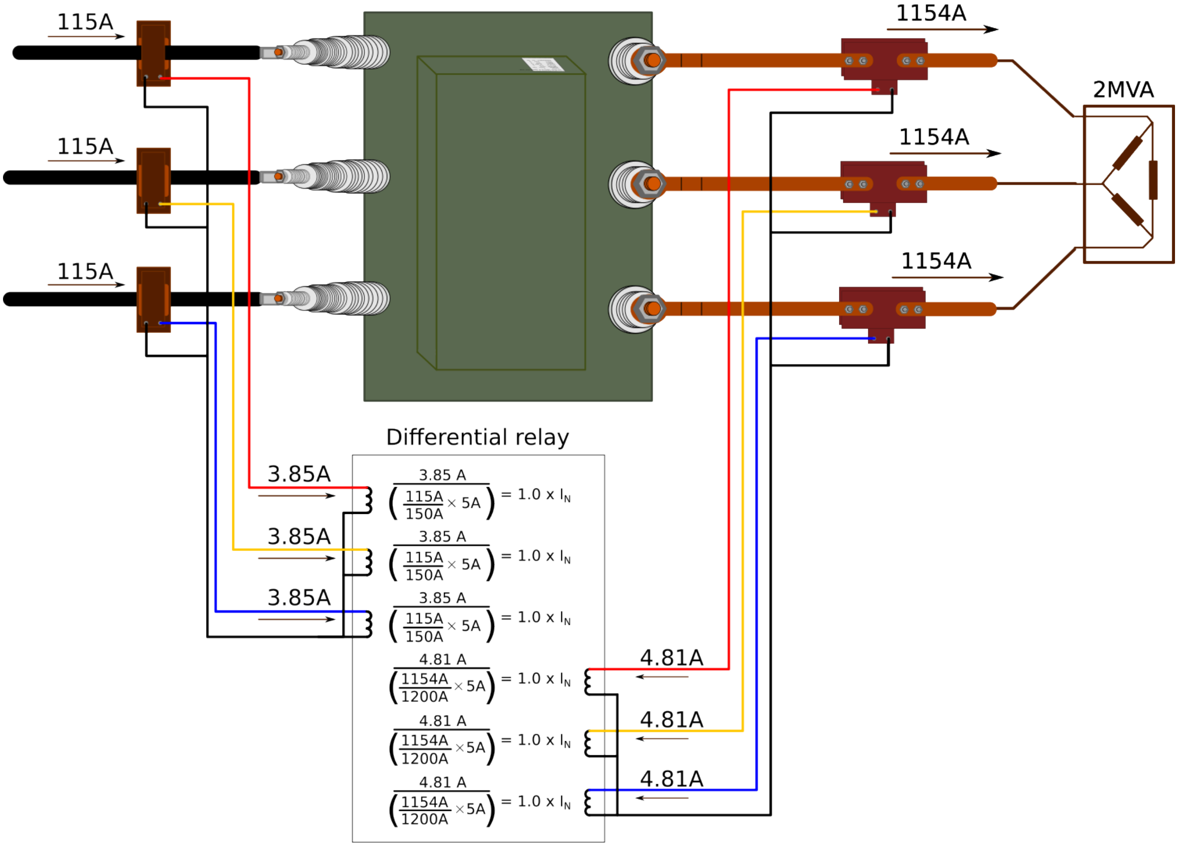
$$I_{n,LV} = \frac{S_n}{\sqrt{3} \times U_{LV}} = \frac{2\,000\,000\ \mathrm{VA}}{\sqrt{3} \times 1\,000\ \mathrm{V}} = 1154.7\ \mathrm{A}$$

$$I_{pu,pri,LV} = \frac{I_{n,LV}}{CT_{pri,LV}} = \frac{1154.7\ \mathrm{A}}{1200\ \mathrm{A}} = 0.96$$

$$I_{pu,sec,LV} = I_{pu,pri,LV} \times CT_{sec,LV} = 0.96 \times 5\ \mathrm{A} = 4.81\ \mathrm{A}$$

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. 4.4.22 - 101. Amplitude scaling to match the nominal currents and CTs in the differential relay.

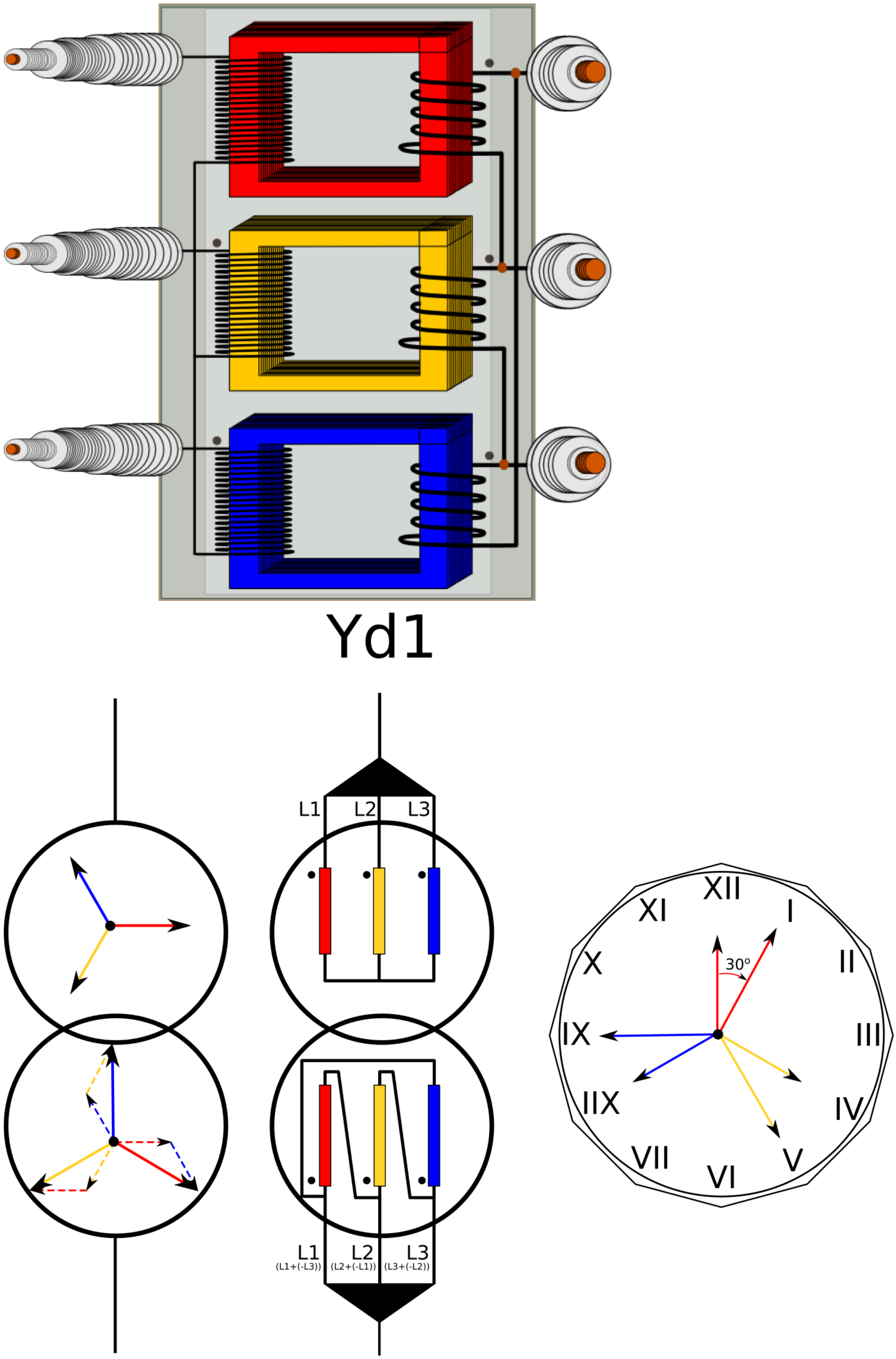


Nominal current matching is only part of the differential protection settings. The vector group of the transformer is also important, since the differential function is interested in the angle difference of the measured current vectors. In this example the transformer's vector group is Yd1, which means 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. 4.4.22 - 102. Yd1 transformer's internal connection (in theory).



In modern protection 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 protection relay (such as with zigzag transformers).

In this example, the function translates 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 protection 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 protection 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. 4.4.22 - 103. 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. 4.4.22 - 104. "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. 4.4.22 - 105. "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. 4.4.22 - 106. CTs' starpoints requiring the "Add" mode.

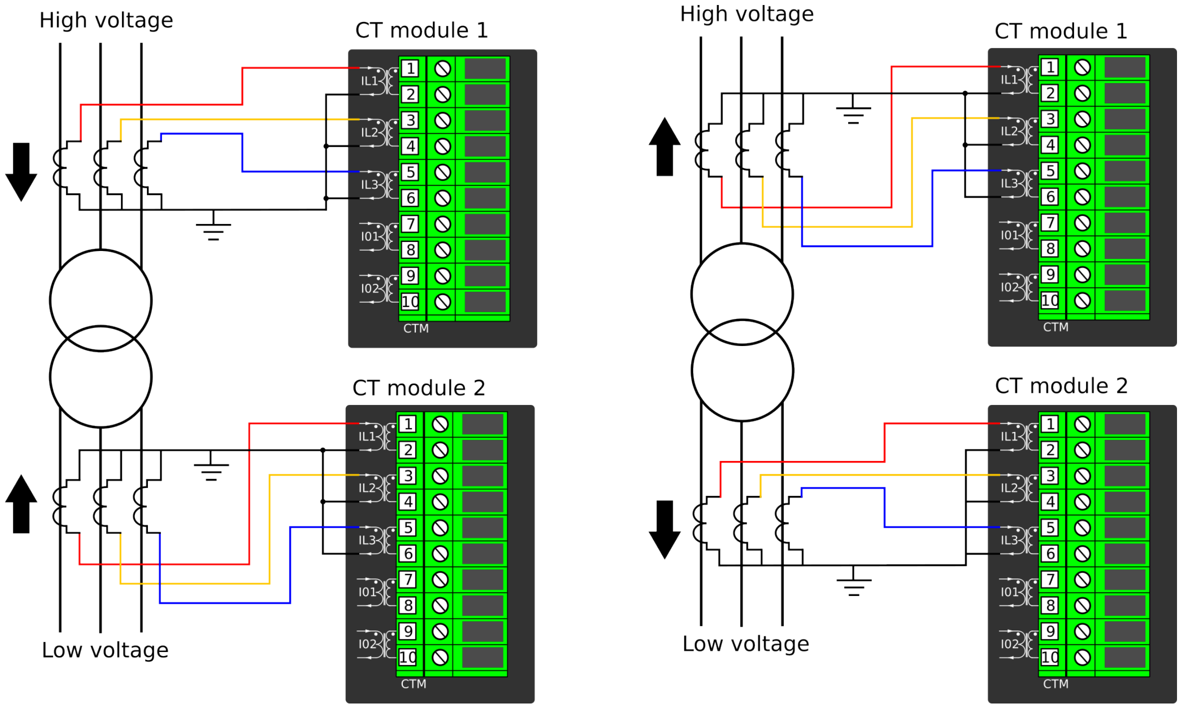
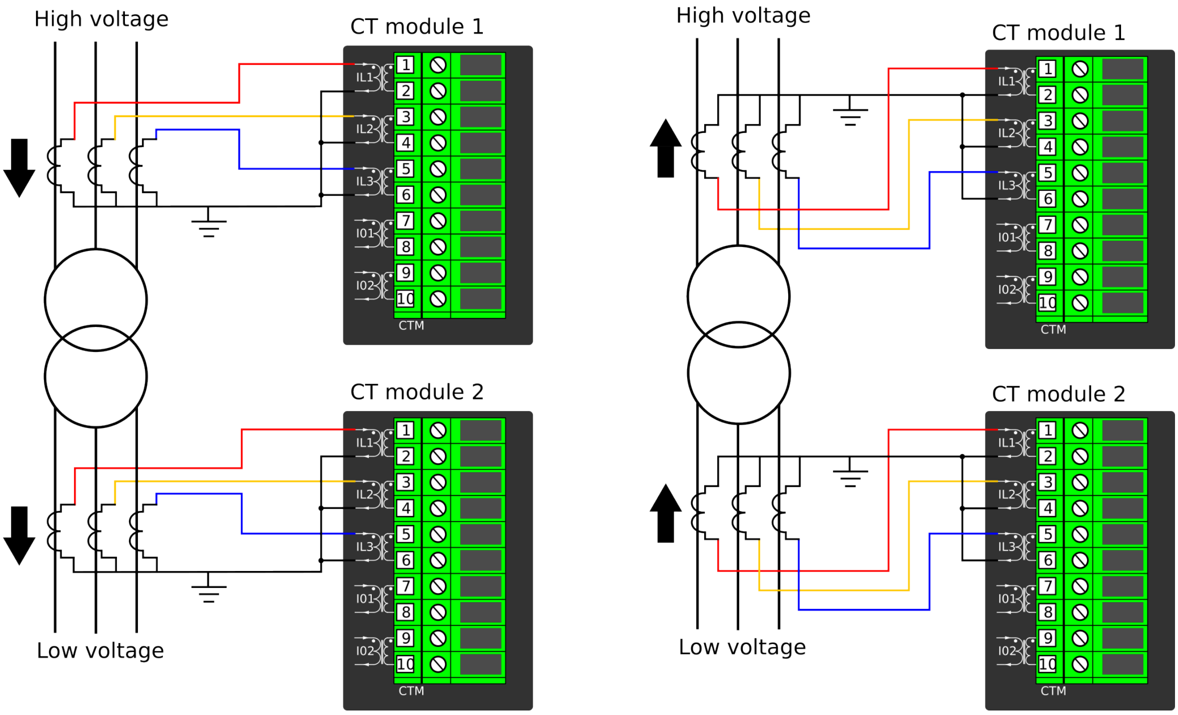


Figure. 4.4.22 - 107. CTs' starpoints requiring the "Subtract" mode.



The differential function has two (2) separate stages built into the function. Non-restraint characteristics use only the "Average mode and Max mode formulas (described below) 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. 4.4.22 - 108. 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. 4.4.22 - 109. Max mode (coarse biasing).

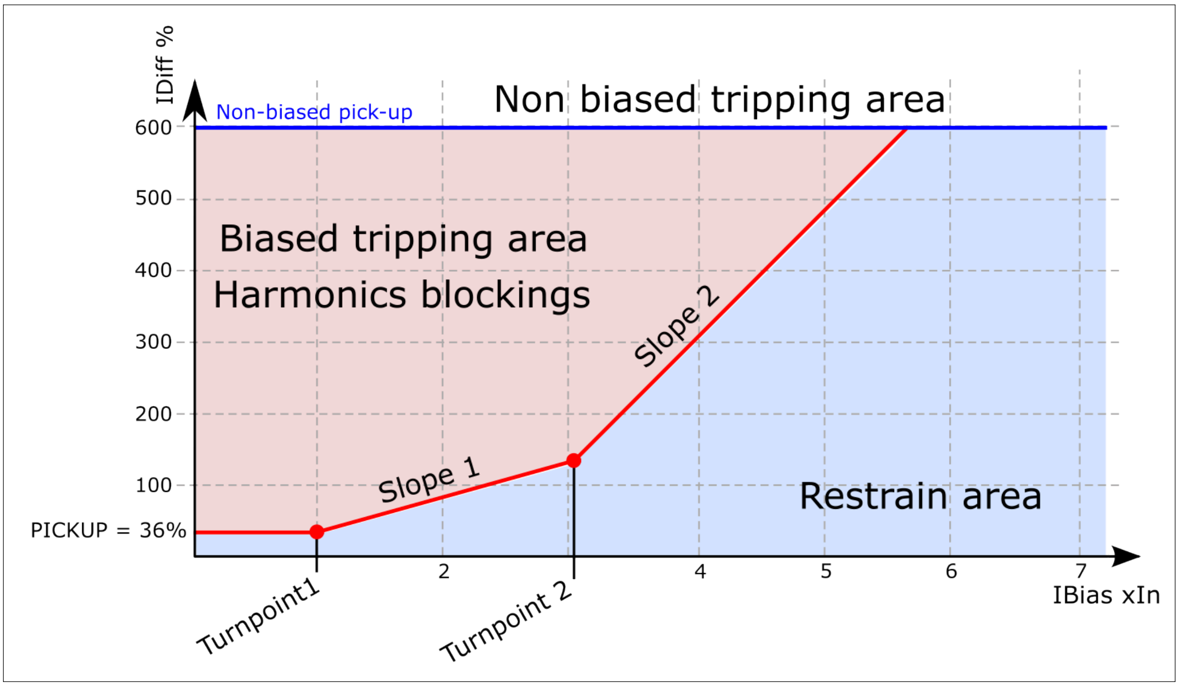
$$L1BIAS_{MAX} = \max\left(|\mathrm{IL1_{HV}}|, |\mathrm{IL1_{LV}}|\right)$$

$$L2BIAS_{MAX} = \max\left(|\mathrm{IL2_{HV}}|, |\mathrm{IL2_{LV}}|\right)$$

$$L3BIAS_{MAX} = \max\left(|\mathrm{IL3_{HV}}|, |\mathrm{IL3_{LV}}|\right)$$

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. 4.4.22 - 110. 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.

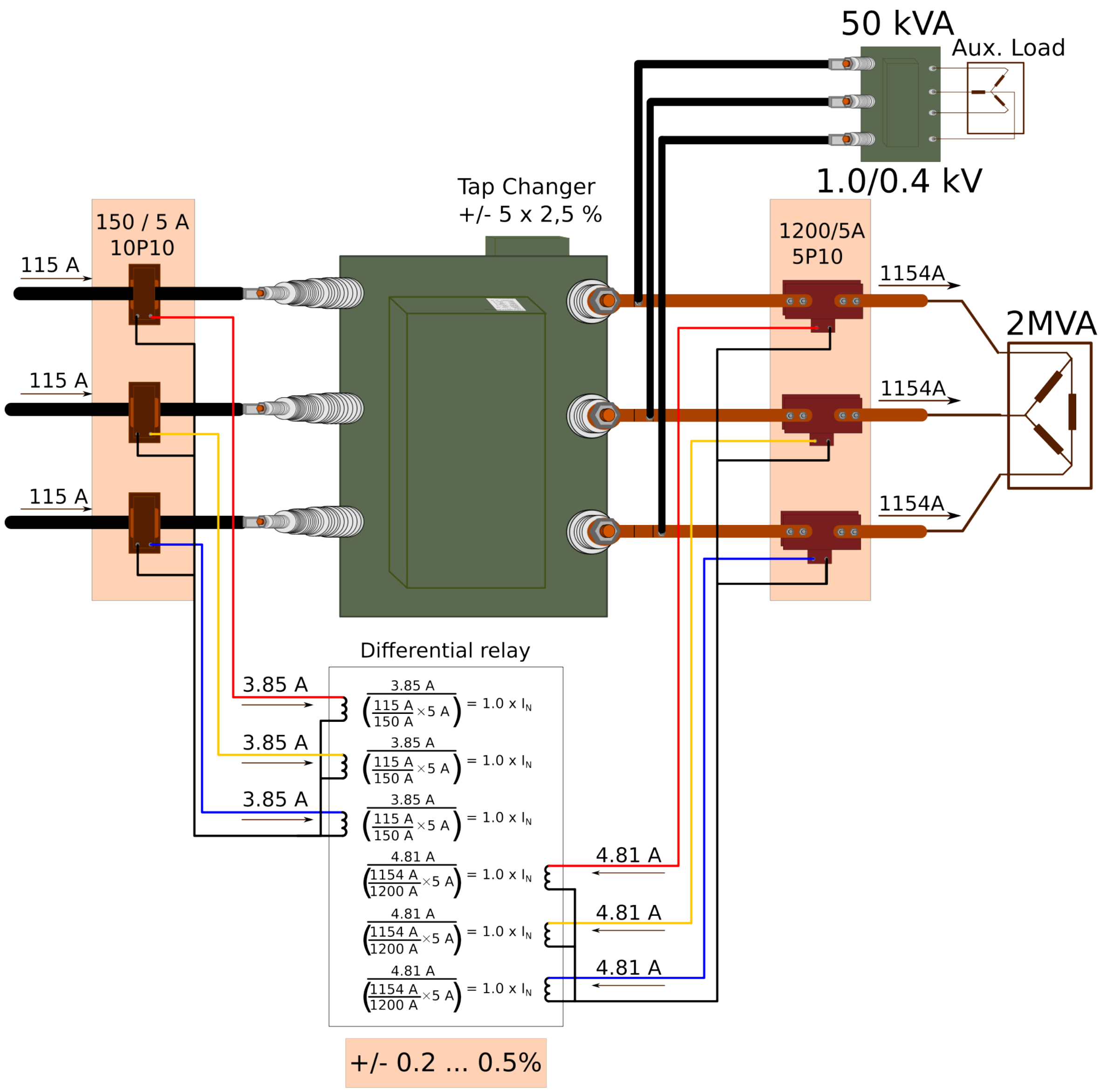
$Diff_{bias<TP1} = I_{d>pick-up}$

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. 4.4.22 - 111. 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) Protection relay measurement accuracy (primary and secondary) (RE_m)
The protection 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):

$$AUTE = \frac{AUX}{NOM} \times 100\ \% = \frac{50\ 000\ \mathrm{VA}}{2\ 000\ 000\ \mathrm{VA}} \times 100\ \% = 2.5\ \%$$

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:

$$I_{TM} = \frac{U_{PRI}}{j\omega L_P}$$

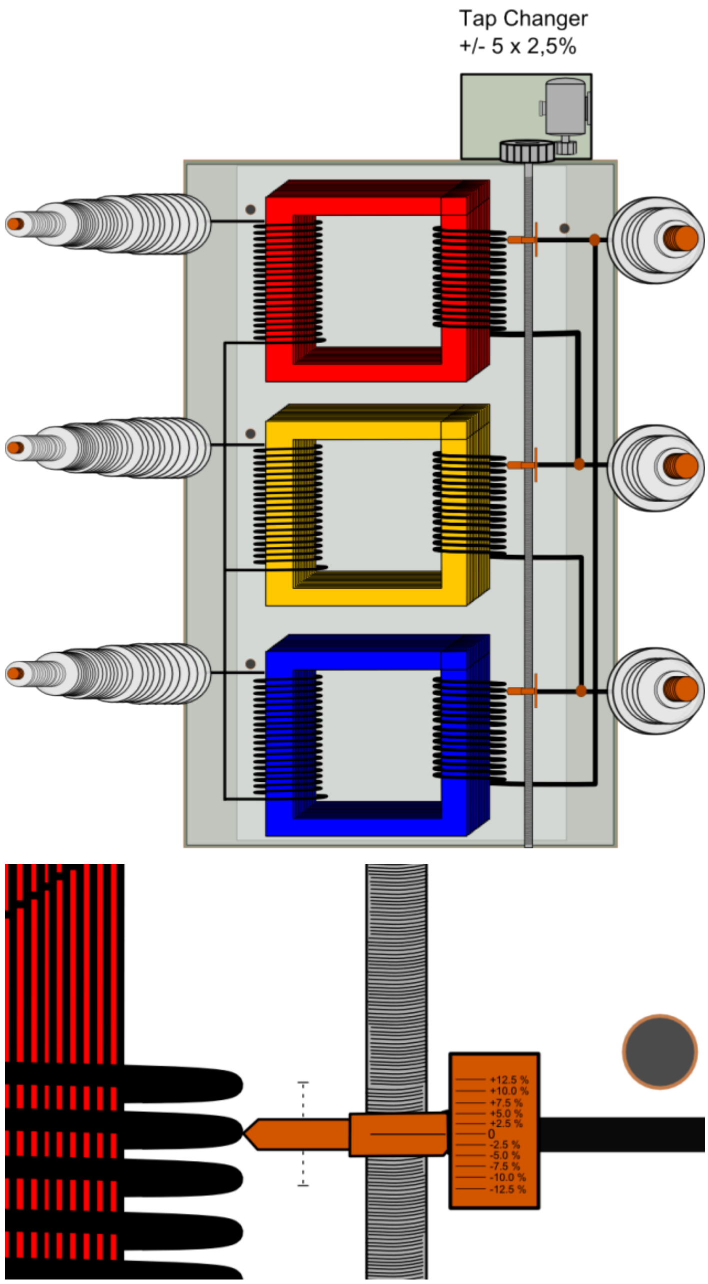
When the primary inductance is known, the magnetizing current value is compared to the HV side's nominal current and the resulting percentage is directly the TME value. If the transformer's primary inductance is unknown, one can use a conservative estimate of 3 % as the TME value.

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 changer 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 variations, 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 protection 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. 4.4.22 - 112. 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):

$$I_{meas,unc} = \frac{CTE_{pri} + CTE_{sec} + TCE + (CTE_{sec} + TCE)}{1 + TCE} \times 100 \qquad I_{meas,unc} = \frac{0.1 + 0.05 + 0.125 + (0.05 \times 0.125)}{1 + 0.125} \times 100 = 25\,\%$$

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:

$$I_{db>\,pick-up} = \left(\frac{CTE_{pri} + CTE_{sec} + TCE + CTE_{sec} \times TCE}{1 + TCE} \times 100\right) + 2 \times RE_m + AUTE + TME + SME = 36\,\%$$

Now the base sensitivity takes into account the starting situation (no load to Turnpoint 1) in the characteristics. Next, it needs to be decided 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:

$$I_{db>\,pick-up} = CTE_{pri} + CTE_{sec} + 2 \times RE_m + AUTE + TME + SME$$

$$I_{db>\,pick-up} = 10\,\% + 5\,\% + 2 \times 0.5\,\% + 2.5\,\% + 3\,\% + 5\,\% = 26\,\%$$

Next are the Slope 1 settings, which present the protection 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:

$$Slope\ 1 = \frac{I_{diff}\ TP2}{I_{bias}\ TP2} \times 100\ \%$$

Now the calculation of the maximum differential current in Turnpoint 2 includes the previously calculated correction factors for the HV and LV side CTs.

$$I_{pu\ PRI\ HV} = \frac{In_{HV}}{CT_{PRI\ HV}} = \frac{115.47\ \mathrm{A}}{150\ \mathrm{A}} = 0.77$$

$$I_{pu\ PRI\ LV} = \frac{In_{LV}}{CT_{PRI\ LV}} = \frac{1154.7\ \mathrm{A}}{1200\ \mathrm{A}} = 0.96$$

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).

$$TR_{CORR} = \frac{U_{HV\ VOLTS\ MIN}}{U_{HV}} \times \left(\frac{U_{HV}}{U_{LV}}\right)$$

To get the HV volts minimum 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:

$$TR_{CORR} = \frac{10\ 000\ \mathrm{V} \times (1.0 - 0.125)}{10\ 000\ \mathrm{V}} \times \left(\frac{10\ 000\ \mathrm{V}}{1\ 000\ \mathrm{V}}\right) = 8.75$$

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:

$$I_{LV} = \frac{I_{N\ LV} \times 1.5}{CT_{LV\ SEC} \times I_{pu\ PRI\ LV} \times \left(\frac{CT_{LV\ PRI}}{CT_{LV\ SEC}}\right)} = \frac{1154.7\ \mathrm{A}\ \times 1.5}{5\ \mathrm{A} \times 0.96 \times \left(\frac{1200\ \mathrm{A}}{5\ \mathrm{A}}\right)} = 1.5\ \mathrm{x\ In}$$

The currents of the HV side are as follows:

$$I_{HV} = \frac{\left(\frac{I_{N\ LV} \times 1.5}{TR_{CORR}}\right)}{CT_{HV\ SEC} \times I_{pu\ PRI\ HV} \times \left(\frac{CT_{HV\ PRI}}{CT_{HV\ SEC}}\right)} = \frac{\left(\frac{1154.7\ \mathrm{A} \times 1.5}{8.75}\right)}{5\ A \times 0.77 \times \left(\frac{150\ \mathrm{A}}{5\ \mathrm{A}}\right)} = 1.7\ x\ In$$

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:

$$L_{x\ BIAS\ AVG} = \frac{|I_{Lx\ HV}| + |I_{Lx\ LV}|}{2}$$

$$Slope\ 1 = \frac{I_{diff\ TP2}}{L_{x\ BIAS\ AVG}} \times 100\ \% = \frac{|I_{LV} - I_{HV}|}{\left(\frac{I_{LV} + I_{HV}}{2}\right)} \times 100\ \% = \frac{1.5 - 1.7}{\left(\frac{1.5 + 1.7}{2}\right)} \times 100\ \% = 12.5\ \%$$

If the user wants more stable settings, the Maximum mode is selected and the Slope 1 calculation is as follows:

$$L_{x\ BIAS\ MAX} = \max\left(|I_{Lx\ HV}|, |I_{Lx\ LV}|\right)$$

$$Slope\ 1 = \frac{I_{diff\ TP2}}{L_{x\ BIAS\ max}} \times 100\ \% = \frac{|I_{LV} - I_{HV}|}{\max\left(|I_{LV}|, |I_{HV}|\right)} \times 100\ \% = \frac{1.5 - 1.7}{1.7} \times 100\ \% = 11.7\ \%$$

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:

$$L_{x\ BIAS\ AVG} = \frac{|I_{Lx\ HV}| + |0|}{2}$$

Therefore, the differential current is the following:

$$|I_{Lx\ HV}|$$

$$Slope\ 2 = \frac{|I_{Lx\ HV}|}{\frac{|I_{Lx\ HV}|}{2}} \times 100\ \% = \frac{|1|}{\left(\frac{1}{2}\right)} \times 100\ \% = 200\ \%$$

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:

$$Slope\ 2 = \frac{|I_{Lx\ HV}|}{|I_{Lx\ HV}|} \times 100\ \% = \frac{|1|}{|1|} \times 100\ \% = 100\ \%$$

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:

$$I_{3ph\ SC\ LV} = \frac{S_N}{\sqrt{3} \times Z_k} = \frac{S_N}{\sqrt{3} \times \left(\frac{U_{LV}{}^2}{S_N} \times \frac{Z_{k\%}}{100\ \%}\right)} = \frac{2\ 000\ 000\ \text{VA}}{\sqrt{3} \times \left(\frac{10\ 000\ \text{V}^2}{2\ 000\ 000\ \text{VA}} \times \frac{4.95\ \%}{100\ \%}\right)} = 23327\ \text{A}$$

On the HV side this current is seen as:

$$I_{3ph\ SC\ LV \to HV} = \frac{I_{3ph\ SC\ LV}}{\left(\frac{U_{HV}}{U_{LV}}\right)} = \frac{23\ 327\ \text{A}}{\left(\frac{10\ 000\ \text{V}}{1\ 000\ \text{V}}\right)} = 2\ 332\ \text{A}$$

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:

$$I_{HV\ MAX} = \frac{I_{3ph\ SC\ LV \to HV}}{CT_{HV\ PRI}} = \frac{2\ 332\ \text{A}}{\frac{150\ \text{A}}{5\ \text{A}}} = 77.7\ \text{A}_{SEC}\ (20.18\ x\ In)$$

$$I_{LV\ MAX} = \frac{I_{3ph\ SC\ LV}}{CT_{HV\ PRI}} = \frac{23\ 327\ \text{A}}{\frac{1\ 200\ \text{A}}{5\ \text{A}}} = 97.2\ \text{A}_{SEC}\ (20.2\ x\ In)$$

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 (Ω)
ρ = resistivity of the conductor material (Ω /m)
l = length of the wire in meters (m)
A = cross-section of the conductor (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 protection 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:

$\Delta_\rho = ((\alpha \times \Delta T) \times \rho_0$, where

Δ_ρ = change of resistivity (Ω / m)
α = temperature coefficient (K-1)
ΔT = temperature change (t_1-t_0)
ρ_0 = resistivity in given temperature (°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 °C values are sufficient. If the ambient temperature in your application is higher than +75 °C, 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 rated accuracy limit factor, the “factor after P”
S_{ctrn} = internal burden of the CT secondary (VA)
S_{rated} = the rating of the CT (VA)
S_{actual} = the actual power taken from the CT (VA)

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):

$ALF_{rated} = 10$	$ALF_{rated} = 10$
$S_{rated} = 5\ \text{VA}$	$S_{rated} = 5\ \text{VA}$
$S_{ctrn} = {I_{NS}}^2 \times CT_{RS} = 5^2\ \text{A} \times 0.05\ \Omega = 1.25\ \text{VA}$	$S_{ctrn} = {I_{NS}}^2 \times CT_{RS} = 5^2 A \times 0.09\ \Omega = 2.25\ \text{VA}$
$R_{wire} = (10\ m \times 1.3) \times 0.00508\ \frac{\Omega}{\text{m}} = 0.066\ \Omega$	$R_{wire} = (5\ m \times 1.3) \times 0.00508\ \frac{\Omega}{\text{m}} = 0.033\ \Omega$
$S_{actual} = {I_{NS}}^2 \times (R_{wire} + R_{relay}) = 5^2\ \text{A} \times (0.066\ \Omega + 0.0005\ \Omega) = 1.65\ \text{VA}$	$S_{actual} = {I_{NS}}^2 \times (R_{wire} + R_{relay}) = 5^2\ A \times (0.033\ \Omega + 0.0005\ \Omega) = 0.838\ \text{VA}$
$ALF_{act} = ALF_{rated} \times \left\|\frac{S_{ctrn} + S_{rated}}{S_{ctrn} + S_{actual}}\right\| = 10 \times \left\|\frac{1.25\ \text{VA} + 5\ \text{VA}}{1.25\ \text{VA} + 1.65\ \text{VA}}\right\| = 21.55$	$ALF_{act} = ALF_{rated} \times \left\|\frac{S_{ctrn} + S_{rated}}{S_{ctrn} + S_{actual}}\right\| = 10 \times \left\|\frac{2.25\ VA + 5\ \text{VA}}{2.25\ VA + 0.838\ VA}\right\| = 23.5$

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. 4.4.22 - 113. Example configuration for the transformer differential function.

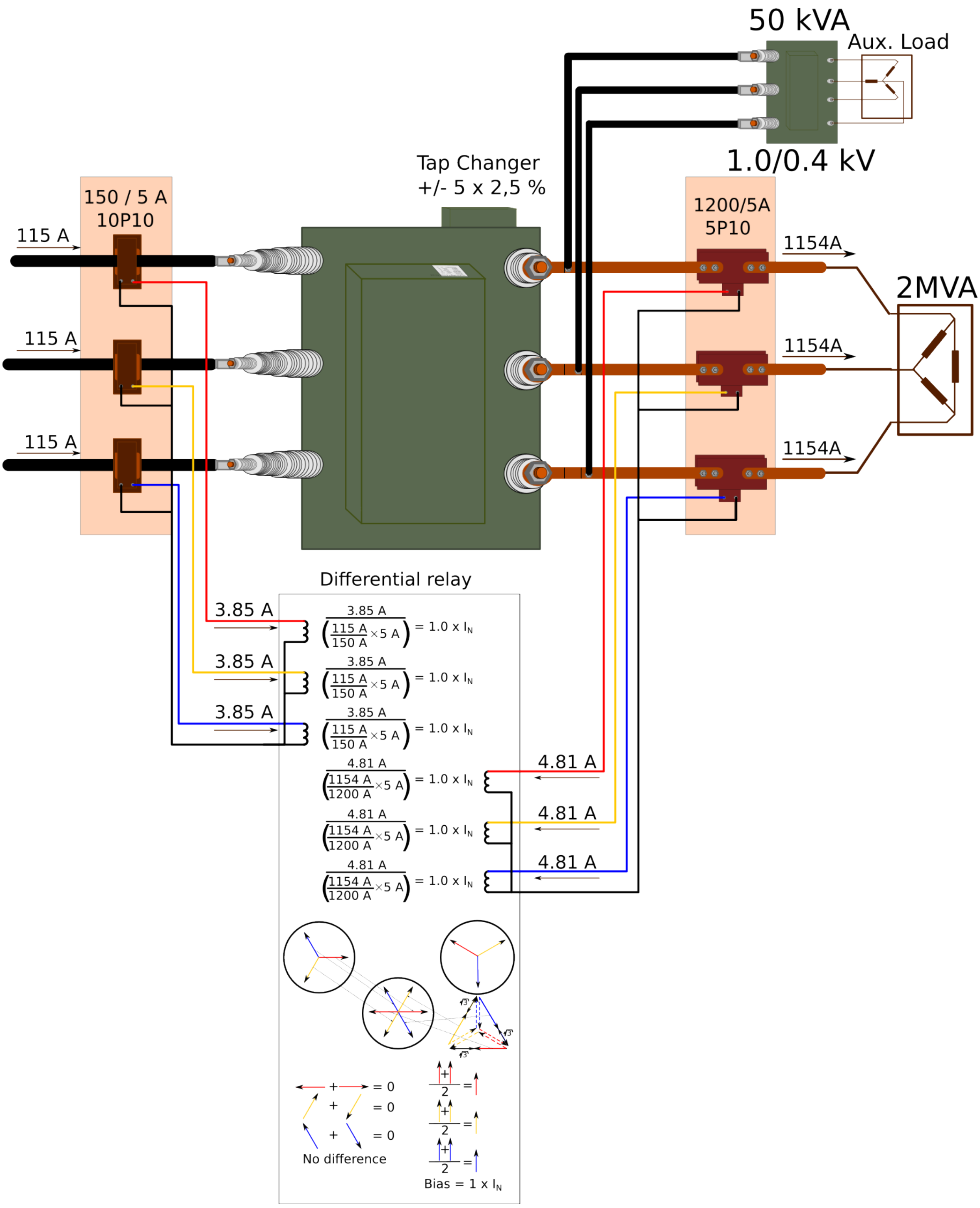
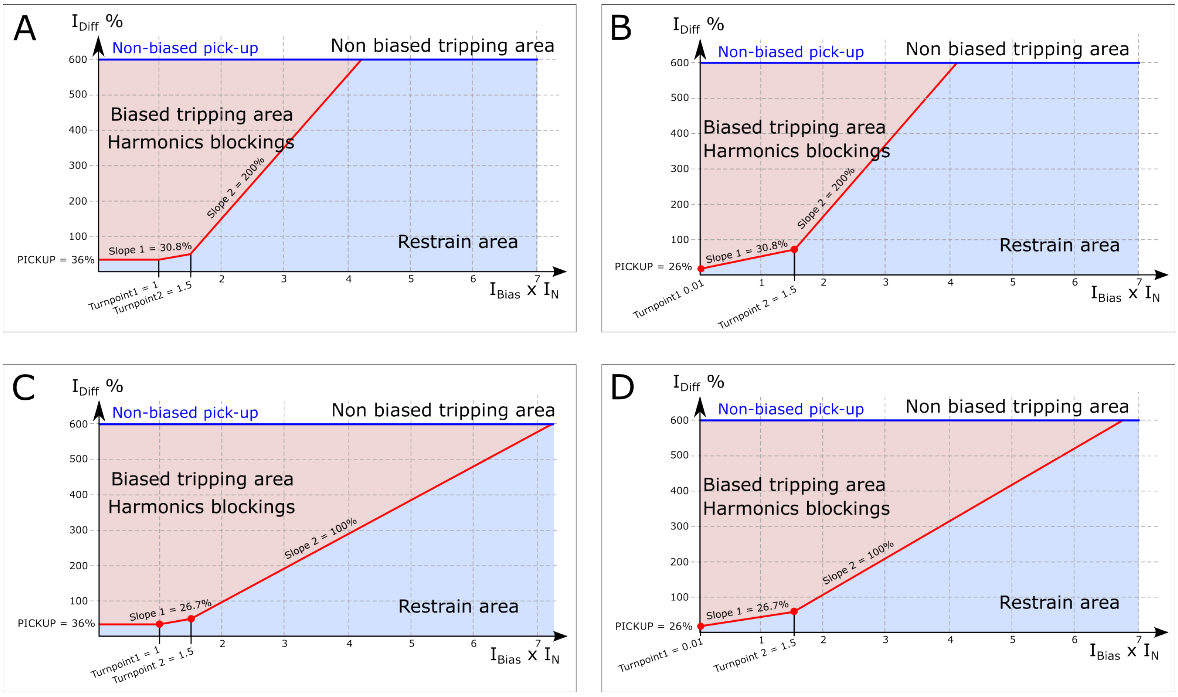


Figure. 4.4.22 - 114. Example differential characteristics

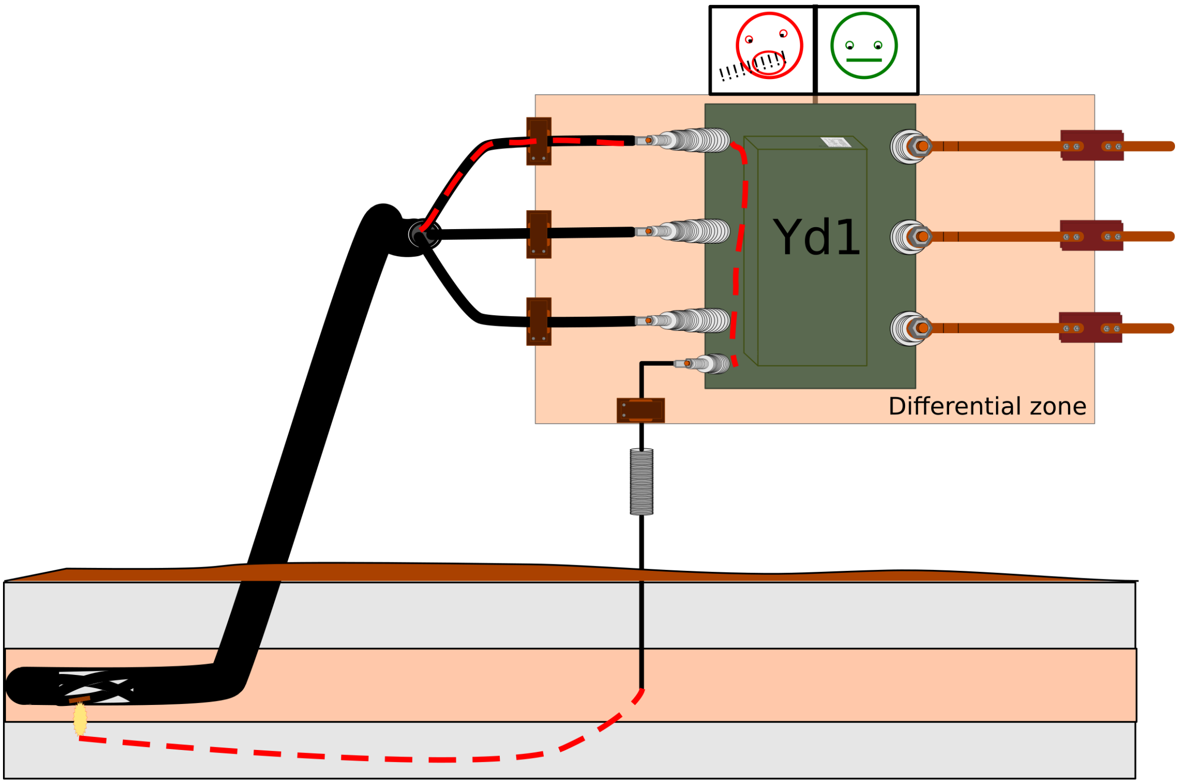


The four characteristics (the image above) present the setting variations based to the Average restraint calculation mode (figures A and B) and the Maximum restraint calculation modes (figures C and D). The characteristics are set to be equally sensitive in each of them. You can also see the variations 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. 4.4.22 - 115. 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.

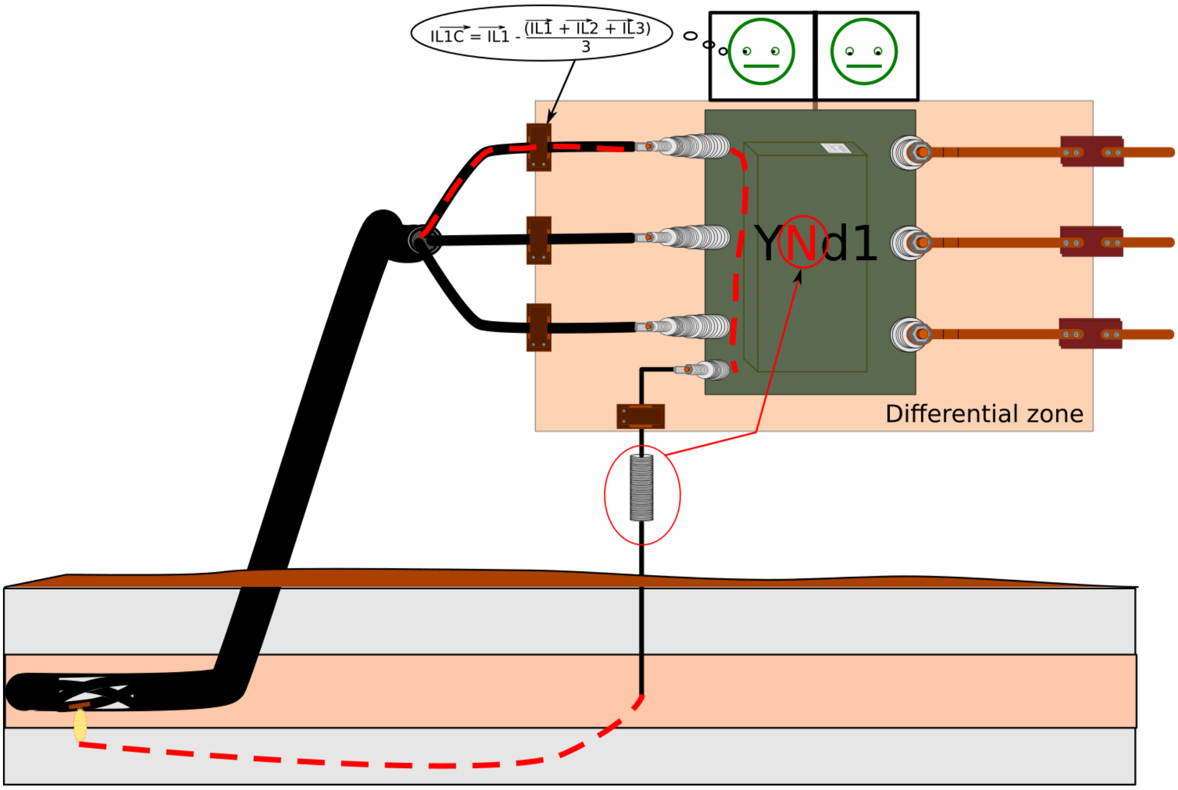
In many cases the zero sequence current is monitored by the CT in the earthing.

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. 4.4.22 - 116. 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).

$HV_{I0d\ bias\ avg} = \frac{\lvert(\overrightarrow{IL1}_{HV} + \overrightarrow{IL2}_{HV} + \overrightarrow{IL3}_{HV}) + \overrightarrow{I0}_{HV\ meas}\rvert}{2}$	$LV_{I0d\ bias\ avg} = \frac{\lvert(\overrightarrow{IL1}_{LV} + \overrightarrow{IL2}_{LV} + \overrightarrow{IL3}_{LV}) + \overrightarrow{I0}_{LV\ meas}\rvert}{2}$
$HV_{I0d\ bias\ max} = \max((\overrightarrow{IL1}_{HV} + \overrightarrow{IL2}_{HV} + \overrightarrow{IL3}_{HV}), \overrightarrow{I0}_{HV\ meas})$	$LV_{I0d\ bias\ max} = \max((\overrightarrow{IL1}_{LV} + \overrightarrow{IL2}_{LV} + \overrightarrow{IL3}_{LV}), \overrightarrow{I0}_{LV\ meas})$
$HV_{I0d>\ diff\ add} = \lvert(\overrightarrow{IL1}_{HV} + \overrightarrow{IL2}_{HV} + \overrightarrow{IL3}_{HV}) + \overrightarrow{I0}_{HV\ meas}\rvert$	$LV_{I0d>\ diff\ add} = \lvert(\overrightarrow{IL1}_{LV} + \overrightarrow{IL2}_{LV} + \overrightarrow{IL3}_{LV}) + \overrightarrow{I0}_{LV\ meas}\rvert$
$HV_{I0d>\ diff\ substract} = \lvert(\overrightarrow{IL1}_{HV} + \overrightarrow{IL2}_{HV} + \overrightarrow{IL3}_{HV}) - \overrightarrow{I0}_{HV\ meas}\rvert$	$LV_{I0d>\ diff\ subtract} = \lvert(\overrightarrow{IL1}_{LV} + \overrightarrow{IL2}_{LV} + \overrightarrow{IL3}_{LV}) - \overrightarrow{I0}_{LV\ meas}\rvert$

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 (2^{nd} and 5^{th})

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 2^{nd} harmonic is the most commonly used harmonic in inrush blocking. Overvoltage (and overexcitation) situations generate odd harmonics: the 5^{th} harmonic is mainly used for blocking (the 3^{rd} harmonic is also present in Y windings but absent in delta windings which is why the 5^{th} 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 (2^{nd} and 5^{th}) applied internally. If the Idi> stage (the non-biased differential) needs to be blocked, external blocking must be used.

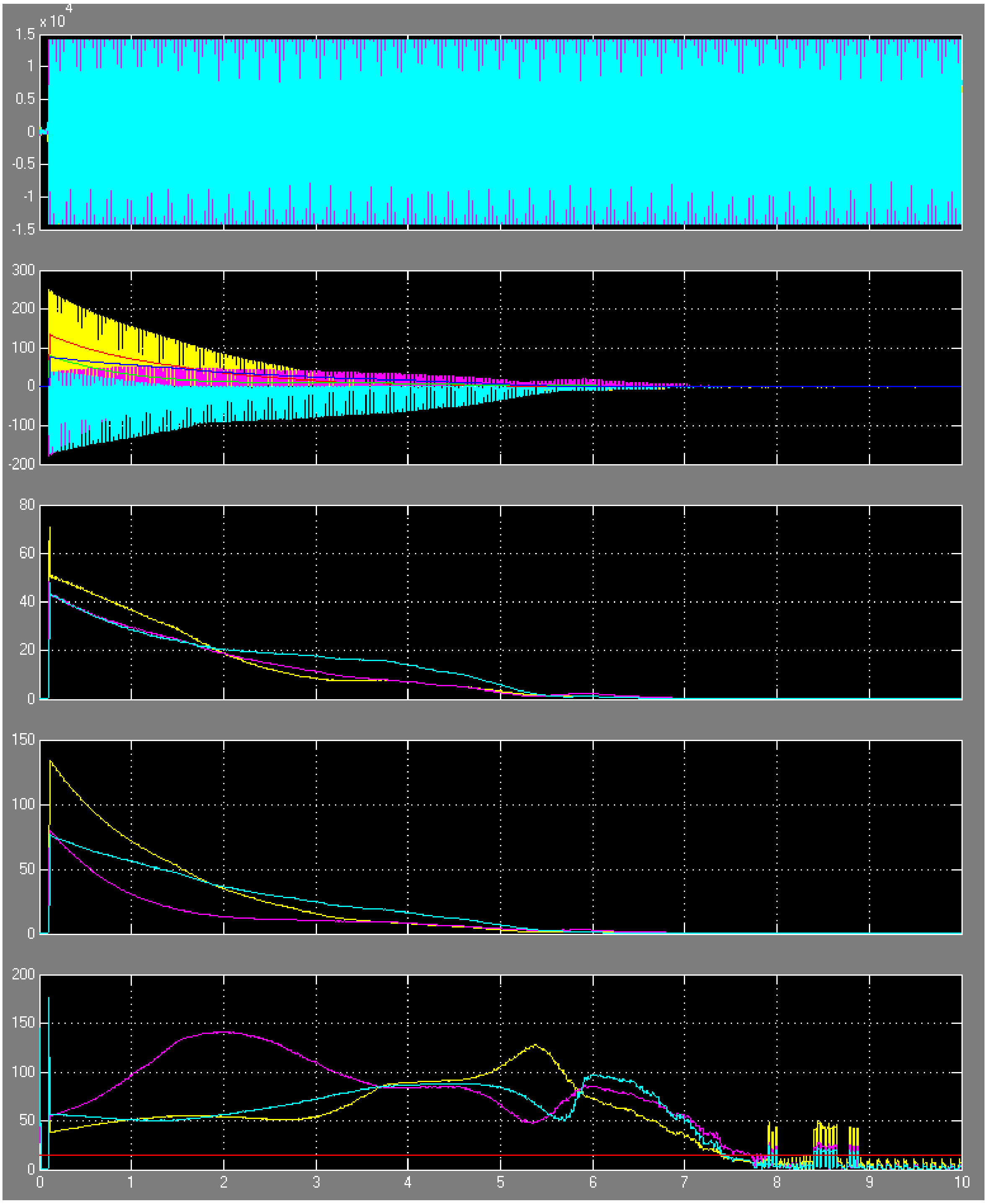
2^{nd} harmonic for magnetizing inrush blocking (principle and usage)

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 2^{nd}). 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 2^{nd} harmonic component which can be used to block the biased sensitive differential stage during energization.

Figure. 4.4.22 - 117. 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:

$$I_{L1\,peak} = 140\text{ A} = 1.2\,x\,In$$

$$I_{L2\,peak} = 75\text{ A} = 0.65\,x\,In$$

$$I_{L3\,peak} = 70\text{ A} = 0.60\,x\,In$$

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:

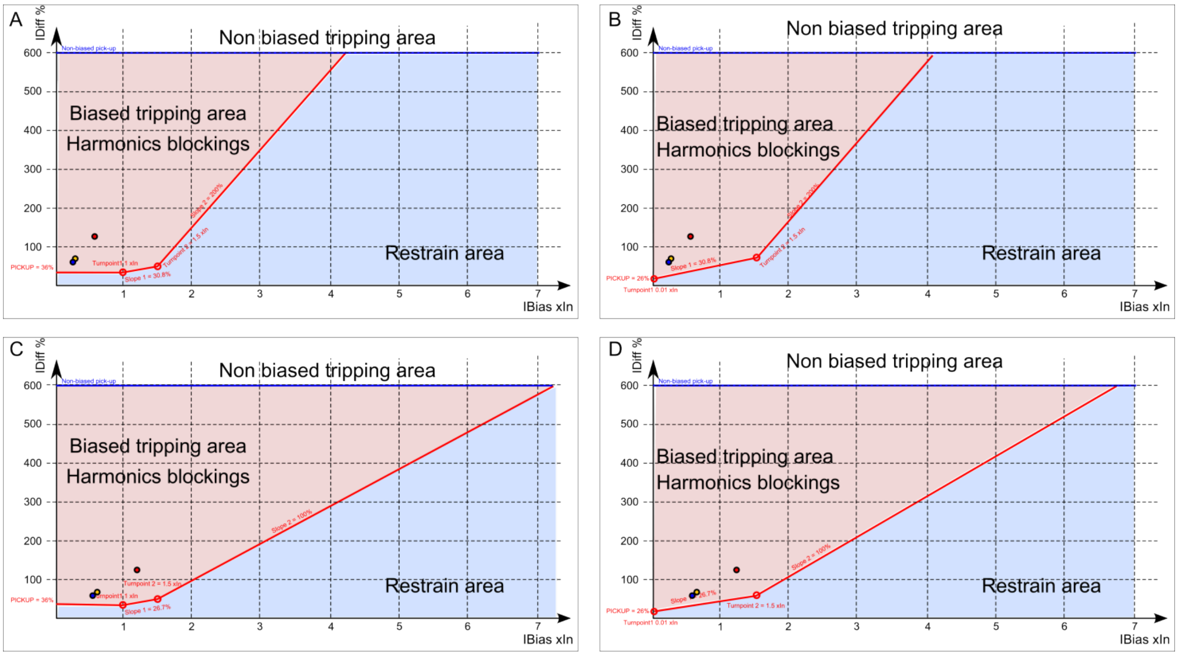
$$I_{L1\,diff} = 120\,\%,\ I_{L1\,bias\,avg} = \frac{1.2\,x\,In}{2} = 0.6\,x\,In,\ I_{L1\,bias\,max} = 1.2\,x\,In$$

$$I_{L2\,diff} = 65\,\%,\ I_{L2\,bias\,avg} = \frac{0.65\,x\,In}{2} = 0.33\,x\,In,\ I_{L2\,bias\,max} = 0.65\,x\,In$$

$$I_{L3\,diff} = 60\,\%,\ I_{L3\,bias\,avg} = \frac{0.60\,x\,In}{2} = 0.30\,x\,In,\ I_{L3\,bias\,max} = 0.60\,x\,In$$

The graph below shows how the differential currents look like when used in the set characteristics.

Figure. 4.4.22 - 118. 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. 4.4.22 - 119. Inrush blocking by using the 2nd harmonic (relative to fundamental frequency).

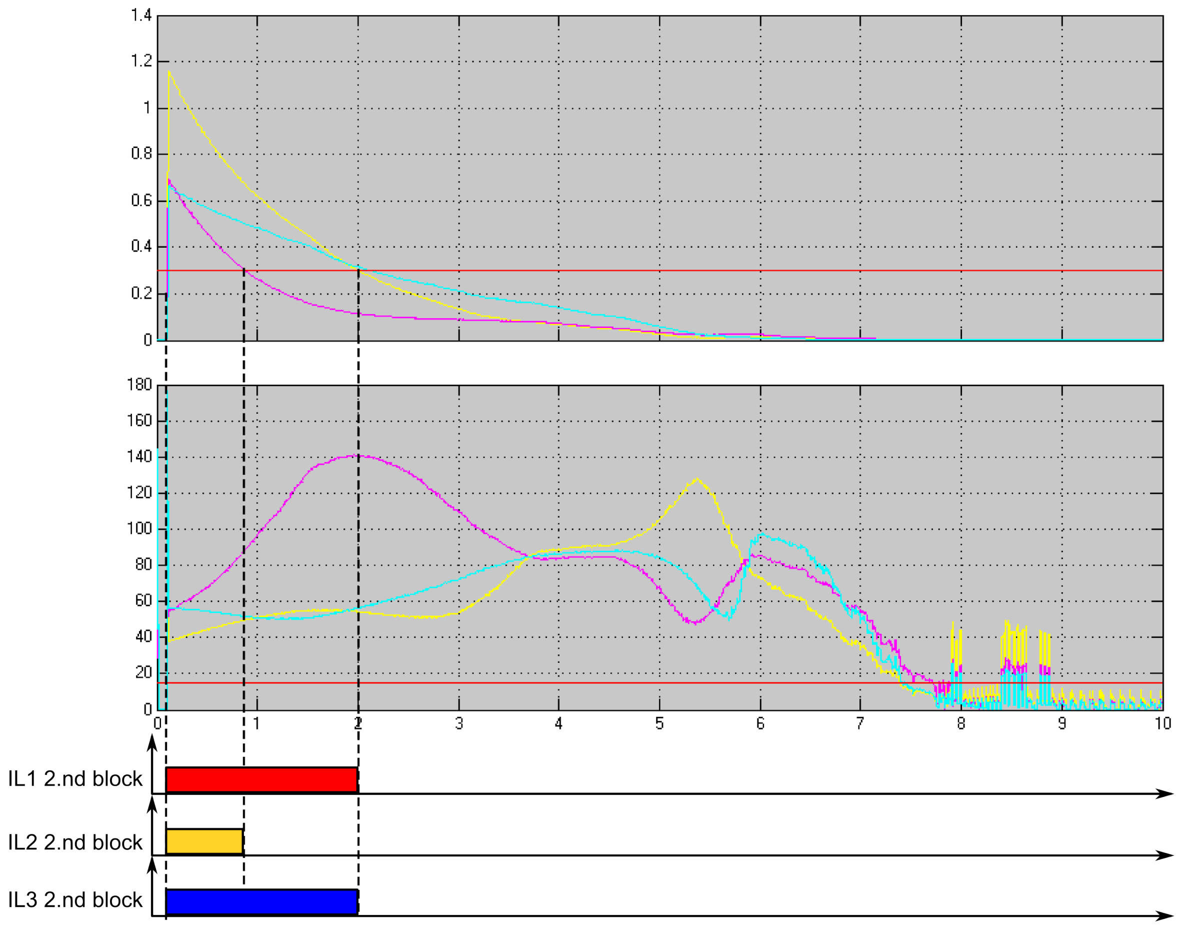
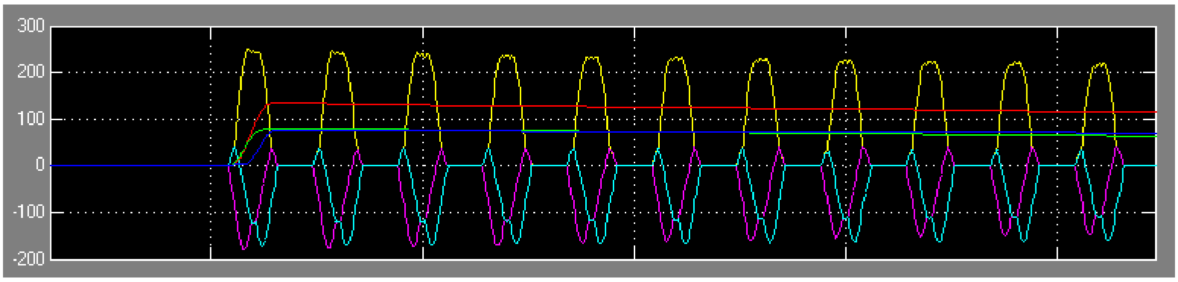


Figure. 4.4.22 - 120. Example of transformer magnetizing inrush currents.



A conservative setting recommendation for standard type transformers:

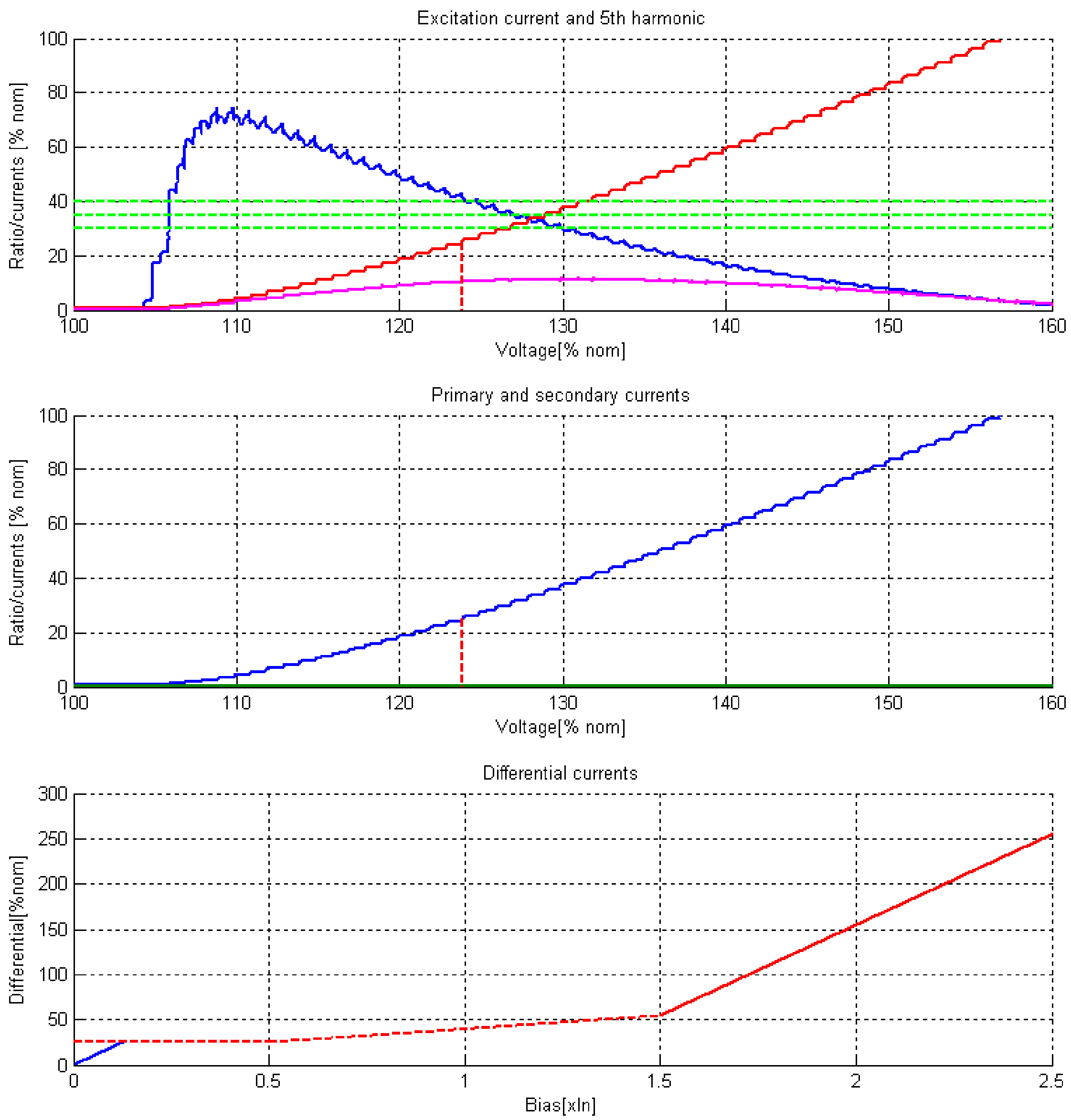
- enabling the 2nd harmonic blocking
- sensitivity appr. 15...20 %
- harmonic content compared to the fundamental frequency.

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. 4.4.22 - 121. Transformer behavior in case of overvoltage caused by overexcitation.

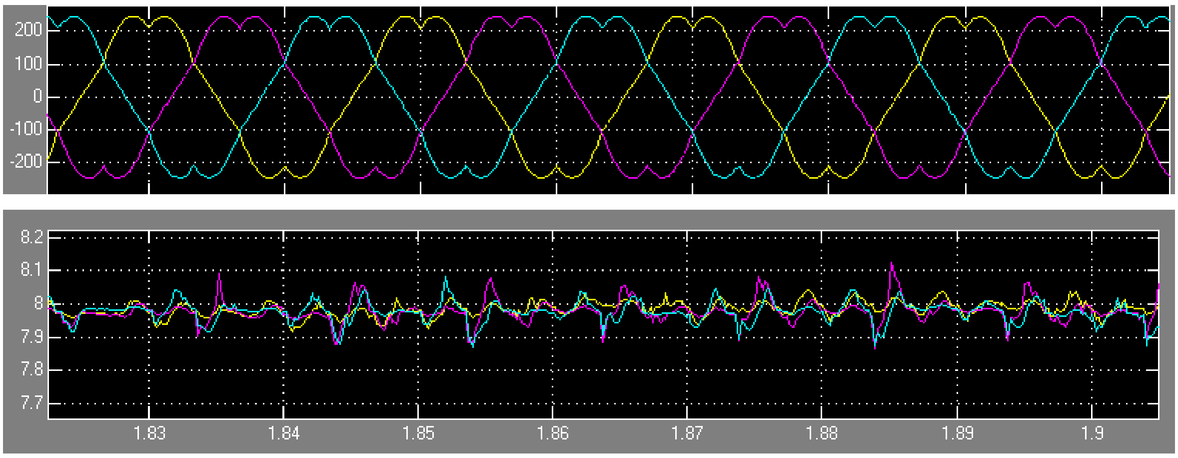


The figure above presents the simulated behavior of a power transformer when overvoltage occurs. In the simulation the transformer was unloaded on the secondary side while the voltage on the primary side was increased with a ramp. The first graph depicts the excitation current, the 5th harmonic component 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 as well as 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.

The figures below present example waveforms of a transformer that is running with a 200 % rated voltage with the corresponding ratio between the 5th harmonic and the fundamental frequency component.

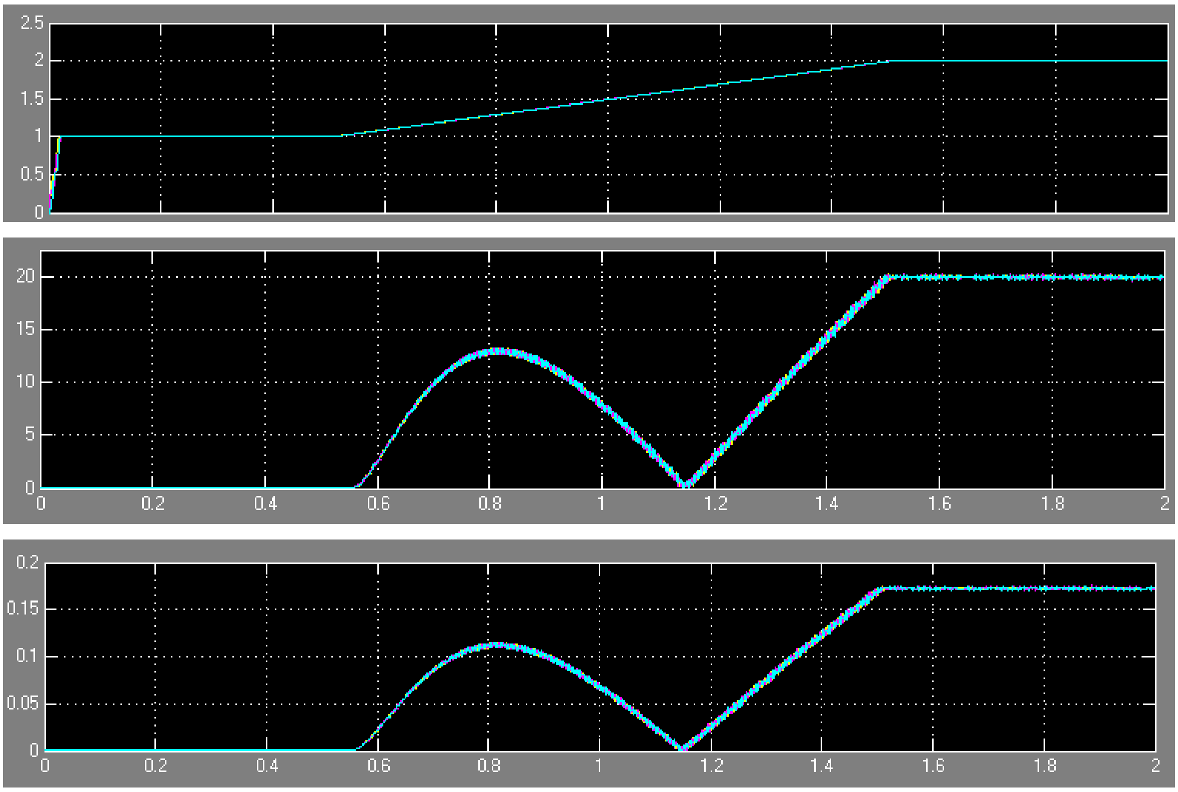
Figure. 4.4.22 - 122. Example waveforms.



Traditionally, the ratio between the 5th harmonic and the fundamental frequency component 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.

The figures below present the system voltage and the magnitude of the 5th harmonic component (both in per-unit), absolute and scaled to the transformer nominal.

Figure. 4.4.22 - 123. System voltage and magnitude of the 5th harmonic component.

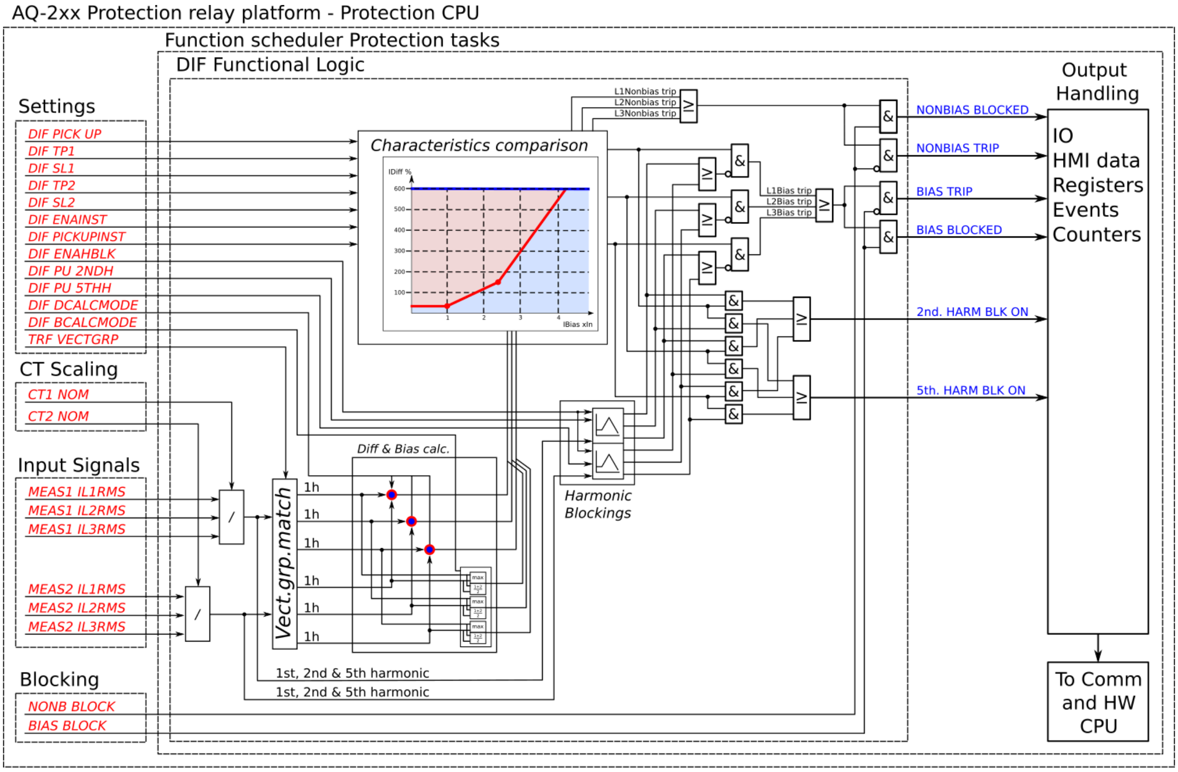


As can be seen in the figure above, the 5th harmonic component first increases, then decreases and then increases again as the system voltage rises. In this case the 5th harmonic seems to disappear completely when around an overvoltage of 160 %. When the harmonic behaves this way, the previously mentioned 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. 4.4.22 - 124. 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. 4.4.22 - 195. Settings related to the differential function's pre-calculation.

Name	Range	Step	Default	Function	Description
Idx> LN mode	• On • Blocked • Test • Test/ Blocked • Off	-	On	-	Set mode of DIF block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.

Name	Range	Step	Default	Function	Description
Idx> force status to	• Normal • Idb Blocked • Idb Trip • Idi Blocked • Idi Trip • H2block On • H5block On • HV I0d> Block On • HV I0d> Trip On • LV I0d> Block On • LV I0d> Trip On	-	Normal	-	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.
Idx> LN behaviour	• On • Blocked • Test • Test/ Blocked • Off	-	-	-	Displays the mode of DIF block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
Transformer nominal	0.1...500.0MVA	0.1MVA	1.0MVA	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…500.0kV	0.1kV	110.0kV	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…500.0kV	0.1kV	110.0kV	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…75Hz	1Hz	50Hz	Info	The transformer's nominal frequency. Used for calculating the transformer's nominal short-circuit inductance.

Name	Range	Step	Default	Function	Description
Transf. vect. group	• Manual • Yy0 • Yyn0 • YNy0 • YNyn0 • Yy6 • Yyn6 • YNy6 • YNyn6 • Yd1 • YNd1 • Yd7 • YNd7 • Yd11 • YNd11 • Yd5 • YNd5 • Dy1 • Dyn1 • Dy7 • Dyn7 • Dy11 • Dyn11 • Dy5 • Dyn5 • Dd0 • Dd6	-	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 "Manual set".
HV side Star or Zigzag/ Delta	• Star/Zigzag • Delta	-	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	• Not grounded • Grounded	-	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	• Lead • Lag	-	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	• Star/Zigzag • Delta	-	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	• Not grounded • Grounded	-	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.

Name	Range	Step	Default	Function	Description
LV side lead or lag HV	• Lead • Lag	-	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...360.00deg	0.1deg	0.0deg	- 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	• - • Check	-	-	- 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.
Enable I0d> (REF) HV side	• Disabled • Enabled	-	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.	• I_{01} • I_{02}	-	I_{01}	- 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	• Disabled • Enabled	-	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.	• I_{01} • I_{02}	-	I_{01}	- 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.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.4.22 - 196. Settings for the operating characteristics.

Name	Range	Step	Default	Description
Differential calculation mode	• Add • Subtract	-	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	• Average • Maximum	-	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	• No harmonic blocking • 2nd harmonic blocking • 5th harmonic blocking • 2nd and 5th harmonic blocking	-	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	• Disabled • Enabled	-	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.

Name	Range	Step	Default	Description
HV I0d> Turnpoint 1	0.01…50.00×In	0.01×In	1.00×In	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×In	0.01×In	3.00×In	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×In	0.01×In	1.00×In	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×In	0.01×In	3.00×In	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. 4.4.22 - 197. 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

Name	Description
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. 4.4.22 - 198. 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 the status changes in the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the TRIP, 2^{nd} Harmonic Block, 5^{th} Harmonic Block, External Block events.

Table. 4.4.22 - 199. Event messages.

Event block name	Event names
DIF1	Idb> Trip ON
DIF1	Idb> Trip OFF
DIF1	Idb> Blocked (ext) ON
DIF1	Idb> Blocked (ext) OFF
DIF1	Idi> Trip ON
DIF1	Idi> Trip OFF
DIF1	Idi> Blocked (ext) ON
DIF1	Idi> Blocked (ext) OFF
DIF1	2^{nd} Harmonic Block ON
DIF1	2^{nd} Harmonic Block OFF
DIF1	5^{th} Harmonic Block ON
DIF1	5^{th} Harmonic Block OFF
DIF1	L1 2^{nd} harmonic ON
DIF1	L1 2^{nd} harmonic OFF
DIF1	L2 2^{nd} harmonic ON
DIF1	L2 2^{nd} harmonic OFF
DIF1	L3 2^{nd} harmonic ON
DIF1	L3 2^{nd} harmonic OFF
DIF1	L1 5^{th} harmonic ON
DIF1	L1 5^{th} harmonic OFF
DIF1	L2 5^{th} harmonic ON
DIF1	L2 5^{th} harmonic OFF
DIF1	L3 5^{th} harmonic ON
DIF1	L3 5^{th} harmonic OFF
DIF1	HV I0d> Block ON
DIF1	HV I0d> Block OFF
DIF1	HV I0d> Trip ON
DIF1	HV I0d> Trip OFF

Event block name	Event names
DIF1	LV I0d> Block ON
DIF1	LV I0d> Block OFF
DIF1	LV I0d> Trip ON
DIF1	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.

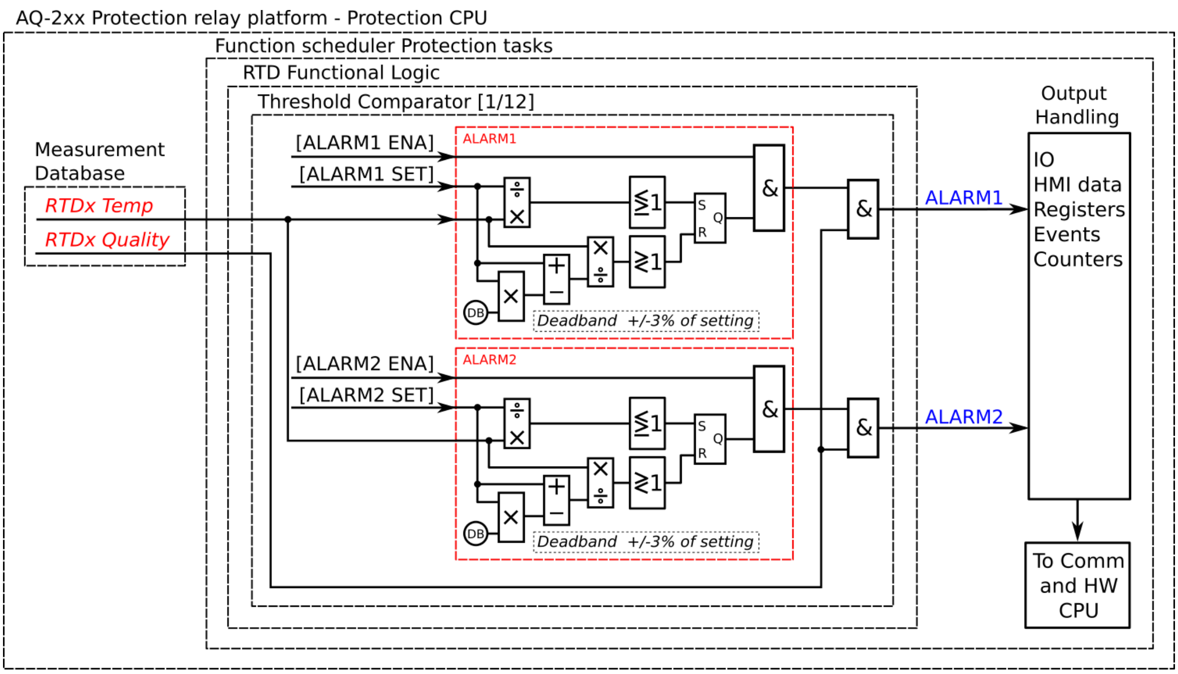
Table. 4.4.22 - 200. Register content.

Name	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
L1 bias current	Phase L1 bias current
L1 diff. current	Phase L1 maximum differential current
L1 char. current	Phase L1 maximum differential current with bias
L2 bias current	Phase L2 bias current
L2 diff. current	Phase L2 maximum differential current
L2 char. current	Phase L2 maximum differential current with bias
L3 bias current	Phase L3 bias current
L3 diff. current	Phase L3 maximum differential current
L3 char. current	Phase L3 maximum differential current with bias
HV I0d> bias current	HV side REF bias current
HV I0d> differential current	HV side REF differential current
HV I0d> characteristics current	HV side REF maximum differential current with bias
LV I0d> bias current	LV side REF bias current
LV I0d> differential current	LV side REF differential current
LV I0d> characteristics current	LV side REF maximum differential current with bias
Setting group in use	Setting group in use
Ftype	Detected fault type (faulty phases)

4.4.23 Resistance temperature detectors (RTD)

Resistance temperature detectors (or RTDs) can be used to measure both temperatures of motors/ generators 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. Up to two (2) separate RTD option cards are supported by this function. Sixteen (16) 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.

Figure. 4.4.23 - 125. Simplified function block diagram of the resistance temperature detection function.



Settings

Table. 4.4.23 - 201. General settings of the function.

Name	Range	Default	Description
RTD LN mode	• On • Blocked • Test • Test/ Blocked • Off	On	Set mode of RTD block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
RTD LN behaviour	• On • Blocked • Test • Test/ Blocked • Off	-	Displays the mode of RTD block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.

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, databits, parity, stopbits and Modbus I/O protocol to be set; this is done at *Communication → Connections*. Once communication 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.

Table. 4.4.23 - 202. Function settings for Channel x (Sx).

Name	Range	Step	Default	Description
S1...S16 enable	No Yes	-	No	Enables/disables the selecion of sensor measurements and alarms.
S1...S16 module	• InternalRTD1 • InternalRTD2 • ExtModuleA • ExtModuleB • ExtModuleC	-	InternalRTD1	Selects the measurement module. Internal RTD modules are option cards installed to the device. External modules are Modbus based external devices.
S1...S16 channel	• Channel 0 • Channel 1 • Channel 2 • Channel 3 • Channel 4 • Channel 5 • Channel 6 • Channel 7	-	Channel 0	Selects the measurement channel in the selected module.
S1...S16 Deg C/Dec F	• Deg C • Deg F	-	Deg C	Selects the measurement temperature scale (Celsius or Fahrenheit).
S1...S16 Measurement	-	-	-	Displays the measurement value in the selected temperature scale.
S1...S16 Sensor	• Ok • 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.
S1...S16 Enable alarm 1	• Disable • Enable	-	Disable	Enables/disables the selection of Alarm 1 for the measurement channel x.
S1...S16 Alarm1 >/<	• > • <	-	>	Selects whether the alarm activates when measurement is above or below the pick-up setting value.
S1...S16 Alarm1	-101.0…2000.0deg	0.1deg	0.0deg	Sets the pick-up 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 >/<").

Name	Range	Step	Default	Description
S1...S16 sensor	• Ok • 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.
S1...S16 Enable alarm 2	• Disable • Enable	-	Disable	Enables/disables the selection of Alarm 2 for the measurement channel x.
S1...S16 Alarm2 >/<	• > • <	-	>	Selects whether the measurement is above or below the setting value.
S1...S16 Alarm2	-101.0…2000.0deg	0.1deg	0.0deg	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 >/<").

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 sixteen (16) 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.

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 the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the ALARM events.

The function offers sixteen (16) independent stages; the events are segregated for each stage operation.

Table. 4.4.23 - 203. Event messages.

Event block name	Event names
RTD1	S1...S16 Alarm1 ON
RTD1	S1...S16 Alarm1 OFF
RTD1	S1...S16 Alarm2 ON
RTD1	S1...S16 Alarm2 OFF
RTD1	S1...S16 Meas Ok
RTD1	S1...S16 Meas Invalid

4.4.24 Programmable stage (PSx>/<; 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 device has ten programmable stages, and each can be set to follow one to three analog measurements. The programmable stages have three available pick up terms options: overX, underX and rate-of-change of the selected signal. Each stage 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 group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

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. 4.4.24 - 204. General settings of the function.

Name	Range	Description
PSx >/< LN mode	• On • Blocked • Test • Test/ Blocked • Off	Set mode of PSx block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
PSx >/< LN behaviour	• On • Blocked • Test • Test/ Blocked • Off	Displays the mode of PSx block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
PSx >/< Available stages	1...10	Defines the available amount of stages.
PSx >/< Enabled	• Disabled • Enabled	Enables the stage.
PSx >/< Force status to	• Normal • Start • Trip • Blocked	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.

Name	Range	Description
PSx >/< Measurement setting	• One magnitude comp • Two magnitude comp • Three magnitude comp	Defines how many measurement magnitudes are used by the stage.
PSx >/< Magnitude handling ("Two magnitude comp" selected)	Mag1 x Mag2	Multiplies Signal 1 by Signal 2. The comparison uses the product of this calculation.
	Mag1 / Mag2	Divides Signal 1 by Signal 2. The comparison uses the product of this calculation.
	Max (Mag1, Mag2)	The bigger value of the chosen signals is used in the comparison.
	Min (Mag1, Mag2)	The smaller value of the chosen signals is used in the comparison.
	Mag1 OR Mag2	Either of the chosen signals has to fulfill the pick-up condition. Both signals have their own pick-up setting.
	Mag1 AND Mag2	Both of the chosen signals have to fulfill the pick-up condition. Both signals have their own pick-up setting.
	Mag1 – Mag2	Subtracts Signal 2 from Signal 1. The comparison uses the product of this calculation.
PSx >/< Magnitude handling ("Three magnitude comp" selected)	Mag1 x Mag2 x Mag3	Multiplies Signals 1, 2 and 3. The comparison uses the product of this calculation.
	Max (Mag1, Mag2, Mag3);	The biggest value of the chosen signals is used in the comparison.
	Min (Mag1, Mag2, Mag3)	The smallest value of the chosen signals is used in the comparison.
	Mag1 OR Mag2 OR Mag3	Any of the signals fulfills the pick-up condition. Each signal has their own pick-up setting.
	Mag1 AND Mag2 AND Mag3	All of the signals need to fulfill the pick-up condition. Each signal has their own pick-up setting.
	(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.
PSx Magnitude selection	• Currents • Voltages • Powers • Impedances and admittances • Others	Defines the measurement type used by the stage
PSx MagnitudeX	See table below.	Defines the measurement used by the stage. Available parameters depend on selected measurement type.

Name	Range	Description
PSx MagnitudeX multiplier	-5 000 000...5 000 000	Multiplies the selected measurement. 1 by default (no multiplication). See section "Magnitude multiplier" for more information.

Analog values

The numerous analog signals have been divided into categories to help the user find the desired value.

Table. 4.4.24 - 205. Phase and residual current measurements (IL1, IL2, IL3, Io1 and Io2)

Name	Description
ILx ff (p.u.)	Fundamental frequency RMS value (in p.u.)
ILx 2^{nd} h.	ILx 2^{nd} harmonic value (in p.u.)
ILx 3^{rd} h.	ILx 3^{nd} harmonic value (in p.u.)
ILx 4^{th} h.	ILx 4^{nd} harmonic value (in p.u.)
ILx 5^{th} h.	ILx 5^{nd} harmonic value (in p.u.)
ILx 7^{th} h.	ILx 7^{nd} harmonic value (in p.u.)
ILx 9^{th} h.	ILx 9^{nd} harmonic value (in p.u.)
ILx 11^{th} h.	ILx 11^{nd} harmonic value (in p.u.)
ILx 13^{th} h.	ILx 13^{nd} harmonic value (in p.u.)
ILx 15^{th} h.	ILx 15^{nd} harmonic value (in p.u.)
ILx 17^{th} h.	ILx 17^{nd} harmonic value (in p.u.)
ILx 19^{th} h.	ILx 19^{nd} harmonic value (in p.u.)
ILx TRMS	ILx TRMS value (in p.u.)
ILx Ang	ILx Angle (degrees)

Table. 4.4.24 - 206. Other current measurements

Name	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.)
I0CALC Ang	Angle of calculated residual current (degrees)

Name	Description
I1 Ang	Angle of positive sequence current (degrees)
I2 Ang	Angle of negative sequence current (degrees)
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
I02ResS	I02 secondary current of a current-resistive component
I02CapS	I02 secondary current of a current-capacitive component

Table. 4.4.24 - 207. Voltage measurements

Name	Description
UL12Mag	UL12 Primary voltage V
UL23Mag	UL23 Primary voltage V
UL31Mag	UL31 Primary voltage V
UL1Mag	UL1 Primary voltage V
UL2Mag	UL2 Primary voltage V
UL3Mag	UL3 Primary voltage V
UL12Ang	UL12 angle (degrees)
UL23Ang	UL23 angle (degrees)
UL31Ang	UL31 angle (degrees)
UL1Ang	UL1 angle (degrees)
UL2Ang	UL2 angle (degrees)
UL3Ang	UL3 angle (degrees)
U0Ang	UL0 angle (degrees)
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 (degrees)
U1 pos.seq.V Ang	Positive sequence voltage angle (degrees)

Name	Description
U2 neg.seq.V Ang	Negative sequence voltage angle (degrees)

Table. 4.4.24 - 208. Power measurements

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
SLx	Phase apparent power L1 / L2 / L3 S (kVA)
PLx	Phase active power L1 / L2 / L3 P (kW)
QLx	Phase reactive power L1 / L2 / L3 Q (kVar)
tanfiLx	Phase active power direction L1 / L2 / L3
cosfiLx	Phase reactive power direction L1 / L2 / L3

Table. 4.4.24 - 209. Phase-to-phase and phase-to-neutral impedances, resistances and reactances

Name	Description
RLxPri	Resistance R L12, L23, L31, L1, L2, L3 primary (Ω)
XLxPri	Reactance X L12, L23, L31, L1, L2, L3 primary (Ω)
ZLxPri	Impedance Z L12, L23, L31, L1, L2, L3 primary (Ω)
RLxSec	Resistance R L12, L23, L31, L1, L2, L3 secondary (Ω)
XLxSec	Reactance X L12, L23, L31, L1, L2, L3 secondary (Ω)
ZLxSec	Impedance Z L12, L23, L31, L1, L2, L3 secondary (Ω)
ZLxAngle	Impedance Z L12, L23, L31, L1, L2, L3 angle

Table. 4.4.24 - 210. Other impedances, resistances and reactances

Name	Description
RSeqPri	Positive Resistance R primary (Ω)
XSeqPri	Positive Reactance X primary (Ω)
RSeqSec	Positive Resistance R secondary (Ω)
XSeqSec	Positive Reactance X secondary (Ω)

Name	Description
ZSeqPri	Positive Impedance Z primary (Ω)
ZSeqSec	Positive Impedance Z secondary (Ω)
ZSeqAngle	Positive Impedance Z angle

Table. 4.4.24 - 211. Conductances, susceptances and admittances (L1, L2, L3)

Name	Description
GLxPri	Conductance G L1, L2, L3 primary (mS)
BLxPri	Susceptance B L1, L2, L3 primary (mS)
YLxPriMag	Admittance Y L1, L2, L3 primary (mS)
GLxSec	Conductance G L1, L2, L3 secondary (mS)
BLxSec	Susceptance B L1, L2, L3 secondary (mS)
YLxSecMag	Admittance Y L1, L2, L3 secondary (mS)
YLxAngle	Admittance Y L1, L2, L3 angle (degrees)

Table. 4.4.24 - 212. Other conductances, susceptances and admittances

Name	Description
G0Pri	Conductance G0 primary (mS)
B0Pri	Susceptance B0 primary (mS)
G0Sec	Conductance G0 secondary (mS)
B0Sec	Susceptance B0 secondary (mS)
Y0Pri	Admittance Y0 primary (mS)
Y0Sec	Admittance Y0 secondary (mS)
Y0Angle	Admittance Y0 angle

Table. 4.4.24 - 213. Other measurements

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

Name	Description
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

Magnitude multiplier

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 zero sequence 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 zero sequence 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. Similarly, any chosen measurement value can be scaled to the desired form.

Read-only parameters

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

Table. 4.4.24 - 214. Information displayed by the function.

Name	Range	Description
PSx >/< LN behaviour	• On • Blocked • Test • Test/Blocked • Off	Displays the mode of PSx block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
Condition	• Normal • Start • Trip • Blocked	Displays status of the function.
Expected operating time	-1800.000...1800.000s	Displays the expected operating time when a fault occurs.
Time remaining to trip	0.000...1800.000s	When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs.

Name	Range	Description
PSx Scaled magnitude X	-5 000 000...5 000 000	Displays measurement value after multiplying it the value set to *PSx Magnitude multiplier*.
PSx >/< MeasMag1/ MagSet1 at the moment	-5 000 000...5 000 000	The ratio between measured magnitude and the pick-up setting.
PSx >/< MeasMag2/ MagSet2 at the moment	-5 000 000...5 000 000	The ratio between measured magnitude and the pick-up setting.
PSx >/< MeasMag3/ MagSet3 at the moment	-5 000 000...5 000 000	The ratio between measured magnitude and the pick-up setting.
PSx >/< CalcMeasMag/ MagSet at the moment	-5 000 000...5 000 000	The ratio between calculated magnitude and the pick-up setting.

Pick-up settings

The *Pick-up setting Mag* setting parameter controls the pick-up of the PSx>/< 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. 4.4.24 - 215. Pick-up settings.

Name	Range	Step	Default	Description
PS# Pick-up term Mag#	• Over > • Over (abs) > • Under < • Under (abs) < • Delta set (%) +/- > • Delta abs (%) > • Delta +/- measval • Delta abs measval	-	Over	Comparator mode for the magnitude. See "Comparator modes" section below for more information.
PS# Pick-up setting Mag#/calc >/<	-5 000 000.0000…5 000 000.0000	0.0001	0.01	Pick-up magnitude
PS# Setting hysteresis Mag#	0.0000…50.0000%	0.0001%	3%	Setting hysteresis
Definite operating time delay	0.000…1800.000s	0.005s	0.04s	Delay setting
Release time delays	0.000…1800.000s	0.005s	0.06s	Pick-up release delay

Comparator modes

When setting the comparators, the user must first choose a comparator mode.

Table. 4.4.24 - 216. Comparator modes

Mode	Description
Over >	Greater than. If the measured signal is greater than the set pick-up level, the comparison condition is fulfilled.
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.
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.
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.
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.
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.
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.
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.

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 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 "PSx" in event block names) generates events and registers from the status changes in the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

Table. 4.4.24 - 217. Event messages.

Event block name	Event names
PSx	PS1...10 >/< Start ON
PSx	PS1...10 >/< Start OFF
PSx	PS1...10 >/< Trip ON
PSx	PS1...10 >/< Trip OFF
PSx	PS1...10 >/< Block ON
PSx	PS1...10 >/< 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.

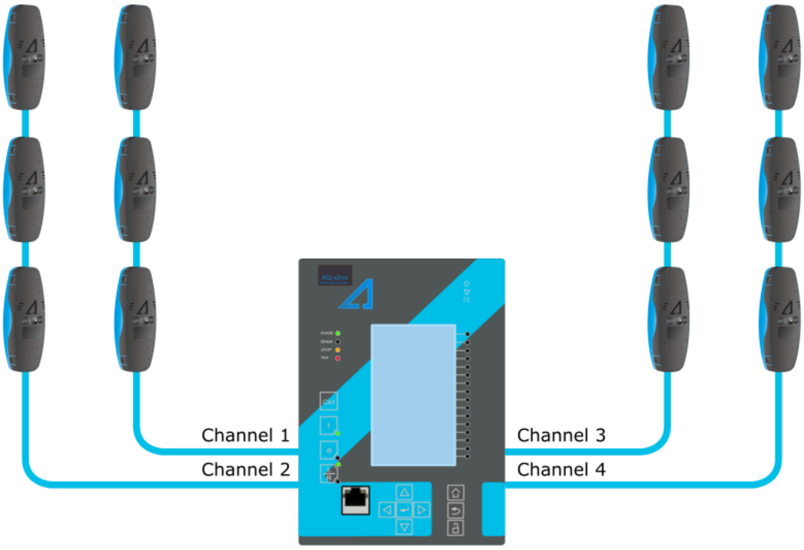
Table. 4.4.24 - 218. Register content.

Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
>/< Mag#	The numerical value of the magnitude
Mag#/Set#	Ratio between the measured magnitude and the pick-up setting
Trip time remaining	0 ms...1800s
Setting group in use	Setting group 1...8 active

4.4.25 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 devices 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. 4.4.25 - 126. Protection device 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.

Table. 4.4.25 - 219. 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.
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.

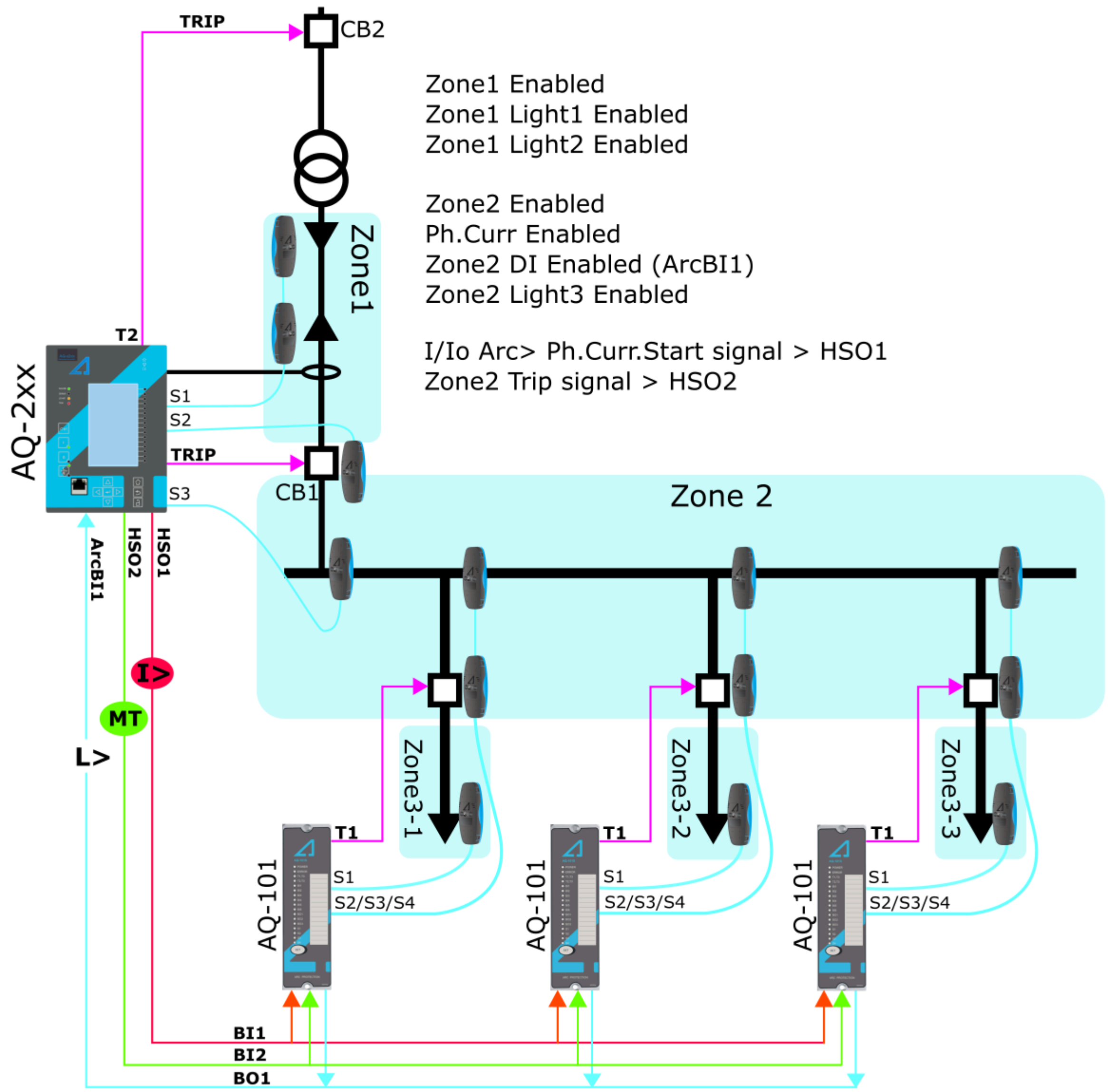
Outputs	Activation condition
I/I0 Arc> Ph. curr. BLOCKED I/I0 Arc> Res. curr. BLOCKED	The phase current or the residual current measurement is blocked by an input.
I/I0 Arc> Zone 1 TRIP I/I0 Arc> Zone 2 TRIP I/I0 Arc> Zone 3 TRIP I/I0 Arc> Zone 4 TRIP	All required conditions for tripping the zone are 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.

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).

This scheme is a single-line diagram with AQ-200 series devices and with AQ-101 arc protection relays. The settings are for an incoming feeder AQ-200 device.

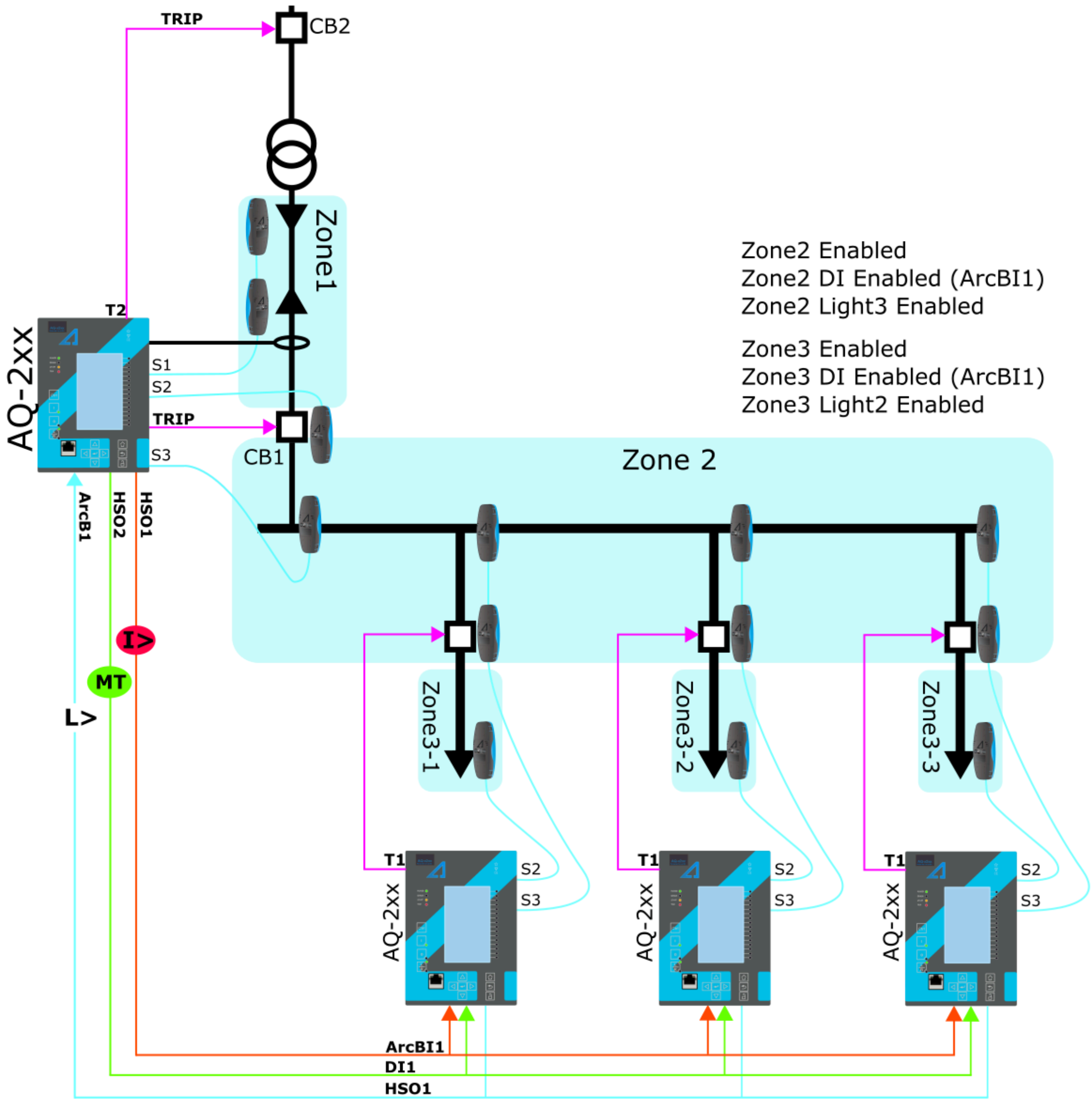
Figure. 4.4.25 - 127. Scheme with AQ-101 arc protection relays.



To set the zones for the AQ-200 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 200 series devices. However, this time each outgoing feeder has an AQ-200 protection device instead of an AQ-101 arc protection relay.

Figure. 4.4.25 - 128. Scheme with AQ-200 protection devices.



The settings for the device supervising the incoming feeder are the same as in the first example. The devices 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 use either phase currents, residual currents or both.

Table. 4.4.25 - 220. Measurement inputs of the U1/U2>/< function.

Signal	Description	Time base
I_{L1} samples	Samples received by I_{L1} current measurement channel	5ms
I_{L2} samples	Samples received by I_{L2} current measurement channel	5ms
I_{L3} samples	Samples received by I_{L3} current measurement channel	5ms
I_{01} samples	Samples received by I_{01} current measurement channel	5ms
I_{02} samples	Samples received by I_{02} current measurement channel	5ms

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. 4.4.25 - 221. General settings of the function.

<table>
<tr><th>Name</th><th>Range</th><th>Default</th><th>Description</th></tr>
<tr><td>I/I0 Arc> LN mode</td><td>• On
• Blocked
• Test
• Test/Blocked
• Off</td><td>On</td><td>Set mode of ARC block.
This parameter is visible only when Allow setting of individual LN mode is enabled in General menu.</td></tr>
<tr><td>I/I0 Arc> force status to</td><td>• Normal
• PH curr blocked
• PH curr Start
• ResCurr Blocked
• ResCurr Start
• Zone 1 Trip
• Zone1 Blocked
• Zone2 Trip
• Zone2 Blocked
• Zone3 Trip
• Zone3 Blocked
• Zone4 Trip
• Zone4 Blocked</td><td>Normal</td><td>Force the status of the function. Visible only when Enable stage forcing parameter is enabled in General menu.</td></tr>
<tr><td>Channel 1 sensors</td><td rowspan="2">• No sensors
• 1 sensor
• 2 sensors
• 3 sensors</td><td rowspan="2">No sensors</td><td rowspan="2">Defines the number of sensors connected to the channel (channels 1/2/3/4).</td></tr>
<tr><td>Channel 2 sensors</td></tr>
</table>

Name	Range	Default	Description
Channel 3 sensors			
Channel 4 sensors			
Channel 1 sensor status	• Sensors OK • Configuration fault state	-	Displays the status of the sensor channel. If the number of sensors connected to the channel does not match with the set "Channel 1/2/3/4 sensors" setting, this parameter will go to the "Configuration fault" state.
Channel 2 sensor status			
Channel 3 sensor status			
Channel 4 sensor status			

Pick-up settings

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.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.4.25 - 222. Enabled Zone pick-up settings.

Name	Range	Step	Default	Description
Phase current pick-up	0.05...40.00 x I_n	0.01 x I_n	1.2 x I_n	The phase current measurement's pick-up value (in p.u.).
I0 input selection	• None • I01 • I02	-	None	Selects the residual current channel (I01 or I02).
Res.current pick-up	0.05...40.00 x $I0_n$	0.01 x $I0_n$	1.2 x $I0_n$	The residual current measurement's pick-up value (in p.u.).
Zone1/2/3/4 Enabled	• Disabled • Enabled	-	Disabled	Enables the chosen zone. Up to 4 zones can be enabled.

Name	Range	Step	Default	Description
Zone1/2/3/4 Ph. curr. Enabled	• Disabled • Enabled	-	Disabled	The phase overcurrent allows the zone to trip when light is detected.
Zone1/2/3/4 Res. curr. Enabled	• Disabled • Enabled	-	Disabled	The residual overcurrent allows the zone to trip when light is detected.
Zone1/2/3/4 Light 1 Enabled	• Disabled • Enabled	-	Disabled	Light detected in sensor channel 1 trips the zone.
Zone1/2/3/4 Light 2 Enabled	• Disabled • Enabled	-	Disabled	Light detected in sensor channel 2 trips the zone.
Zone1/2/3/4 Light 3 Enabled	• Disabled • Enabled	-	Disabled	Light detected in sensor channel 3 trips the zone.
Zone1/2/3/4 Light 4 Enabled	• Disabled • Enabled	-	Disabled	Light detected in sensor channel 4 trips the zone.
Zone1/2/3/4 Pres. 1 Enabled	• Disabled • Enabled	-	Disabled	Pressure detected in sensor channel 1 trips the zone.
Zone1/2/3/4 Pres. 2 Enabled	• Disabled • Enabled	-	Disabled	Pressure detected in sensor channel 2 trips the zone.
Zone1/2/3/4 Pres. 3 Enabled	• Disabled • Enabled	-	Disabled	Pressure detected in sensor channel 3 trips the zone.
Zone1/2/3/4 Pres. 4 Enabled	• Disabled • Enabled	-	Disabled	Pressure detected in sensor channel 4 trips the zone.
Zone1/2/3/4 DI Enabled	• Disabled • Light In • Current In	-	Disabled	Arc protection option card digital input function selection. "Light In" mode trips the zone when digital input is active. In "Current In" mode digital input must be active at the same time as any of the sensor channels for the zone to trip.

Read-only parameters

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

Table. 4.4.25 - 223. Information displayed by the function.

Name	Range	Description

I/I0 Arc> LN behaviour	• On • Blocked • Test • Test/Blocked • Off	Displays the mode of ARC block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
I/I0 Arc> condition	• Z1 Trip • Z1 Blocked • Z2 Trip • Z2 Blocked • Z3 Trip • Z3 Blocked • Z4 Trip • Z4 Blocked	Displays status of the protection function.
Sensor status	• Ph Curr Blocked • Ph Curr Start • Res Curr Blocked • Res Curr Start • Channel1 Light • Channel1 Pressure • Channel2 Light • Channel2 Pressure • Channel3 Light • Channel3 Pressure • Channel4 Light • Channel4 Pressure • Digital input • I/I0 Arc> Sensor 1 Fault • I/I0 Arc> Sensor 2 Fault • I/I0 Arc> Sensor 3 Fault • I/I0 Arc> Sensor 4 Fault • I/I0 Arc> I/O-unit Fault	Displays the general status of sensors.

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.

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.

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 the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the events.

Table. 4.4.25 - 224. Event messages.

Event block name	Event names
ARC1	Zone 1...4 Trip ON
ARC1	Zone 1...4 Trip OFF
ARC1	Zone 1...4 Block ON
ARC1	Zone 1...4 Block OFF
ARC1	Phase current Blocked ON
ARC1	Phase current Blocked OFF
ARC1	Phase current Start ON
ARC1	Phase current Start OFF
ARC1	Residual current Blocked ON
ARC1	Residual current Blocked OFF
ARC1	Residual current Start ON
ARC1	Residual current Start OFF
ARC1	Channel 1...4 Light ON
ARC1	Channel 1...4 Light OFF
ARC1	Channel 1...4 Pressure ON
ARC1	Channel 1...4 Pressure OFF
ARC1	DI Signal ON
ARC1	DI Signal OFF
ARC1	I/I0 Arc> Sensor 1...4 Fault ON
ARC1	I/I0 Arc> Sensor 1...4 Fault OFF
ARC1	I/I0 Arc> I/O-unit Fault ON
ARC1	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. 4.4.25 - 225. Register content.

Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
Phase A current	Trip current
Phase B current	
Phase C current	
Residual current	
Active sensors	1...4
Setting group in use	Setting group 1...8 active

4.5 Control functions

4.5.1 Common signals

Common signals function has all protection function start and trip signals internally connected to Common START and TRIP output signals. When any of the activated protection functions generate a START or a TRIP signal, Common signals function will also generate the same signal.

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. 4.5.1 - 226. General settings of the function.

Name	Range	Default	Description
Common force status to	• Normal • Start • Trip	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.

Common signals function has all START and TRIP signals of protection functions internally connected to Common START and TRIP output signals. But it is also possible to assign extra signals to activate Common START and TRIP.

Table. 4.5.1 - 227. Common signals extra inputs.

Name	Description
Common Start In	Assign extra signals to activate common START signal. Please note that all protection function START signals are already assigned internally to Common START.
Common Trip In	Assign extra signals to activate common TRIP signal. Please note that all protection function TRIP signals are already assigned internally to Common TRIP.

Read-only parameters

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

Table. 4.5.1 - 228. Information displayed by the function.

Name	Range	Description
Common signals condition	• Normal • Start • Trip	Displays status of the function.

Function blocking

Common signals function itself doesn't have blocking input signals. Blocking of tripping should be done in each protection function settings.

Events

The common signals function (abbreviated "GNSIG" in event block names) generates events from the status changes in the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the START and TRIP events.

The events triggered by the function are recorded with a time stamp.

Table. 4.5.1 - 229. Event messages.

Event block name	Event names
GNSIG	Common Start ON
GNSIG	Common Start OFF
GNSIG	Common Trip ON
GNSIG	Common Trip OFF

4.5.2 Automatic voltage regulator (90)

The automatic voltage regulator (abbreviated AVR in this document) is used for controlling secondary side voltage of the 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. 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 operating windows for voltage raise and lower commands. Both raise and lower commands have two operating stages with different operation voltage levels and operation times. First stage of both voltage and raise commands have common definite time delay for operation. Second stage Voltage raise and lower commands have a common definite and inverse operating time, whereas undervoltage the in-built overcurrent function blocks all commands to raise or lower the voltage. 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 blocking signal and the setting group selection control the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running. The function has a total of eight (8) setting groups available.

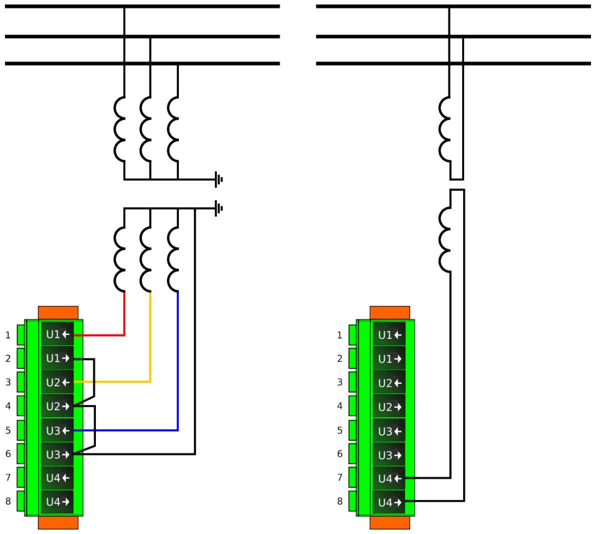
The following examples present how to configure the automatic voltage regulator.

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. 4.5.2 - 129. Two connection options for voltage measurement.



The connection on the left shows the voltage transformer module 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).

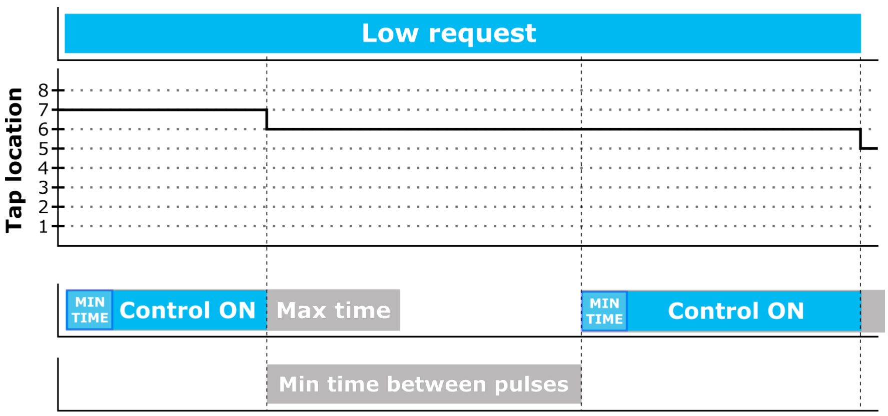
The general settings also include various online measurements and calculations from the AVR function as well as the location of the tap changer. Information about the settings and AVR status can be found later in this document.

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. 4.5.2 - 130. Control pulse timing settings.



First, the user sets the minimum and maximum times for control pulses. If the tap changes location 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 even if tap location hasn't changed. 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. There are several different ways to connect tap position indication:

- mA input cards installed to the AQ-200 unit
- External mA input units (ADAM-4016) connected to AQ-200 units RS-485 serial port
- Binary coded inputs (with digital inputs)
- BCD coded inputs (with digital inputs)
- Measuring resistance with RTD channel
- Measuring voltage with a digital input

Setting up tap position indication for all of the above mentioned options are described below.

mA input

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 total (Raise voltage steps + lower voltage steps)	18 steps
Tap center (Nominal voltage 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. 4.5.2 - 131. Connecting mA input to option card.

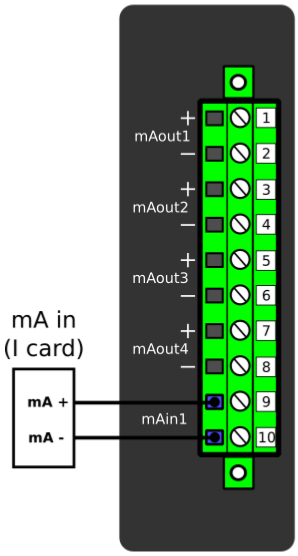
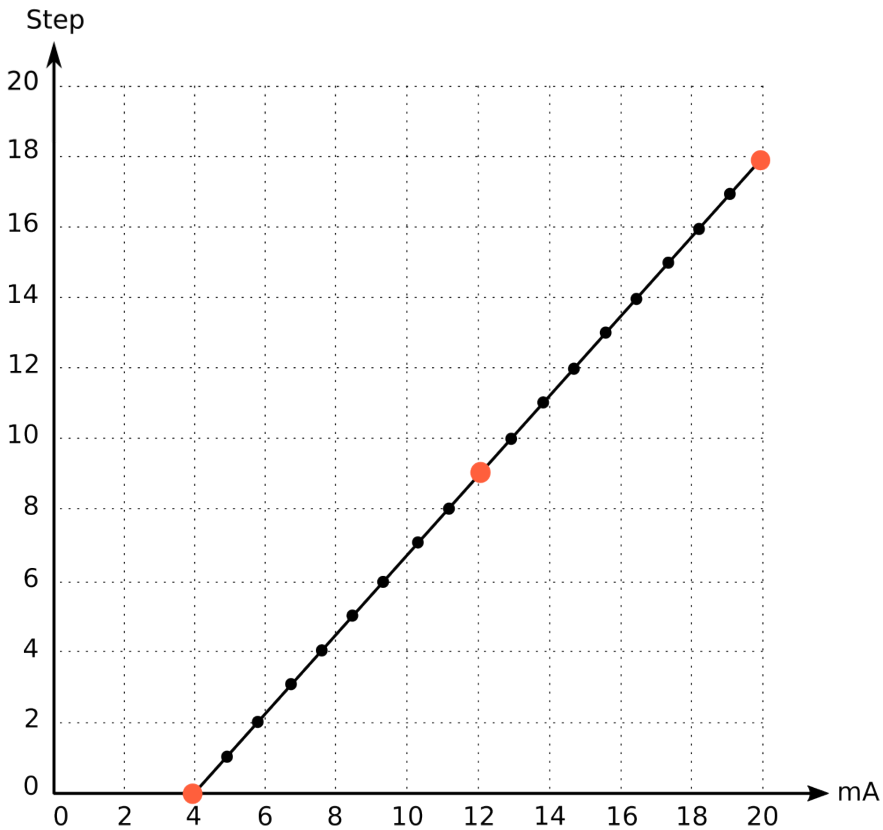
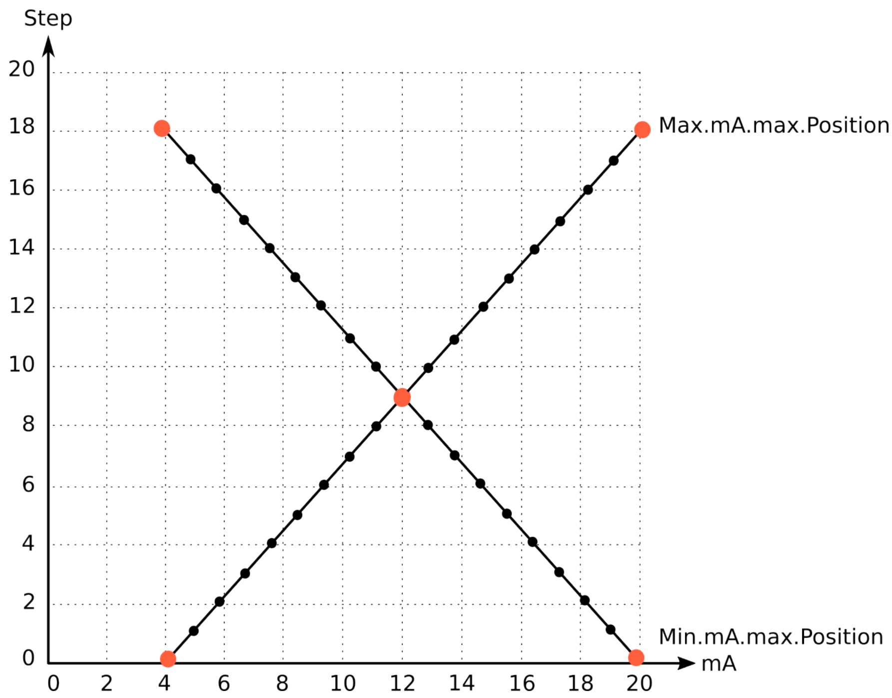


Figure. 4.5.2 - 132. Tap position indication (according to the example settings).



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.

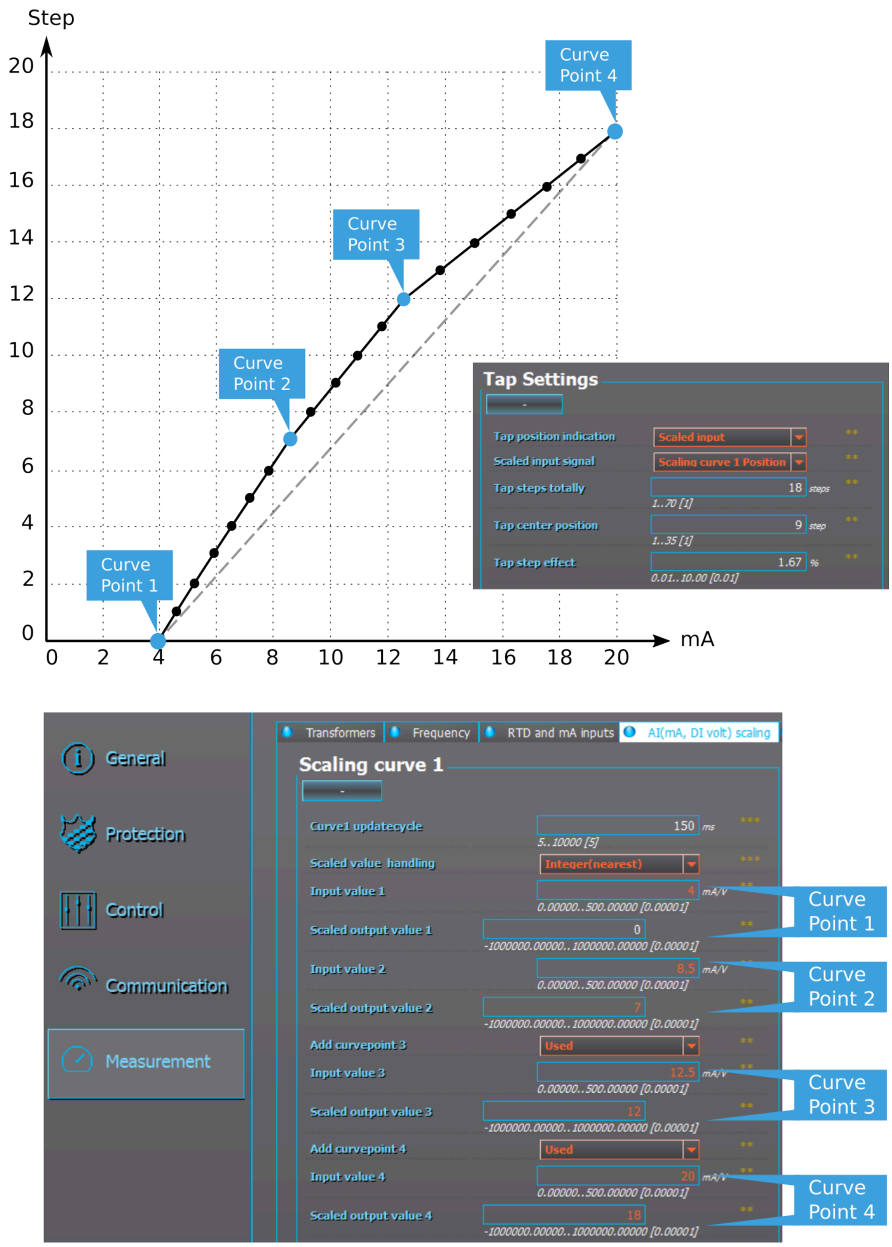
Figure. 4.5.2 - 133. Switching the tap position indication.



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 at *Measurement → AI (mA, DI volt) scaling*. 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. 4.5.2 - 134. 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.

Binary coded inputs

Sometimes tap position indication is done by using multiple digital inputs. With binary coded inputs any one decimal numeral can be represented by a five-bit pattern. You can use binary input code by setting the "Tap position indication" to "Binary coded inputs" at the Tap settings. The digital inputs are then defined in the regulator's menu at *Control → Control functions → Voltage regulator → IO → Input signal control*. Up to five digital inputs can be set for binary input coding, and up to 31 positions can be indicated with binary coding (see the image below).

Binary code input	5	4	3	2	1	Decimal digit
	0	0	0	0	0	0
	0	0	0	0	1	1
	0	0	0	1	0	2
	0	0	0	1	1	3
	0	0	1	0	0	4
	0	0	1	0	1	5
	0	0	1	1	0	6
	0	0	1	1	1	7
	0	1	0	0	0	8
	0	1	0	0	1	9
	0	1	0	1	0	10
	0	1	0	1	1	11
	0	1	1	0	0	12
	0	1	1	0	1	13
	0	1	1	1	0	14
	0	1	1	1	1	15
	1	0	0	0	0	16
	1	0	0	0	1	17
	1	0	0	1	0	18
	1	0	0	1	1	19
	1	0	1	0	0	20
	1	0	1	0	1	21
	1	0	1	1	0	22
	1	0	1	1	1	23
	1	1	0	0	0	24
	1	1	0	0	1	25
	1	1	0	1	0	26
	1	1	0	1	1	27
	1	1	1	0	0	28
	1	1	1	0	1	29
	1	1	1	1	0	30
	1	1	1	1	1	31

BCD-coded digital inputs

Just like binary coded input position indication, "Binary coded decimal" (BCD) position indication also uses multiple digital inputs. But they are not interchangeable. Difference between the two is the numbering format. Whereas binary coded mode 4-bit hexadecimal number is valid up to F_{16} representing binary 1111_2 (decimal 15), BCD numbers stop at decimal 9 (1001_2 in binary). Because of this decimal 10 is 1 0000_2 in binary. 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 *Control → Control functions → Voltage regulator →IO → Input signal control*. Up to five digital inputs can be set for BCD coding, and up to 18 positions can be indicated with BCD coding (see the image below).

BCD code input	5	4	3	2	1	Decimal digit
	0	0	0	0	0	0
	0	0	0	0	1	1
	0	0	0	1	0	2
	0	0	0	1	1	3
	0	0	1	0	0	4
	0	0	1	0	1	5
	0	0	1	1	0	6
	0	0	1	1	1	7
	0	1	0	0	0	8
	0	1	0	0	1	9
	1	0	0	0	0	10
	1	0	0	0	1	11
	1	0	0	1	0	12
	1	0	0	1	1	13
	1	0	1	0	0	14
	1	0	1	0	1	15
	1	0	1	1	0	16
	1	0	1	1	1	17
	1	1	0	0	0	18

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. 4.5.2 - 135. Example scaling for tap position indication with RTD measurement.

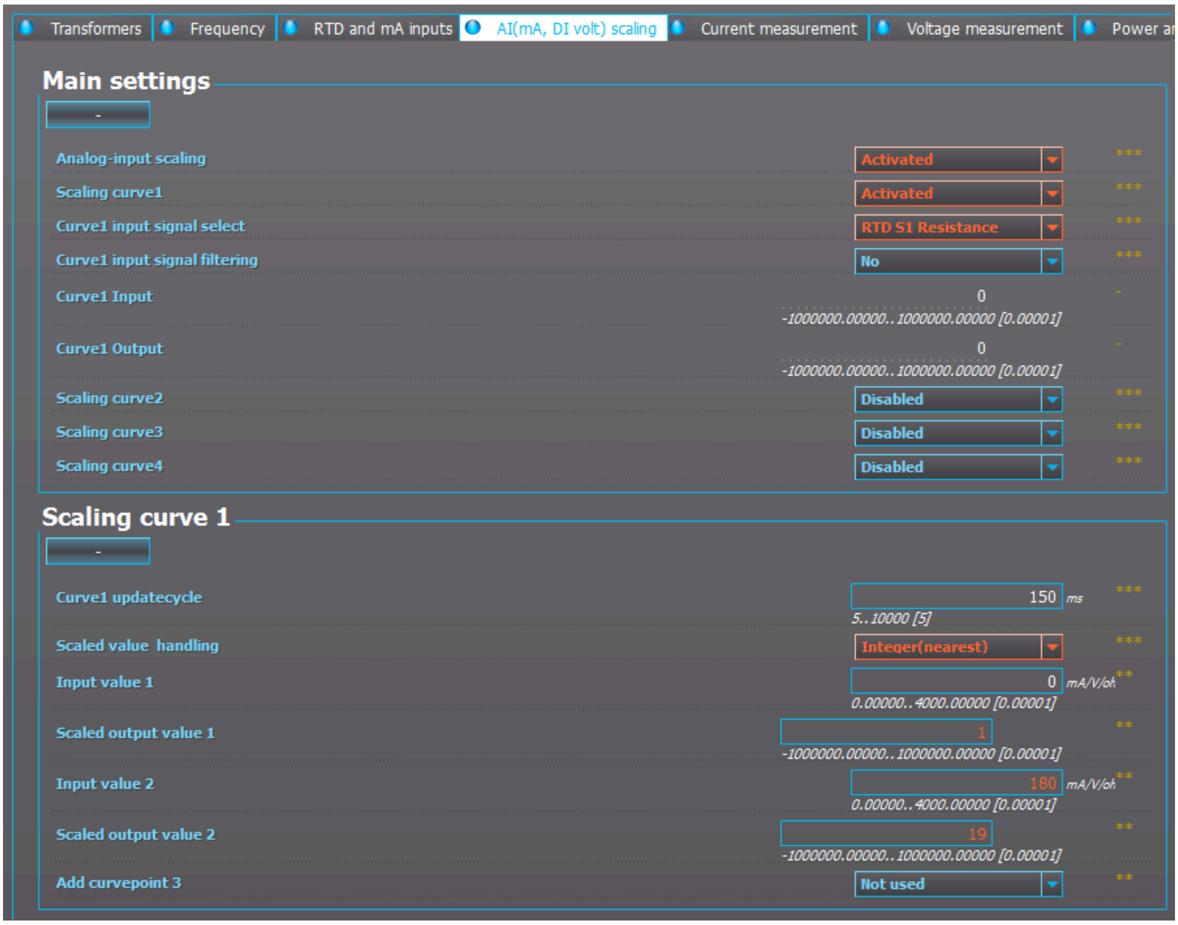
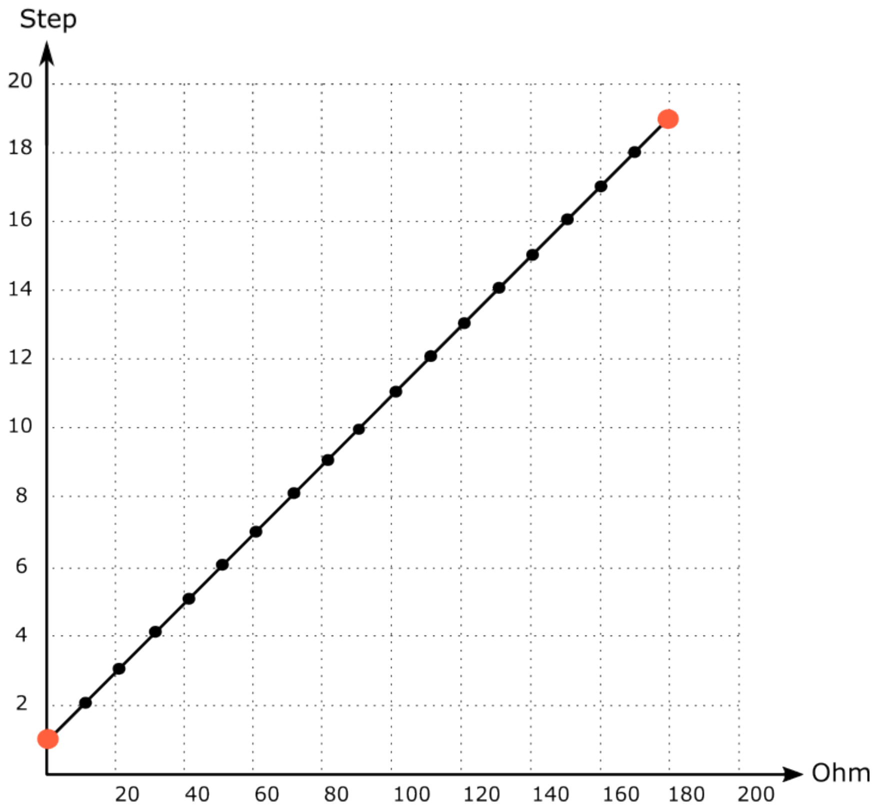


Figure. 4.5.2 - 136. Result of the above-mentioned example.



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, binary coding 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 voltage 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:

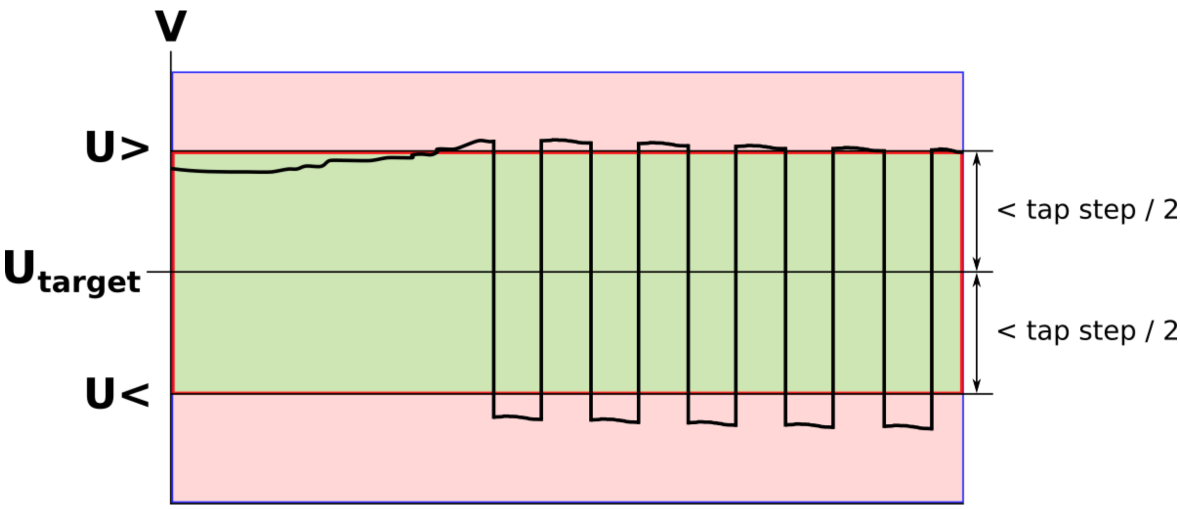
$$U >/<_{window} = 1.2 \times tap\ step\ effect\ \%$$

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 regulating 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.

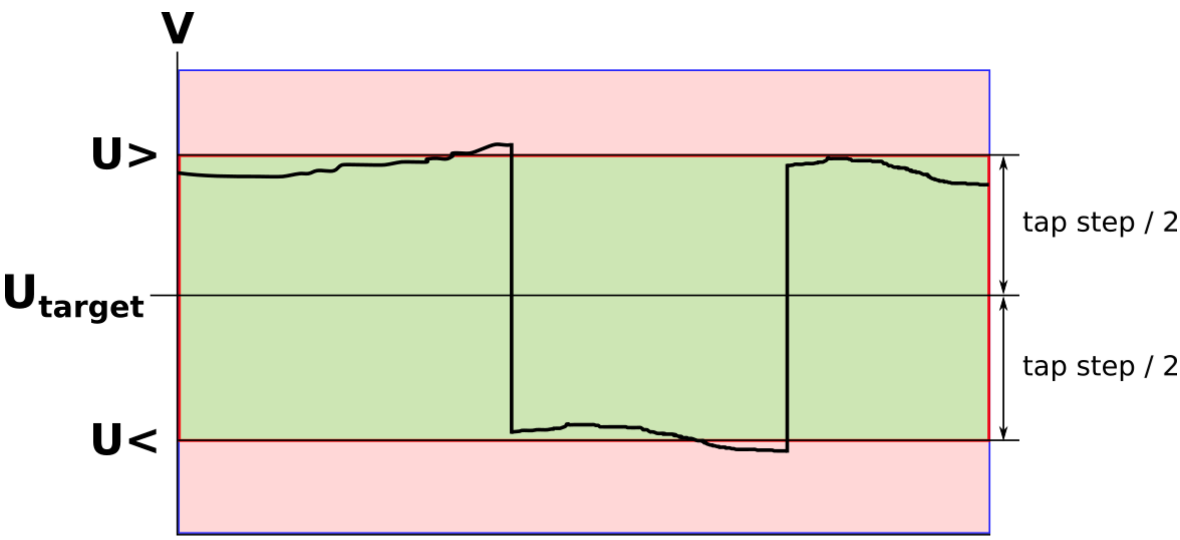
The following three images present various situations with the setting of the voltage window.

Figure. 4.5.2 - 137. Tight voltage window (window not reached).



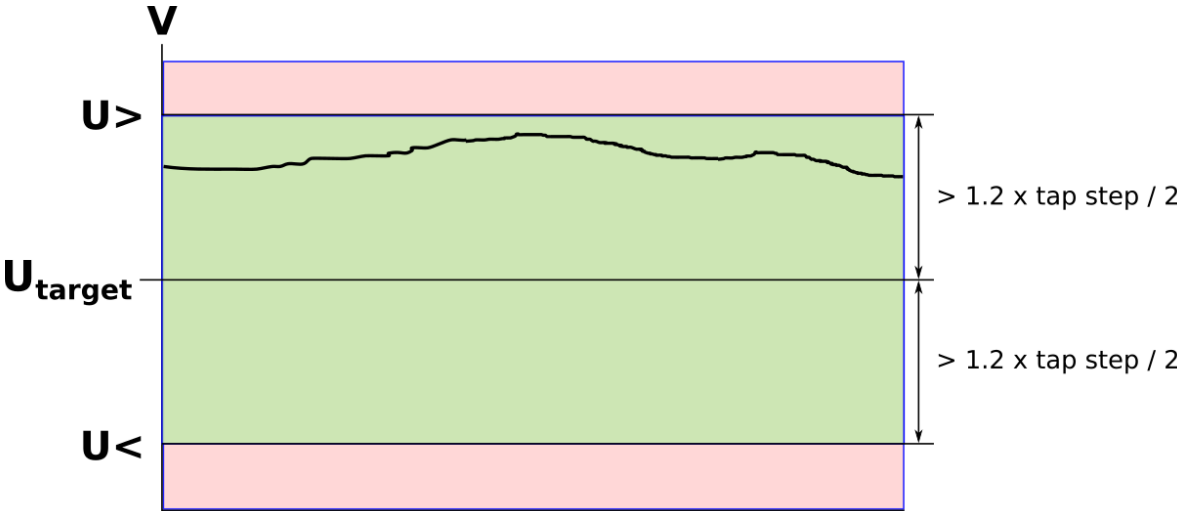
In this example situation the set voltage window is too tight compared to the tap effect. The AVR cannot reach the target window and thus lowers the voltage. Eventually a stable voltage may be found but the next tap change request will cause similar fluctuation and the cycle begins again.

Figure. 4.5.2 - 138. 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. 4.5.2 - 139. Voltage window according to the recommendation.

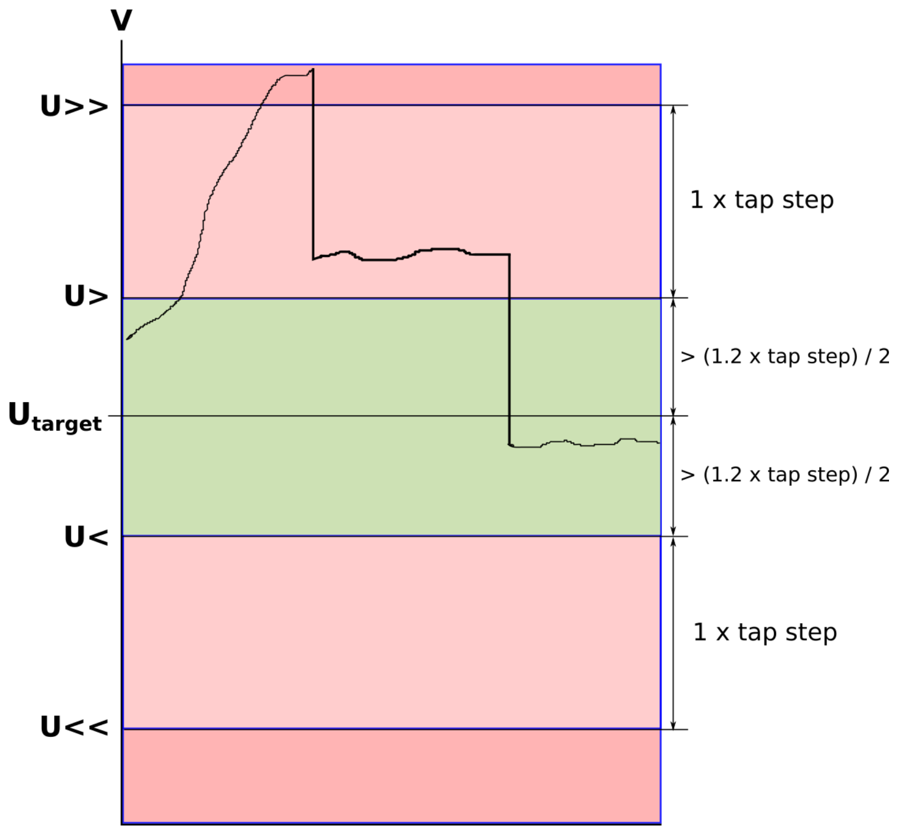


In this example the voltage window limits are set according to the recommendation: the set window is 20 % bigger than the tap step effect. This ensures that after tap changing the voltage it's not too near the opposite voltage window limit. If the user wants more sensitivity, the voltage window can be 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. 4.5.2 - 140. Second voltage window two tap steps from the first voltage window.



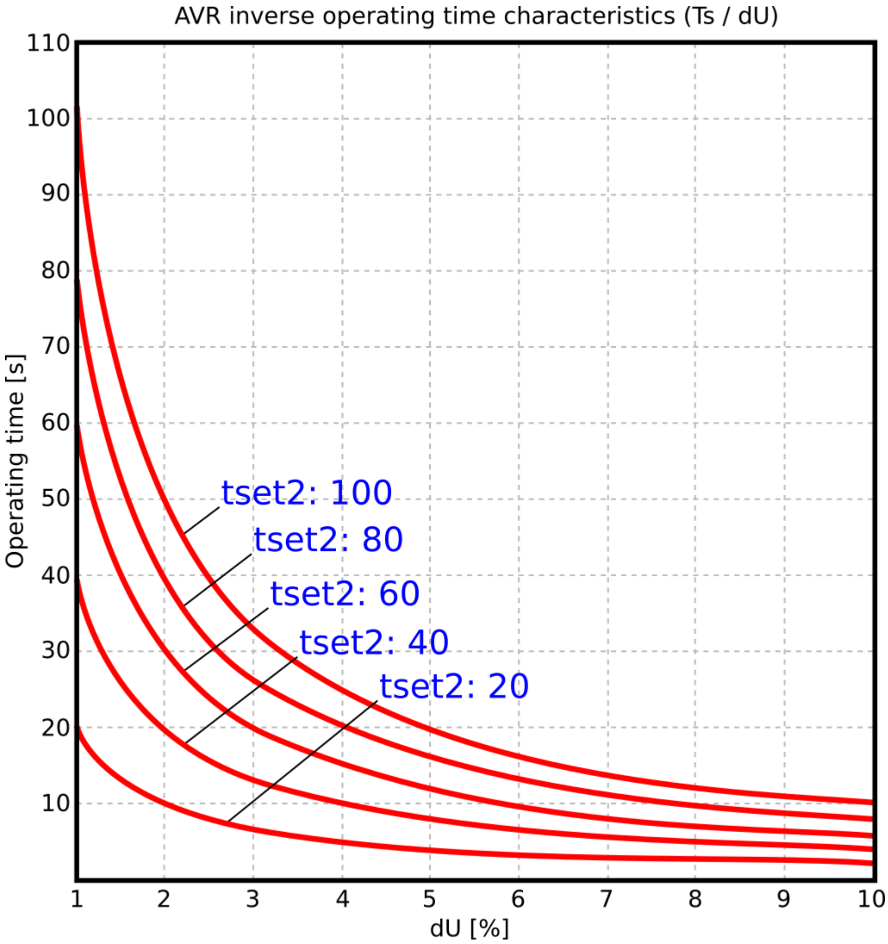
It is recommended that the operating time for the second (fast) window is in inverse mode, although it can also be set to the definite operating mode. Therefore, the more the measured voltage exceeds the threshold, the faster the operating time will be.

The AVR inverse operating time is calculated with the following equation:

$$\text{Operating time} = \frac{U \gg / \ll \ time\ delay}{|\Delta U\%| * 100 * Tap\ effect\%}$$

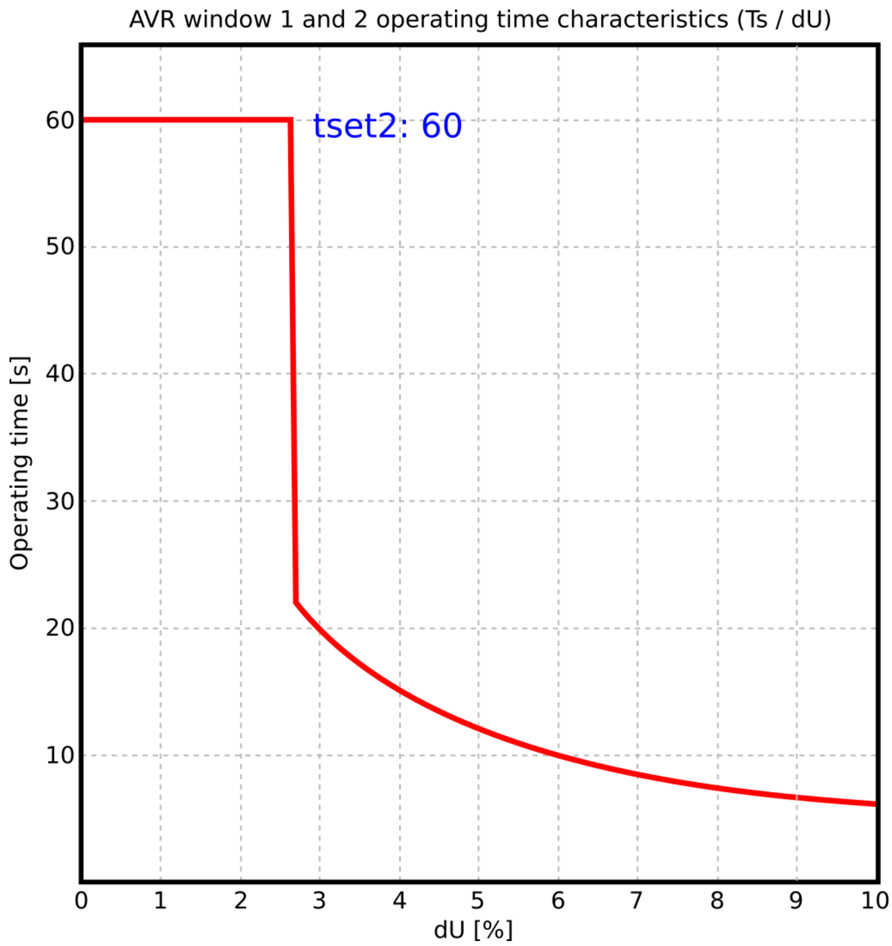
For example, if *U >>/<<< time delay* has been set to 40 seconds and the measured voltage difference from the set target is 4 %, using the formula above the operating time can be determined to be 10 seconds (40s / 4)

Figure. 4.5.2 - 141. 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. 4.5.2 - 142. 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:

$$\text{U} >/< \text{pick-up} = \frac{(1.2 \times tap\ step\ effect)}{2} = \frac{(1.2 \times 1.67\ \%)}{2} \approx 1\ \%$$

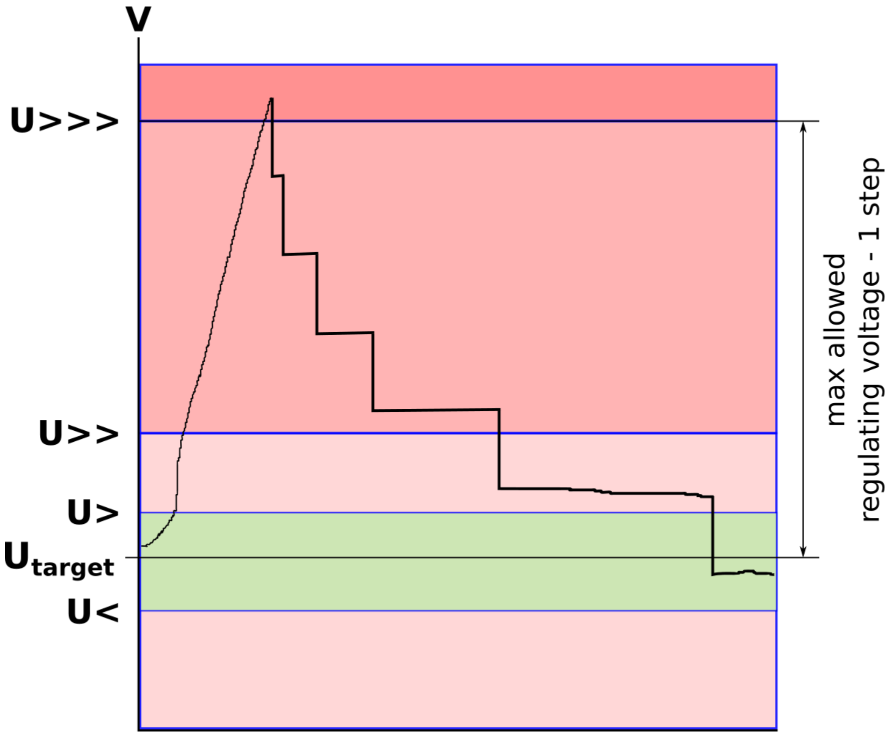
➔ operating time is 60 seconds

$$\text{U} \gg/\ll \text{pick-up} = U >< pick\text{-}up + tap\ step\ effect = 1\ \% + 1.67\ \% \approx 2.67\ \%$$

➔ operating time is 60 seconds

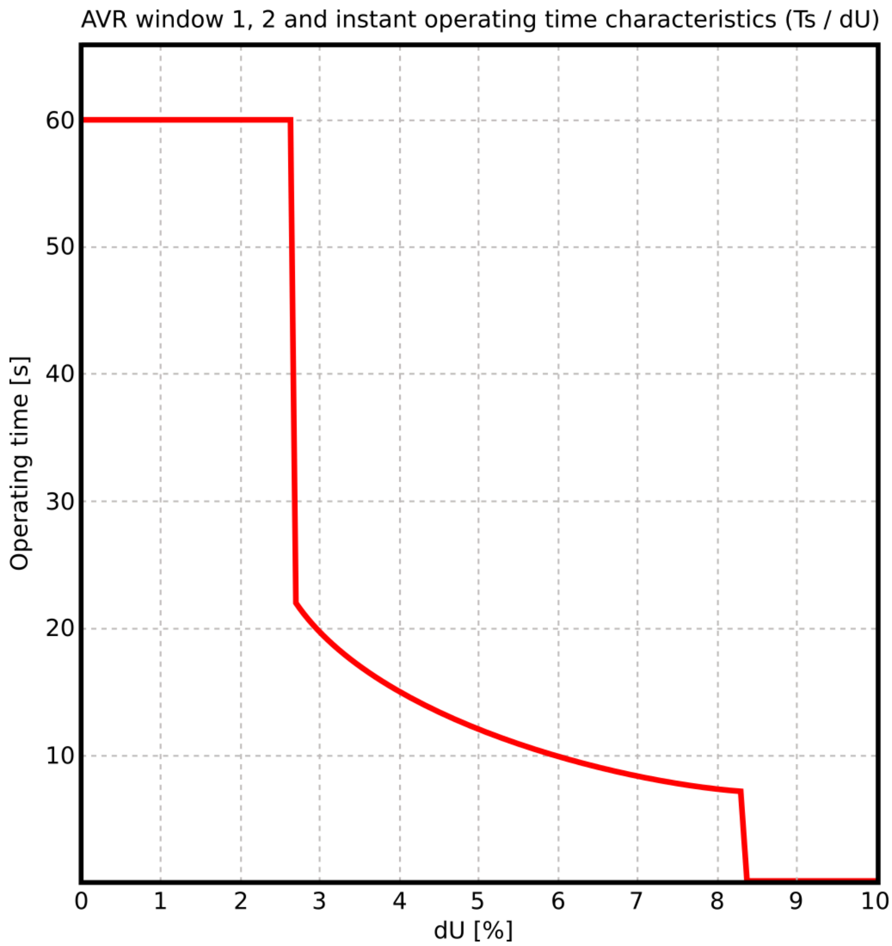
When a very high overvoltage occurs, the regulator instantly lowers the voltage without any other delays but the given minimum time between control pulses. This lowering function remains in use until the measured voltage is below the set instant low threshold level (U>>> Instant setting). After this level is reached, the time characteristics of the corresponding window calculate the consecutive time delays until the desired target window is reached.

Figure. 4.5.2 - 143. Instant low command with two time-delayed windows.



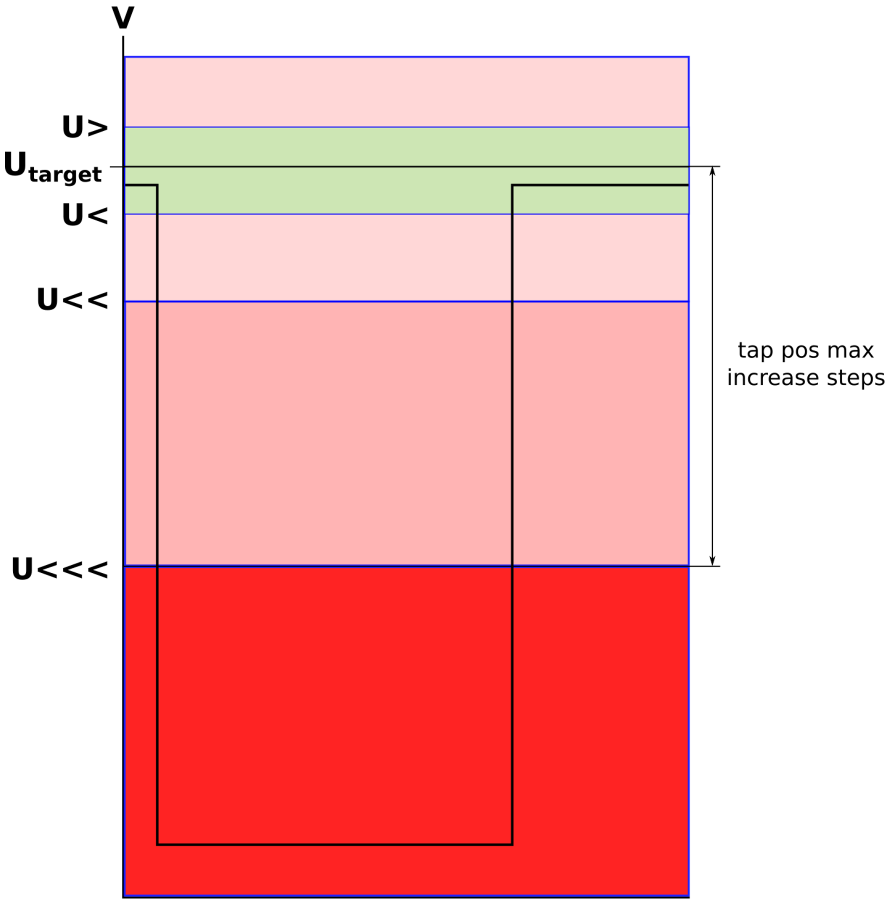
The pick-up setting recommendation for the instant low function is equal to the the maximum allowed overvoltage subtracted by the tap effect. This way there should not be situations where the voltage is allowed to stay above the maximum allowed voltage for a long time. For example, if the maximum allowed 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. 4.5.2 - 144. 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. 4.5.2 - 145. 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 protection device or transformer protection device (GOOSE or a wired signal to the AVR's digital input).

Measured input

The AVR measures fundamental frequency component of phase-to-phase voltages for supervising the voltage level. Fundamental frequency component of phase currents can be used for overcurrent blocking.

Table. 4.5.2 - 230. Measurement inputs of the automatic voltage regulator function.

Signal	Description	Time base
U_1 RMS	Fundamental frequency component of voltage channel U_1/V	5ms
U_2 RMS	Fundamental frequency component of voltage channel U_2/V	5ms

Signal	Description	Time base
U_3 RMS	Fundamental frequency component of voltage channel U_3/V	5ms
U_4 RMS	Fundamental frequency component of voltage channel U_4/V	5ms
I_{L1} RMS	Fundamental frequency component of phase L1 (A) current	5ms
I_{L2} RMS	Fundamental frequency component of phase L2 (B) current	5ms
I_{L3} RMS	Fundamental frequency component of phase L1 (C) current	5ms

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. 4.5.2 - 231. General setting parameters.

Name	Range	Step	Default	Description
Vreg LN mode	• On • Blocked • Test • Test/Blocked • Off	-	On	Set mode of VRG block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
Vreg LN behaviour	• On • Blocked • Test • Test/Blocked • Off	-	-	Displays the mode of VRG block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
Vreg settings condition	• U>> set too low • U< set too high • U> set higher than U>> • U< set lower than U<< • U>>> set too low • U<<< set too high • VT selection not ok	-	-	When opened displays the internal information about the settings. If the value differs from 0, the settings are not correct.

Name	Range	Step	Default	Description
Vreg condition	• Raise command on • Lower command on • Operation blocked • Output control blocked • U<<< block on • I> block on • Tap on highlimit • Tap on lowlimit • Operation blocked • U>/< pick-up on • U>>/<< pick-up on • Control wait time on • Manual control mode on	-	-	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	• - • Fine tune decrease • Fine tune increase • Low set decrease • High set decrease • Instant decrease • Low set increase • High set increase	-	-	Displays the timer, when the AVR is counting time. Time left to operation is indicated by "Time left to operation" parameter.
Time left to operation	0.000…1800.000s	0.005s	-	Displays the time the counter has left before action. "Vreg timer active" displays which timer is counting down.
Voltage now	0.00…140.00%U_n	0.01%U_n	-	Displays the measured reference voltage.
Voltage difference to set target	0.00…140.00%U_n	0.01%U_n	-	Displays the difference between the measured reference voltage and the set target voltage.
Voltage set now to	-50 000…50 000V_{pri}	0.01V_{pri}	-	Displays the primary voltage deviation. Based on the location of the tap changer. Calculation formula is "Absolute tap location" times "Tap step effect".
U>>> (instant) setting	0.00…140.00%	0.01%	-	Displays the set instant stage (compared to the nominal 100 % level).

Name	Range	Step	Default	Description
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<<< (block) setting	0.00…140.00%	0.01%	-	Displays the set undervoltage blocking limit.
Voltage measurement	• U12 • U23 • U31 • U4 input	-	U12	Displays the selected voltage. Please check that the selected voltage input is correct.
Voltage measurement condition	• Not configured • System U12 • System U23 • System U31 • VT4 meas U12 • VT4 meas U23 • VT4 meas U31 • VT4 conf not ok	-	-	Displays which voltage is used by the function.
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	• No • Yes	-	No	Indicates when the tap changer has reached the maximum voltage high position.
Tap changer on low border	• No • Yes	-	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. 4.5.2 - 232. Control settings parameters.

Name	Range	Step	Default	Description
Control mode	• Auto • Manual	-	Auto	Displays the control mode: automatic or manual.
Max control pulse length	0.000…1800.000s	0.005s	2.000s	Sets the maximum time the tap control's output contact can be closed.
Min control pulse length	0.000…1800.000s	0.005s	2.000s	Sets the minimum time the tap control's output contact must be closed.
Min time between pulses	0.000…1800.000s	0.005s	0.500s	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. 4.5.2 - 233. Tap settings parameters.

Name	Range	Step	Default	Description
Tap position status ("Tap position indication")	• Select • mA internal input 7 • mA internal input 8 • mA external input • Scaled input • Binary coded inputs • mAIn1 (card 1) • mAIn2 (card 2) • BCD coded inputs	-	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 ADAM 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" and "Binary coded inputs" options refer to the digital inputs. The "mAIn x" options are the mA inputs included in the mA input card.
Tap position indication setting	• Not selected • Set Ok • Wrong setting • Meas.Quality Fault.	-	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	• CH0 • CH1 • CH2 • CH3 • CH4 • CH5 • CH6 • CH7	-	CH0	Selects the external mA input channel. This setting is only visible when "mA external input" is the selected input mode.

Name	Range	Step	Default	Description
Scaled input signal	• Scaling curve 1 (mA) • Scaling curve 2 (mA) • Scaling curve 3 (mA) • Scaling curve 4 (mA) • Scaling curve 1 (position) • Scaling curve 2 (position) • Scaling curve 3 (position) • Scaling curve 4 (position)	-	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	• Not selected • Set Ok • Wrong setting • Meas.Quality Fault.	-	-	Indicates the status of tap position indication settings. A read-only parameter.
Tap steps total (Raise voltage steps + lower voltage steps)	1…70	1	18	Defines the number of steps from minimum to maximum.
Tap center (Nominal voltage position)	1…35	1	9	Defines the position of the nominal, non-regulated tap location.
Tap step effect	0.01…10.00%	0.01%	1.67%	Defines the effect of a step (in percentage based on the nominal voltage).
Tap step voltage effect	0.00…5000.00V_{pri}	0.01V_{pri}	0V_{pri}	Displays the effect of one tap step on the primary voltage.
Tap maximum decrease	-140.00…0.00%	0.01%	0%	Displays the maximum voltage decrease from the nominal position.
Tap maximum increase	0.00…140.00%	0.01%	0%	Displays the maximum voltage increase from the nominal position.
Tap control band	0.00…140.00%	0.01%	0%	Displays the tap changer's control band.
Tap position indication	• Max.mA.max.Pos. • Min.mA.max.Pos	-	Max.mA.max.Pos	Selects the hightest tap position, the maximum or the minimum value of mA measurement. This setting is not visible when "BCD coded inputs" or "Binary coded inputs" is the selected input mode.
mA input low range	0.000…20.000mA	0.001mA	4.000mA	Sets the minimum tap position measurement value. This setting is not visible when "BCD coded inputs" or "Binary coded inputs" is the selected input mode.

Name	Range	Step	Default	Description
mA input high range	0.010…20.000mA	0.001mA	20.000mA	Sets the maximum tap position measurement value. This setting is not visible when "BCD coded inputs" or "Binary coded inputs" is the selected input mode.
Tap step in mA	0.000…20.000mA	0.001mA	0mA	Sets the effect of one tap step on the mA measurement. This setting is not visible when "BCD coded inputs" or "Binary coded inputs" is the selected input mode.
mA input now (from the measurement)	0.000…20.000mA	0.001mA	-	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…20.000mA	0.001mA	-	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. 4.5.2 - 234. 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	• - • Clear	Clears the statistics and resets the counters to zero.

Active settings

These settings define the AVR's regulating behavior.

Table. 4.5.2 - 235. Active setting parameters.

Name	Range	Step	Default	Description
Voltage measurement	• U12 • U23 • U31 • U4	-	U12	Selects the measured system voltage from the UL12, UL23, UL31 and U4 inputs.
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	• Not in use • In use	-	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 "voltage high" 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 "voltage low" 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…1800.000s	0.005s	60.000s	Sets the operating time delay before a regulating command is sent for the low-set voltage window's threshold deviation. This setting is only visible, when the "U>/< window in use" parameter is activated.
U>>/<< window in use	• Not in use • In use	-	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 "voltage high" 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 "voltage low" 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	• Definite • Integral	-	Integral	Selects the time delay mode for the high-set voltage window.
U>>/<< time delay (DT/Multiplier)	0.000…1800.000s	0.005s	60.000s	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	• Not in use • In use	-	Not in use	Selects whether or not the instant low stage is in use.

Name	Range	Step	Default	Description
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. When measured voltage is under this level, tap control is blocked.
Internal OC blocking	• Not in use • In use	-	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 needs to be blocked externally, it can be done with digital inputs, logical signals or 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. This type of blocking is intended to be used for blocking tap changer that is in active use. The second one only blocks the output contacts while the control algorithm is still operational. This type of blocking can be used to test the operation of algorithm and event recording without physically controlling the tap changer.

Table. 4.5.2 - 236. 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.

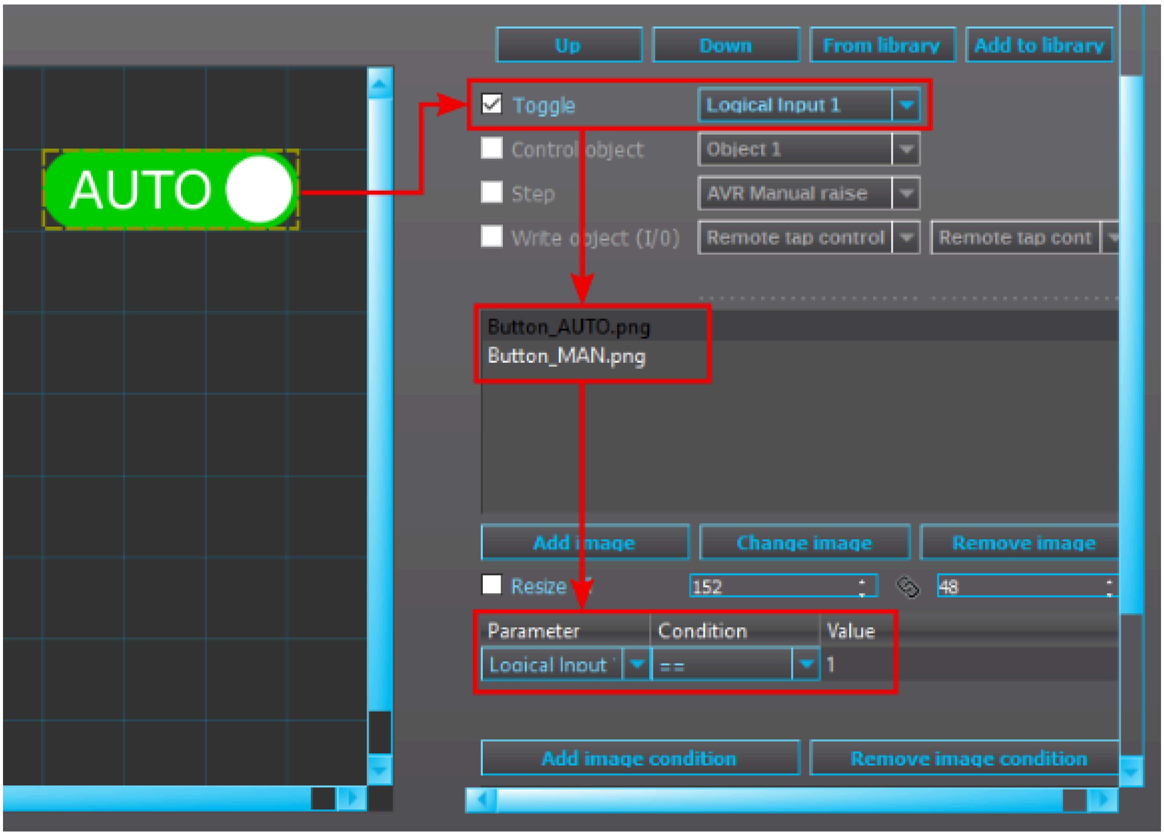
Table. 4.5.2 - 237. Output signals.

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.

Name	Description
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 device, 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 device, this virtual button can be controlled in through the device HMI panel: choose it with the Ctrl 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 device is not capable of prohibiting 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 the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

Table. 4.5.2 - 238. Event messages.

Event block name	Description
VRG1	Tap Raise command On
VRG1	Tap Raise command Off
VRG1	Tap Lower command On
VRG1	Tap Lower command Off
VRG1	Block operation On
VRG1	Block Operation Off
VRG1	Block Output commands On
VRG1	Block Output commands Off
VRG1	Low voltage blocking On
VRG1	Low voltage blocking Off
VRG1	Overcurrent blocking On
VRG1	Overcurrent blocking Off
VRG1	Tap on highlimit On
VRG1	Tap on highlimit Off
VRG1	Tap on lowlimit On
VRG1	Tap on lowlimit Off
VRG1	Operation blocked On
VRG1	Operation blocked Off
VRG1	U>/< Start On
VRG1	U>/< Start Off
VRG1	U>>/<< Start On
VRG1	U>>/<< Start Off
VRG1	Control wait time On
VRG1	Control wait time Off
VRG1	Manual control mode
VRG1	Automatic control mode
VRG1	Tap raise request On
VRG1	Tap raise request Off
VRG1	Tap lower request On
VRG1	Tap lower request Off

VRG1	Tap control circuit failure On
VRG1	Tap control circuit failure Off
VRG1	Tap difference failure On
VRG1	Tap difference failure Off
VRG1	Parallel communication failure On
VRG1	Parallel communication failure Off
VRG1	Transformer independent control mode
VRG1	Transformer parallel control mode
VRG1	Tranformer operates as Master
VRG1	Tranformer operates as Follower
VRG1	Circulating reactive current mode
VRG1	Master and follower mode

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. 4.5.2 - 239. Register content.

Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
Voltage now	Voltage at the moment of event
Tap now	Target voltage
Target volt	Target voltage
Control mode	• Auto • Manual
Setting group in use	Setting group 1...8 active

4.5.3 Parallel voltage regulator

Automatic voltage regulator function is able to control up to four transformer tap changers in parallel with plug and play GOOSE configuration. Tap control can be switched between parallel and independent control modes. Mimic can be set up to display feedback from each transformer. Tap control can be either in "Master & follower" mode or "Circulating current" control mode.

Setting up communication between the devices

Each voltage regulating device must have a unique ID number chosen. This can be done at *Control → Control functions → Voltage regulator* menu with *Local paraller transformer ID* parameter. Define the total number of voltage regulating devices with *Parallel group relays* parameter. If the number of detected voltage regulating devices doesn't match with *Parallel group relays* setting, an alarm will be issued.If there are four voltage regulating devices, the devices must be given an ID from 1 to 4.

Enable IEC61850 at *Communication → Protocols → IEC61580/GOOSE → IEC61850* with *Enable IEC61850* parameter. Then enable GOOSE subscriber at *Communication → Protocols → IEC61580/ GOOSE → GOOSE* with *GOOSE subscriber enable* parameter and then reconfigure GOOSE with *Reconfigure GOOSE* parameter.

If every voltage regulating device has been set up and communication link is connected, the devices should now be communicating with each other.

General settings

This chapter describes parameters and settings for parallel tap changer applications. Basic settings for single tap changer applications are described in chapter titled "Automatic voltage regulator (90)".

Table. 4.5.3 - 240. General setting parameters.

Name	Range	Step	Default	Description
CT selection	• CT1 • CT2	-	CT1	Circulating current measurement mode requires current negative sequence component measurement, which is achieved by connecting three phase currents to the device CT inputs. It is necessary to choose which side CT is used for tap changer circulating current measurement.
Parallel mode	• Parallel mode • Independent mode	-	Independent mode	As a default, the device operates as an independent tap controller unit. In independent mode, all parallel operation related settings are hidden.
Control mode	• Auto • Manual	-	Auto	Whether automatic tap control is in use or not. This setting can be bypassed with logic programming.
Local parallel hierarchy	• Master & follower • Circulating reactive current	-	Master & follower	Parallel control method selection. In "master follower" mode, the master operates as an independent transformer and the follower operates based on leading device operations. In "circulating reactive current" mode, all devices are controlling based on a formula that is trying to minimize the circulating current and voltage difference between parallel controlled transformers.
Status	• Follower • Master	-	-	Follower device is trying to mimic either master device tap position or tap +/- control pulses. There can be only one master device selected at a time. When communication is operational between the devices, “only one master” is monitored automatically and it is not possible to choose two masters simultaneously.

Name	Range	Step	Default	Description
Follow operation	• Follow master raise/lower commands • Follow master tap position	-	Follow master raise / lower commands	Follower devices are giving tap +/- commands based on either master tap position or master raise/lower commands.
Allowed tap difference	1-9 steps	-	2 steps	In case master device operates and following device leaves behind for more than allowed tap difference, a tap difference error will take place if maximum allowed tap difference time is exceeded.
Maximum allowed tap difference time	0.0...1800.0 s	0.1 s	60 s	Please see the description above (Allowed tap difference).
Transformer rated apparent power (Sn)	1.0...400.0 MVA	0.1 MVA	40.0 MVA	These values are used for calculating transformer Xk value. Xk value is used in circulating current control mode.
Transformer rated voltage (Un)	1.0...400.0 kV	0.1 kV	20.0 kV	
Transformer short circuit impedance (Zk%)	1.0...20.0 %	0.1 %	3.0 %	
Local parallel transformer ID	1...9	1	N/A	Device ID. Each voltage regulating device must have a unique ID number to operate correctly and without communication alarm. Always start choosing device IDs from 1 and proceed accordingly with second, and then third optional third device etc.
Parallel group relays	• Relay IDs 1 - 2 • Relay IDs 1 - 3 • Relay IDs 1 - 4	-	Relay IDs 1 - 2	Choose how many parallel voltage regulating devices are used in application. If more or less, than the actual used amount is selected, communication alarm will activate.
Tap control failure blocking	• Disabled • Enabled	-	Disabled	Once enabled, a possible tap control failure will disable automatic tap control in "Master & follower" mode.
Clear tap control failure	• - • Clear	-	-	Displays the set undervoltage blocking limit.

Settings

Table. 4.5.3 - 241. General setting parameters.

Name	Range	Step	Default	Description
U>/< fast tap recontrol delay T2 in use	• Not in use • In use	-	Not in use	Activate fast tap re-control for independent and master follower schemes. Fast re-control delay is used if first control command is not sufficient to achieve proper system voltage level.
U> setting (+UTGT)	0.10...30.00 %Un	0.01 %Un	1.50 %Un	UTGT setting window operates as a pickup for an independent transformer. In master/follower mode, the master device operates as an independent transformer device and uses UTGT setting for operation. Follower device follows master activity. In circulating reactive current mode, both UTGT+/- and B+/- settings are used.
U< setting (-UTGT)				
U>/< time delay (DT)	0.000...1800.000 s	0.001 s	6.000 s	This time delay is used in master/follower mode and when transformer operates as an independent unit.
U>/< T2 fast recontrol delay (DT)	0.000...1800.000 s	0.001 s	30.000 s	This time delay is used in master/follower mode and when transformer operates as an independent unit.
Reactive control factor k	0.1...10.0	0.1	1.0	Reactive control factor for circulating reactive current mode.
Circulating current time delay (Slow T1)	0.000...1800.000 s	0.001 s	20.0 s	Primary tap control time delay in circulating reactive current mode. Runs when pickup conditions for I_{CRC} mode are fulfilled.
Circulating current time delay (Fast T2)	0.000...1800.000 s	0.001 s	10.0 s	Faster secondary time delay for I_{CRC} mode. Follows T1 delay in case conditions are met.
Voltage deviation setting (B+/-)	1.00...100.00 %Un	0.01 %Un	8.00 %Un	Primary pickup setting of circulating reactive current (I_{CRC}) mode.

Measurements

The following measurements are available in the function menus.

Table. 4.5.3 - 242. Measurements used by the parallel voltage regulator function.

Name	Range	Step	Description
Circulating current (A)	-50000.00…50000.00 A	0.01 A	Measured circulating reactive current amplitude and direction (+/-) from our device perspective

Name	Range	Step	Description
Circulating current deviation (%Un)	-50000.00…50000.00 %Un	0.01 %Un	Measured circulating reactive current amplitude and direction (+/-) converted to voltage from our device perspective. [Idev]
Voltage deviation (%Un)	-50000.00…50000.00 %Un	0.01 %Un	Voltage deviation indicates the difference between measured bus voltage level and nominal bus voltage. [Udev]
Total deviation (%Un)	-50000.00…50000.00 %Un	0.01 %Un	Total deviation combines the measured voltage deviation together with circulating current (voltage) deviation. [Dtot]

The following measurements can be added to the device display mimic:

- Transformer ID status to mimic, own transformer ID to display (variable number)
- Circulating current (A), circulating current Amperage
- Circulating current deviation (%Un), circulating current amplitude as per voltage
- Voltage deviation (%Un), bus voltage deviation to nominal
- Total deviation (%Un), bus voltage + circulating current total deviation
- Tap voltage (kV), measured tap voltage (kV)
- Voltage difference (kV), measured voltage difference to nominal bus voltage level (kV)
- Time left to operation (s), estimated time left to tap control
- Voltage now (kV), measured bus voltage (kV)
- Tap location now (- 0 +), tap position (own transformer)
- Absolute tap location, absolute tap position (own transformer)
- T1-T4 tap location now (- 0 +), from GOOSE, tap position (other transformers)
- T1-T4 voltage deviation, from GOOSE, voltage deviation (other transformers)
- T1-T4 circulating current deviation, from GOOSE, circ. curr. %Un (other transformers)
- T1-T4 total deviation, from GOOSE, total deviation (other transformers)

Following visibility conditions are available in 250 series parallel tap changer device mimic:

- Follower operation status to mimic, follow master raise/lower or tap
- AVR tap control status, when tap is controlled up or down
- T1-T4 Auto/Manual, from GOOSE, auto/manual status (other transformers)
- T1-T4 Independent/parallel, from GOOSE, independent/parallel status (other transformers)
- AVR Independent/parallel status to mimic, independent/parallel status (own transformer)
- AVR Follower/Master status to mimic, follower/master status
- AVR no master selected, no master selected among any parallel device
- No parallel communication, no parallel communication failure
- AVR tap differential failure, tap differential failure
- Tap high limit reached, tap high limit reached alarm
- Tap low limit reached, tap low limit reached alarm
- AVR circulating current mode failure, circulating reactive current failure
- Current master, which parallel device is currently master (ID value)
- Hierarchy status to mimic, single/parallel status
- Auto/Manual status to mimic

You can adjust premade default mimic for up to four parallel transformers based on application needs.

Device internal logic VRG> signals

Following logical signals are available in parallel tap changer function:

- T1-T4 Auto/Manual

- T1-T4 Independent/Parallel
- AVR no master selected
- AVR no parallel communication
- AVR tap differential failure
- AVR circulating current mode failure

Pick-up

Circulating reactive current mode

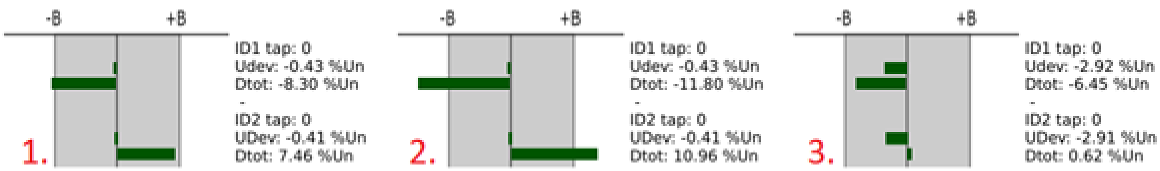
In circulating reactive current mode, the tap control is decided based on several criteria's:

- Current tap position value
- Bus/tap voltage level compared to the nominal value (Udev)
- Measured circulating reactive current amplitude and direction (Idev)

Once above-mentioned terms are fulfilled, tap control takes place after deviation delay T1 has passed. In case one control step will not resolve the matter, another step is taken with faster time delay T2.

In master & follower mode, the tap control operation is based on UTGT+/- voltage windows. Once voltage drops or increases the set limit, master device controls and following device will follow. In circulating reactive current mode, both UTGT+/- setting and individual B+/- setting (follows total deviation) are used for tap control scheme. Few basic operating principles are presented below:

Figure. 4.5.3 - 146. VRG> circulating reactive current mode operating principle.

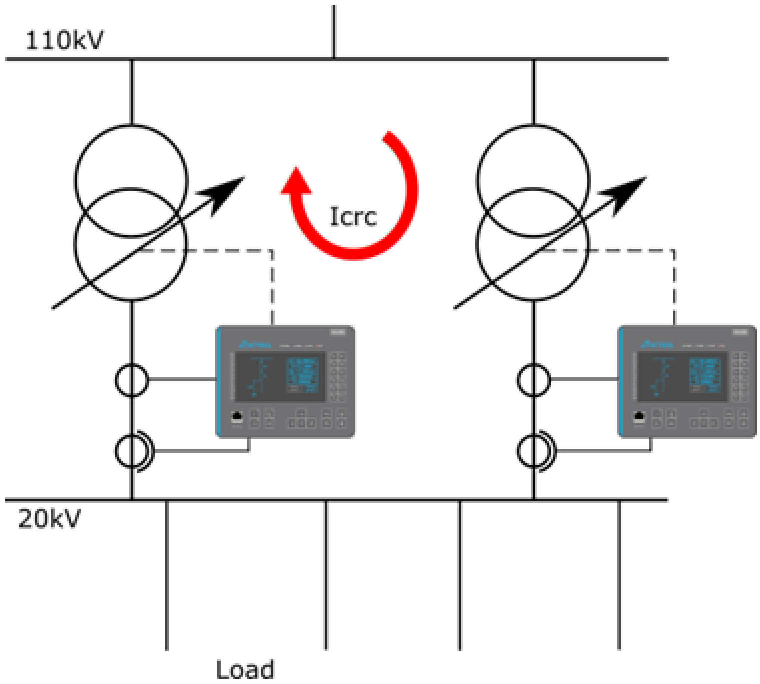


1. In first example measured voltage deviation is less than nominal bus voltage (Udev < Ubus) . Voltage deviation Udev is –0.43%Un. To fulfill criteria to this first example case, the Udev value has to be less than 50% of the UTGT+/- setting. In this example, the UTGT– (negative) setting is 1.5%Un, so the less than 50% term is passed. Total deviation setting B +/- is set to 8%Un. Total deviation Dtot consists of voltage deviation Udev (-0.43%Un) and circulating reactive current deviation as per voltage Idev (-7.87%Un) in device ID1. Device ID2 total deviation flows to the other (positive) direction due to circulating current circulation direction in the parallel transformer system. Device ID1 has terms to control tap to opposite direction of negative voltage deviation, therefore T1 timer starts and once set time has passed ID1 will control tap to higher position to increase the bus voltage. Device ID2 does nothing.In case, same condition persists regardless the tap+ control, T2 timer is started with faster time delay and another tap+ command is issued in device ID1. T2 timer reruns and tap+ command is given as long as is needed.
2. In second example, measured voltage deviation is similar to first example above and Udev value is less than 50% of the set negative UTGT- value. The main difference is that both devices ID1 and ID2 have exceeded the B+/- setting and in opposite direction. Since measured voltage, deviation is negative, device ID1 has terms to control tap to opposite direction of negative voltage deviation, therefore T1 timer starts and once set time has passed ID1 will control tap to higher position to increase the bus voltage. Device ID2 does nothing.In case, same condition persists regardless the tap + control in device ID1, T2 timer is started with faster time delay, but this time both devices ID1 and ID2 will control tap. Device ID1 will give tap+ command but device ID2 will give tap command to opposite direction Tap-. T2 timer reruns and both devices will repeat the control commands as long as is needed.

3. In third example, both devices are below B+/- setting, but voltage deviation has passed the 100% of UTGT+/- setting (Udev is -2.91%Un). Timer T1 starts and once time has passed both devices, ID1 and ID2 will control tap to opposite direction of the negative Udev voltage. Devices ID1 and ID2 will give tap+ command. If condition remains, T2 timer will start and both devices ID1 and ID2 will control the tap to higher position.

NOTICE!
Circulating current mode follows "Max control pulse length" and "Minimum time between pulses" time delays. In case maximum control pulse length is 2 seconds and time between is 5 seconds, there is total of 7 second delay between T1 timer control command and starting of timer T2. The same applies if T2 timer is rerun multiple times.

Figure. 4.5.3 - 147. VRG> circulating reactive current mode



To run circulating reactive current mode properly, some transformer nameplate values such as transformer rated apparent power Sn, transformer rated voltage Un and transformer short circuit impedance Zk is required. All other data comes automatically via GOOSE messaging once communication between the devices has been established.

Figure. 4.5.3 - 148. Circulating reactive current mathematical formulas below:

$$X_k = \frac{{U_n}^2 / \sqrt{3}}{S_n} \times Z_k$$

$$I_L = \sum_{k=1}^{N} I_k$$

$$B_P \sum_{K=1}^{N} \frac{1}{X_k}$$

$$I_{Lm} = Im(I_L) \frac{1}{X_k \times B_P}$$

$$I_{CRC} = -1 \times (Im(I_k) - I_{LkImag})$$

$$D_{tot} = k \times \frac{(I_{CRCk} + \frac{1}{B_P - B_k}) \times \sqrt{3}}{U_n} \times 100\%$$

- X_k is transformer reactance
- I_L is total combined current amplitude
- B_P is total combined susceptance
- $I_m(I_L)$ = current amplitude imaginary part
- I_{Lm} is total imaginary current amplitude
- I_{CRC} is circulating reactive current amperage
- D_{tot} is circulating current as per voltage
- K is circulating current reactive control factor

Master & follower operating mode

Master follower operating mode is pretty simple and traditional. When two transformers operate in parallel, one of the has to be selected as a master and the other one follows master decisions. There are two ways to follow the leading device.

- Follow master raise and lower commands: In this mode once master device is controlling tap up or down, a signal is sent between all parallel devices and follower devices will control tap similarly to master.
- Follow master tap position: Following device controls tap up or down based on own tap position compared to master device tap position.

Tap differential alarm is available in case master and follower tap difference increases too much in set time.

I/O and function blocking

Following conditions can be altered from AQtivate -setting tool, local device settings, with digital inputs and logical nodes/outputs. It is possible to control an input simultaneously with logic or digital input, since operation of stage uses non-volatile SR-latch. Device logic can be controlled through SCADA or device local MIMIC in case programmable function buttons are configured.

Table. 4.5.3 - 243. Logical inputs of the function.

Setting	Description
AVR independent	Change voltage regulator status to independent transformer.
AVR parallel	Change transformer to operate in parallel with other transformer units.
AVR master	Change parallel operating transformer to work as a master. Only one master can be selected at a time, in case communication is properly set.
AVR follower	Change parallel operating transformer to work as a follower. Once all parallel devices are followers, a new master can be selected.
AVR circulating reactive current	Change parallel operating device operation mode to circulating reactive current.
AVR master & follower	Change parallel operating device operation mode to master & follower.
AVR manual	Change AVR tap control to manual mode.
AVR auto	Change AVR tap control to auto mode.
AVR manual raise	Raise transformer tap position manually while operating in manual mode.
AVR manual lower	Lower transformer tap position manually while operating in manual mode.

Automatic voltage regulator can be blocked internally with two inputs. "AVR Block control outs" blocks output relay controls but doesn't block event activations. "AVR Block op and outs" blocks all operation.

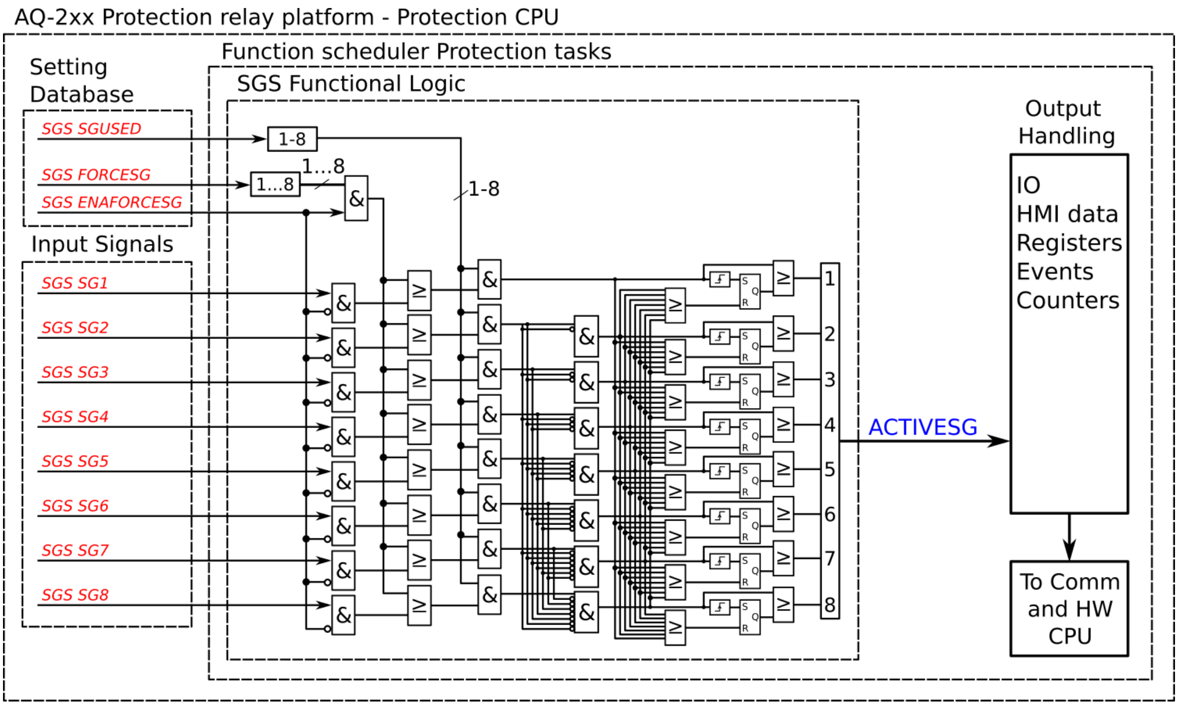
Table. 4.5.3 - 244. Suggested signals to use for blocking the AVR function.

Signal	Description
AVR no Master selected	This signal activates when function is in parallel mode, master&follower local parallel hierarchy is selected and when there is no master selected between any of the parallel device.
AVR no parallel communication	Signal activates in case communication is unplugged or interrupted for any reason or device ID/group is set wrong.
AVR tap differential failure	Tap differential failure activates when master and follower unit tap difference is greater than set limit “allowed tap difference” and operating time “maximum allowed tap difference time” has passed.
AVR circulating current mode failure: I_{CRC}	I_{CRC} mode failure is not yet implemented and signal is forced to stay active (1).

4.5.4 Setting group selection

All device 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 takes control of the setting group activations based on the logic and conditions the user has programmed.

Figure. 4.5.4 - 149. Simplified function block diagram of the setting group selection function.

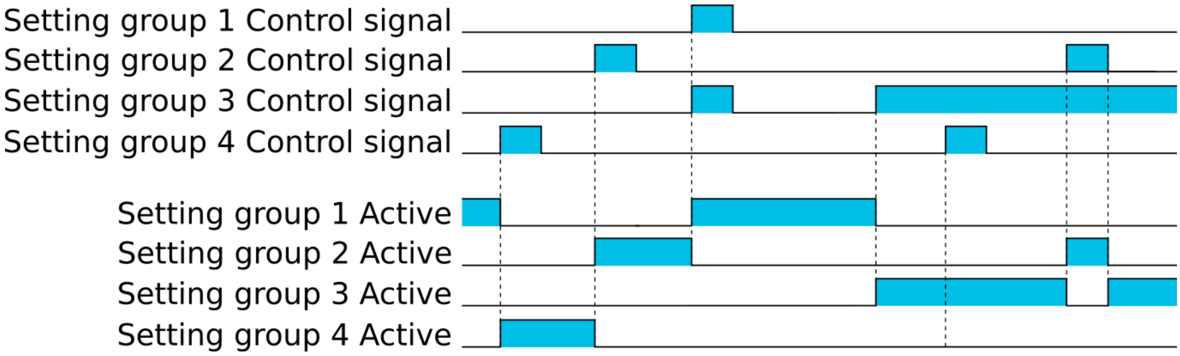


Setting group selection can be applied to each of the setting groups individually by activating one of the various internal logic inputs and connected digital inputs. The user can also force any of the setting groups on when the "Force SG change" setting is enabled by giving the wanted quantity of setting 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.

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.

Setting groups follow a hierarchy in which setting group 1 has the highest priority, setting group 2 has second highest priority etc. If a static activation signal is given for two setting groups, the setting group with higher priority will be active. If setting groups are controlled by pulses, the setting group activated by pulse will stay active until another setting groups receives and activation signal.

Figure. 4.5.4 - 150. 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. 4.5.4 - 245. Settings of the setting group selection function.

Name	Range	Default	Description
Active setting group	• SG1 • SG2 • SG3 • SG4 • SG5 • SG6 • SG7 • SG8	SG1	Displays which setting group is active.
Force setting group	• None • SG1 • SG2 • SG3 • SG4 • SG5 • SG6 • SG7 • SG8	None	The selection of the overriding setting group. After "Force SG change" is enabled, any of the configured setting groups in the device 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 setting group change	• Disabled • Enabled	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.

Name	Range	Default	Description
Used setting groups	• SG1 • SG1...2 • SG1...3 • SG1...4 • SG1...5 • SG1...6 • SG1...7 • SG1...8	SG1	The selection of the activated setting groups in the application. Newly-enabled setting groups use default parameter values.
Remote setting group change	• None • SG1 • SG2 • SG3 • SG4 • SG5 • SG6 • SG7 • SG8	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. 4.5.4 - 246. Signals of the setting group selection function.

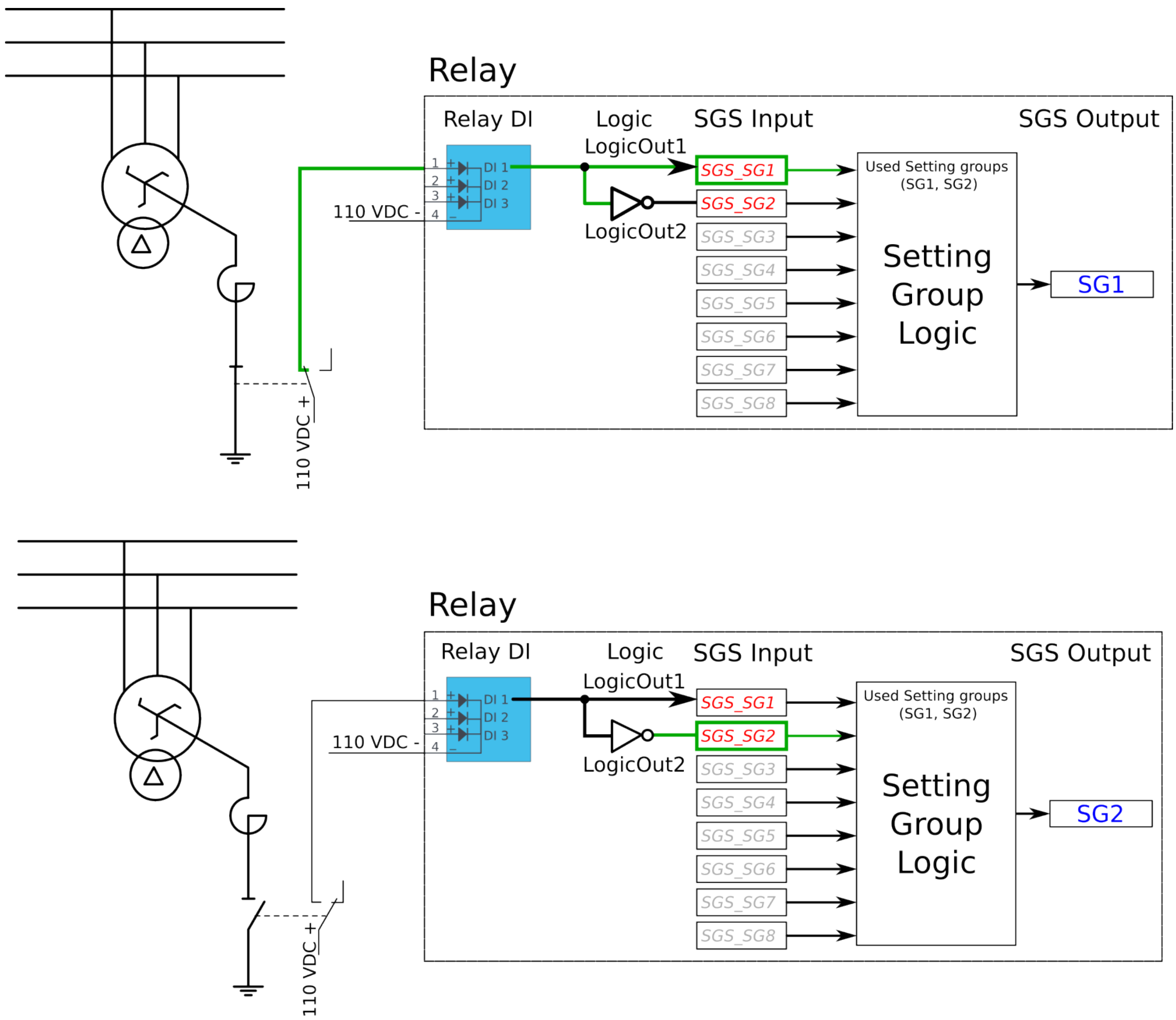
Name	Description
Setting group 1	The selection of Setting group 1 ("SG1"). Has the highest priority input in setting group control. Can be controlled with pulses or static signals. If static signal control is applied, no other SG requests will be processed.
Setting group 2	The selection of Setting group 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	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	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	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	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	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	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. 4.5.4 - 151. 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 to SG2.

Figure. 4.5.4 - 152. Setting group control – two-wire connection from Petersen coil status.

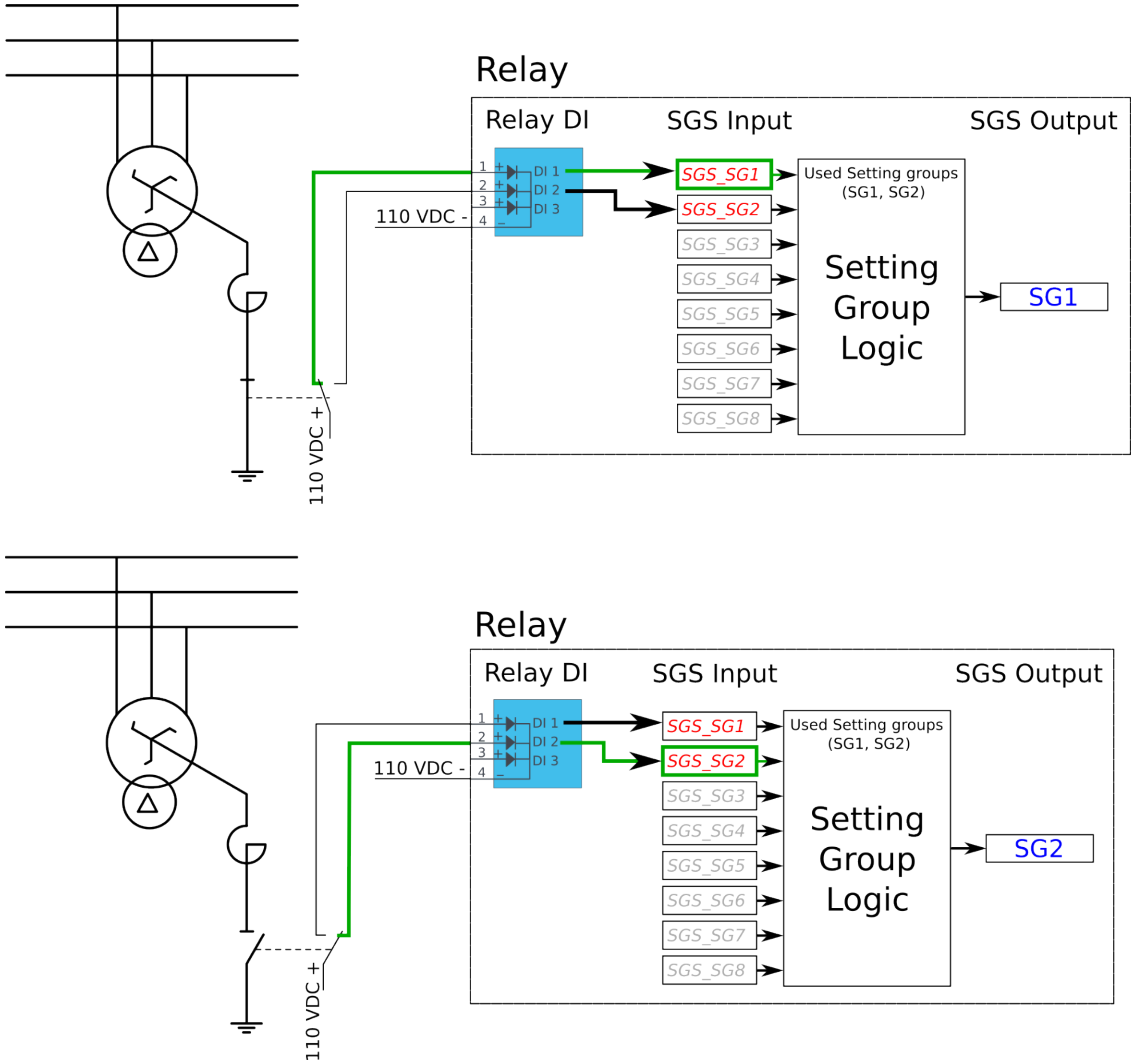
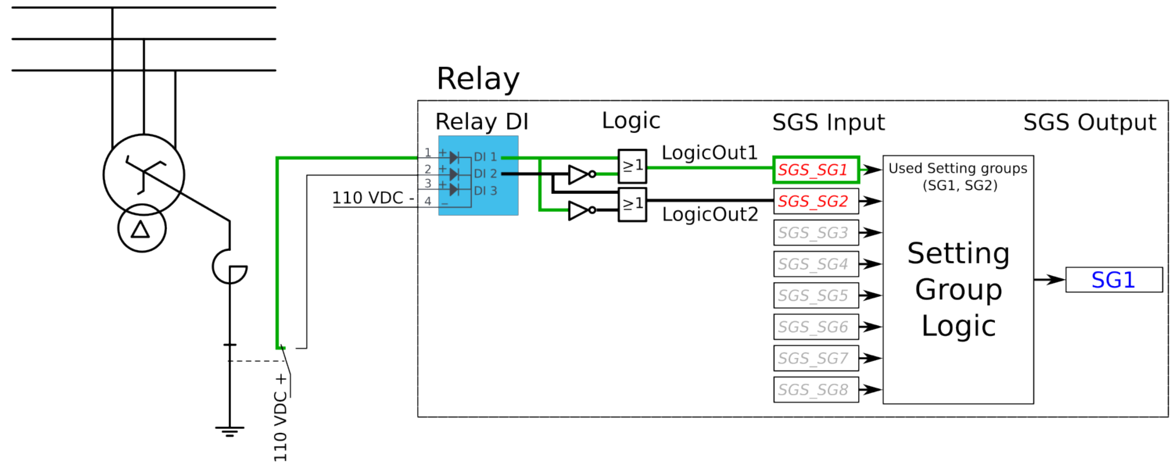
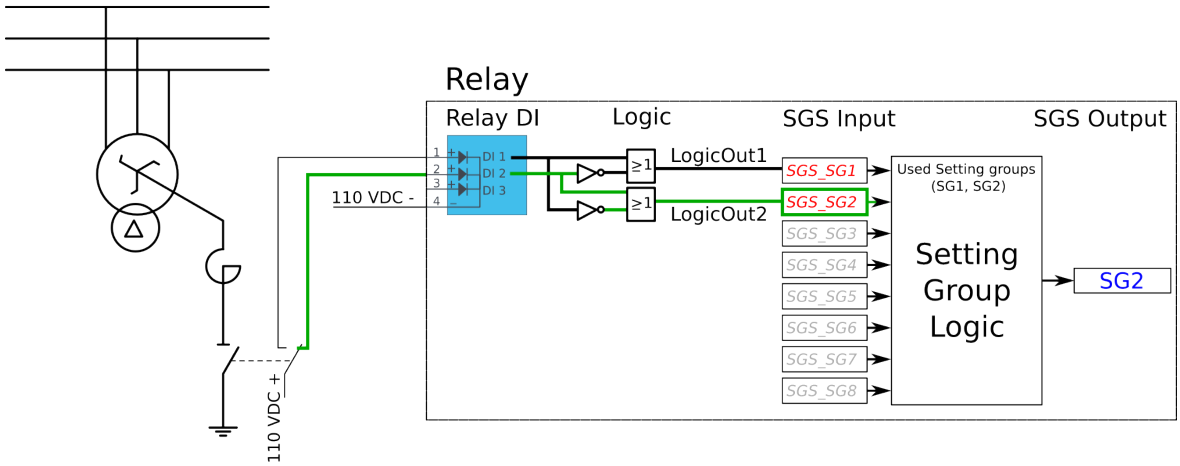


Figure. 4.5.4 - 153. Setting group control – two-wire connection from Petersen coil status with additional logic.

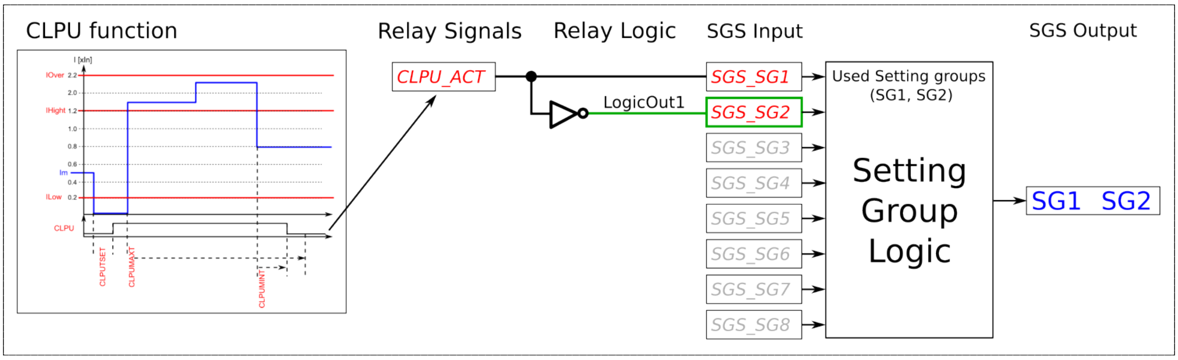


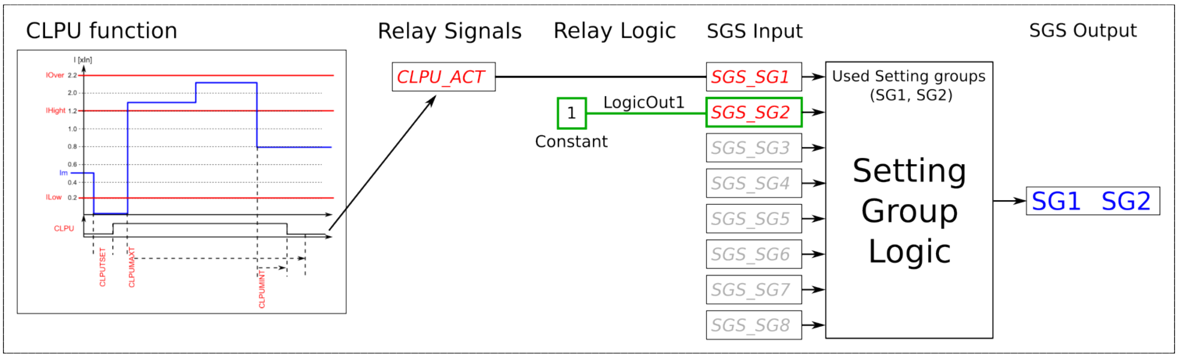


The images above depict a two-wire connection from the Petersen coil: the two images at the top show a direct connection, while the two images on the bottom include additional logic. With a two-wire connection the state of the Petersen coil can be monitored more securely. The additional logic ensures 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 device's internal logics. For example, the setting group change can be based on the cold load pick-up function (see the image below).

Figure. 4.5.4 - 154. Entirely application-controlled setting group change with the cold load pick-up function.





In these examples 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 device'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 the status changes in the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

Table. 4.5.4 - 247. Event messages.

Event block name	Event names
SGS	SG2...8 Enabled
SGS	SG2...8 Disabled
SGS	SG1...8 Request ON
SGS	SG1...8 Request OFF
SGS	Remote Change SG Request ON

Event block name	Event names
SGS	Remote Change SG Request OFF
SGS	Local Change SG Request ON
SGS	Local Change SG Request OFF
SGS	Force Change SG ON
SGS	Force Change SG OFF
SGS	SG Request Fail Not configured SG ON
SGS	SG Request Fail Not configured SG OFF
SGS	Force Request Fail Force ON
SGS	Force Request Fail Force OFF
SGS	SG Req. Fail Lower priority Request ON
SGS	SG Req. Fail Lower priority Request OFF
SGS	SG1...8 Active ON
SGS	SG1...8 Active OFF

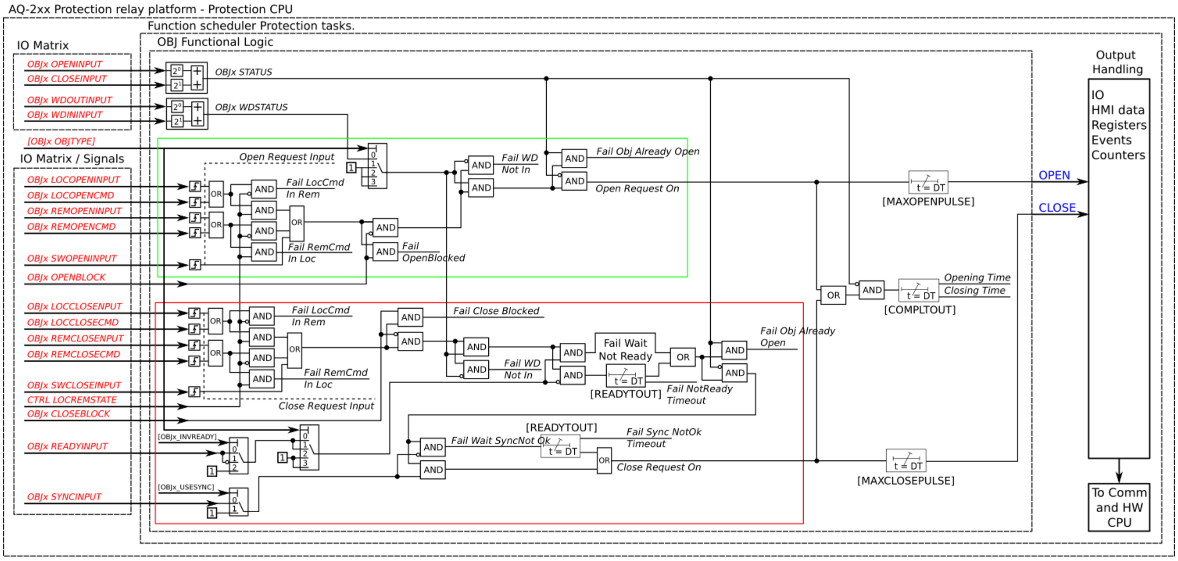
4.5.5 Object control and monitoring

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 device's configured digital inputs and outputs. The number of controllable and monitored objects in each device depends on the device type and amount of digital inputs. 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 manually or automatically. Manual control can be done by local control, or by remote control. Local manual control can be done by devices front panel (HMI) or by external push buttons connected to devices digital inputs. Manual remote control can be done through one of the various communication protocols available (Modbus, IEC101/103/104 etc.). The function supports the modes "Direct control" and "Select before execute" while controlled remotely. Automatic controlling can be done with functions like auto-reclosing function (ANSI 79).

The main 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 user in the function's setup phase.

Figure. 4.5.5 - 155. 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. 4.5.5 - 248. Object settings and status parameters.

Name	Range	Default	Description
Local/Remote status	• Local • Remote	Remote	Displays the status of the device's "local/remote" switch. Local controls cannot override the open and close commands while device is in "Remote" status. The remote controls cannot override the open and close commands while device is in "Local" status.
Object status force to	• Normal • Openreq On • Closereq On • Opensignal On • Closesignal On • WaitNoRdy On • WaitNoSnc On • NotrdyFail On • NosyncFail On • Opentout On • Clotout On • OpenreqUSR On • CloreqUSR On	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.
OBJ LN mode	• On • Blocked • Test • Test/Blocked • Off	On	Set mode of OBJ block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.

Name	Range	Default	Description
OBJ LN behaviour	• On • Blocked • Test • Test/Blocked • Off	-	Displays the mode of OBJ block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
Object name	-	Objectx	The user-set name of the object, at maximum 32 characters long.
Object type	• Withdrawable circuit breaker • Circuit breaker • Disconnector (MC) • Disconnector (GND)	Circuit breaker	The selection of the object type. This selection defines the number of required digital inputs for the monitored object. This affects the symbol displayed in the HMI and the monitoring of the circuit breaker. It also affects whether the withdrawable cart is in/out status is monitored. See the next table ("Object types") for a more detailed look at which functionalities each of the object types have.
Objectx Breaker status	• Intermediate • Open • Closed • 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	• WDIntermediate • WDCartOut • WDCart In • WDBad • 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	• Open Blocked • Open Allowed • Close Blocked • Close Allowed • Object Ready • Object Not Ready • Sync Ok • Sync Not Ok	-	Displays additional information about the status of the object.
Use Synchrocheck	• Not in use • Synchrocheck in use	Not in use	Selects whether the "Synchrocheck" condition is in use for the circuit breaker close command. If "In use" is selected the input chosen to "Sync.check status in" has to be active to be able to close circuit breaker. Synchrocheck status can be either an internal signal generated by synchrocheck function or digital input activation with an external synchrocheck device.
Use Object ready	• Ready High • Ready Low • Not in use	Not in use	Selects whether the "Object ready" condition is in use for the circuit breaker close command. If in use the signal connected to "Object ready status In" has to be high or low to be able to close the breaker (depending on "Ready High or Low" selection).
Open requests	$0...2^{32}-1$	-	Displays the number of successful "Open" requests.
Close requests	$0...2^{32}-1$	-	Displays the number of successful "Close" requests.

Name	Range	Default	Description
Open requests failed	$0…2^{32}–1$	-	Displays the number of failed "Open" requests.
Close requests failed	$0…2^{32}–1$	-	Displays the number of failed "Close" requests.
Clear statistics	• - • Clear	-	Clears the request statistics, setting them back to zero (0). Automatically returns to "-" after the clearing is finished.

Table. 4.5.5 - 249. Object types.

Name	Functionalities	Description
Withdrawable circuit breaker	Breaker cart position Circuit breaker position Circuit breaker control Object ready check before closing breaker Synchrochecking before closing breaker Interlocks	The monitor and control configuration of the withdrawable circuit breaker.
Circuit breaker	Position indication Control Object ready check before closing breaker Synchrochecking before closing breaker 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. 4.5.5 - 250. 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.
Objectx Close input ("Objectx Close Status In")		A link to a physical digital input. The monitored object's CLOSE status. "1" refers to the active close state of the monitored object.
WD Object In ("Withdrw.CartIn.Status In")		A link to a physical digital input. The monitored withdrawable object's position is IN. "1" means that the withdrawable object cart is in.
WD Object Out ("Withdrw.CartOut.Status In")		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.

Signal	Range	Description
Object Ready ("Objectx Ready status In")		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.
Syncrocheck permission ("Sync.Check status In")		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.
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. 4.5.5 - 251. 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. If auto-recloser function controls the object, "final trip" signal is activated only when there are no automatic reclosings expected after opening the breaker.

Table. 4.5.5 - 252. Control settings (DI and Application).

Signal	Range	Description
Access level for MIMIC control	• User • Operator • Configurator • Super user	Defines what level of access is required for MIMIC control. The default is the "Configurator" level.

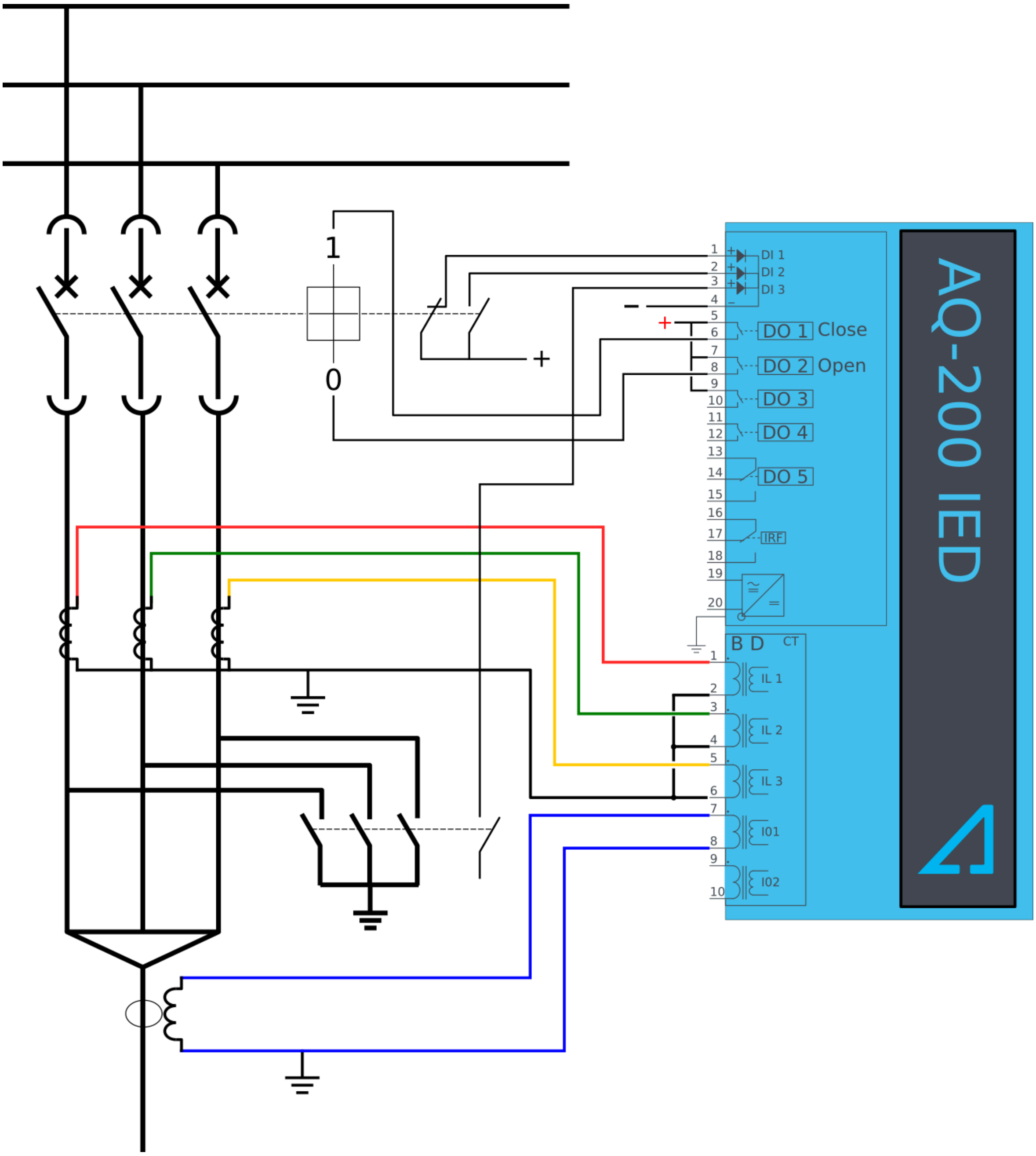
Signal	Range	Description
Objectx LOCAL Close control input	Digital input or other logical signal selected by the user	The local Close command from a physical digital input (e.g. a push button).
Objectx LOCAL Open control input		The local Open command from a physical digital input (e.g. a push button).
Objectx REMOTE Close control input		The remote Close command from a physical digital input (e.g. RTU).
Objectx REMOTE Open control input		The remote Open command from a physical digital input (e.g. RTU).
Objectx Application Close		The Close command from the application. Can be any logical signal.
Objectx Application Open		The Close command from the application. Can be any logical signal.

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 command.

Figure. 4.5.5 - 156. Example of an interlock application.

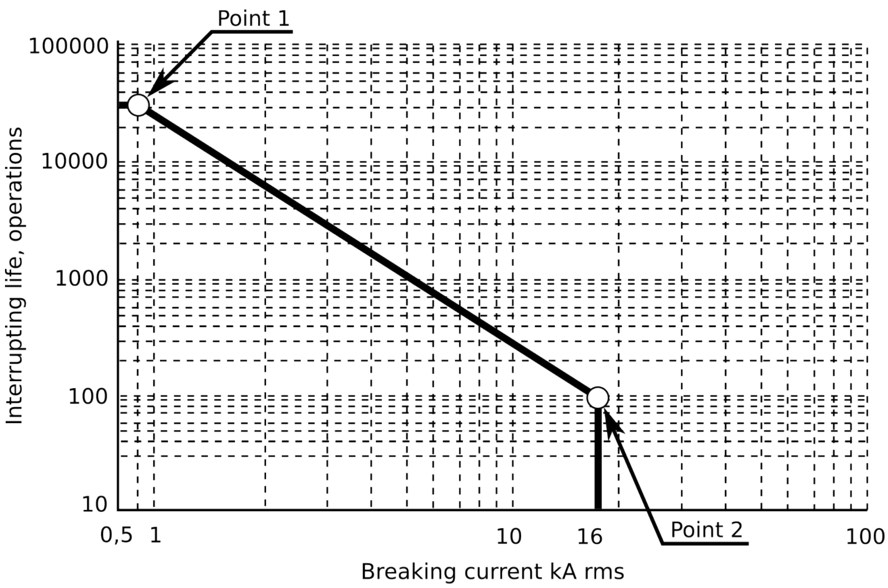


In order for the blocking signal to be received on time, it has to reach the function 5 ms before the control command.

Object condition monitoring (circuit breaker wear monitor)

Each object has integrated circuit breaker wear monitor. 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.

Figure. 4.5.5 - 157. Example of the circuit breaker interrupting life operations. Points 1 and 2 are user settable.



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 function's outputs are ALARM 1 and ALARM 2 signals which can be used for direct I/O controlling and user logic programming.

The function block uses analog current measurement values and always uses the RMS magnitude of the current measurement input.

Table. 4.5.5 - 253. Measurement inputs of the circuit breaker wear function.

Signal	Description	Time base
IL1RMS	RMS measurement of phase L1 (A) current	5ms
IL2RMS	RMS measurement of phase L2 (B) current	5ms
IL3RMS	RMS measurement of phase L3 (C) current	5ms

Condition monitoring parameters can be found from *Control → Objects → Object X → APP CONTR → Condition Monitoring*.

Table. 4.5.5 - 254. Breaker supervision settings and status indications.

Name	Range	Default	Description
Condition monitoring	• Disabled • Enabled	Disabled	Enabled the breaker condition monitoring function.
Monitoring CT side	• CT1 • CT2	CT1	Defines which current measurement module is used by the function.

Name	Range	Default	Description
Condition monitor status	• Normal • Alarm1 On • Alarm2 On	-	Displays the status of the monitor.
Open operations	0...4 294 967 295	-	Displays the total amount of breaker open operations.
Operation time open	0...4 294 967 295 ms	-	Displays the latest breaker opening time.
Close operations	0...4 294 967 295	-	Displays the total amount of breaker close operations.
Operation time close	0...4 294 967 295 ms	-	Displays the latest breaker closing time.
L1 Operations Left L2 Operations Left L3 Operations Left	0...4 294 967 295	-	Displays the amount of operations left in each phase.
Object Cumulated operations	0...4 294 967 295	-	Displays the total amount of operations.
Clear condition monitoring statistics	• - • Clear	-	Clears the operation statistics.
Operations with Current 1 Value allowed	0...200 000	50000	Defines the amount of operations with lower current values. See figure above.
Current 1 Value	0.00...100.00 kA	1.00 kA	Defines the lower current turnpoint. See figure above.
Operations with Current 2 Value allowed	0...200 000	100	Defines amount of operations with higher current values. See figure above.
Current 2 Value	0.00...100.00 kA	20.00 kA	Defines the higher current turnpoint. See figure above.
Condition Alarm 1 Enable	• Disabled • Enabled	Disabled	Enables Alarm 1.
Condition Alarm 1 when operations less than	0...200 000	1000	When the amount of operations left is less than value set here, Alarm 1 will activate.
Condition Alarm 2 Enable	• Disabled • Enabled	Disabled	Enables Alarm 2.
Condition Alarm 2 when operations less than	0...200 000	100	When the amount of operations left is less than value set here, Alarm 2 will activate.

Events and registers

The object control and monitoring function (abbreviated "OBJ" in event block names) generates events and registers from the status changes in the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function also provides a resettable cumulative counter for OPEN, CLOSE, OPEN FAILED, and CLOSE FAILED events.

Table. 4.5.5 - 255. Event messages of the OBJ function instances 1 – 10.

Event block name	Description
OBJ1...OBJ10	Object Intermediate
OBJ1...OBJ10	Object Open
OBJ1...OBJ10	Object Close
OBJ1...OBJ10	Object Bad
OBJ1...OBJ10	WD Intermediate
OBJ1...OBJ10	WD Out
OBJ1...OBJ10	WD in
OBJ1...OBJ10	WD Bad
OBJ1...OBJ10	Open Request On
OBJ1...OBJ10	Open Request Off
OBJ1...OBJ10	Open Command On
OBJ1...OBJ10	Open Command Off
OBJ1...OBJ10	Close Request On
OBJ1...OBJ10	Close Request Off
OBJ1...OBJ10	Close Command On
OBJ1...OBJ10	Close Command Off
OBJ1...OBJ10	Open Blocked On
OBJ1...OBJ10	Open Blocked Off
OBJ1...OBJ10	Close Blocked On
OBJ1...OBJ10	Close Blocked Off
OBJ1...OBJ10	Object Ready
OBJ1...OBJ10	Object Not Ready
OBJ1...OBJ10	Sync Ok
OBJ1...OBJ10	Sync Not Ok

Event block name	Description
OBJ1...OBJ10	Open Command Fail
OBJ1...OBJ10	Close Command Fail
OBJ1...OBJ10	Final trip On
OBJ1...OBJ10	Final trip Off
OBJ1...OBJ10	Contact Abrasion Alarm On
OBJ1...OBJ10	Contact Abrasion Alarm Off
OBJ1...OBJ10	Switch Operating Time Exceeded On
OBJ1...OBJ10	Switch Operating Time Exceeded Off
OBJ1...OBJ10	XCBR Loc On
OBJ1...OBJ10	XCBR Loc Off
OBJ1...OBJ10	XSWI Loc On
OBJ1...OBJ10	XSWI LOC 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. 4.5.5 - 256. Register content.

Name	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
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.

4.5.6 Indicator object monitoring

The indicator object monitoring function takes care of the status monitoring of 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 device's digital inputs. The number of monitored indicators in a device depends on the device type and available inputs. 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 outputs of the function are the monitored indicator statuses (Open, Close, Intermediate and Bad). 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. 4.5.6 - 257. 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")	• Intermediate • Open • Closed • 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. 4.5.6 - 258. 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.
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.

Events

The indicator object monitoring function (abbreviated "CIN" in event block names) generates events from the status changes in the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

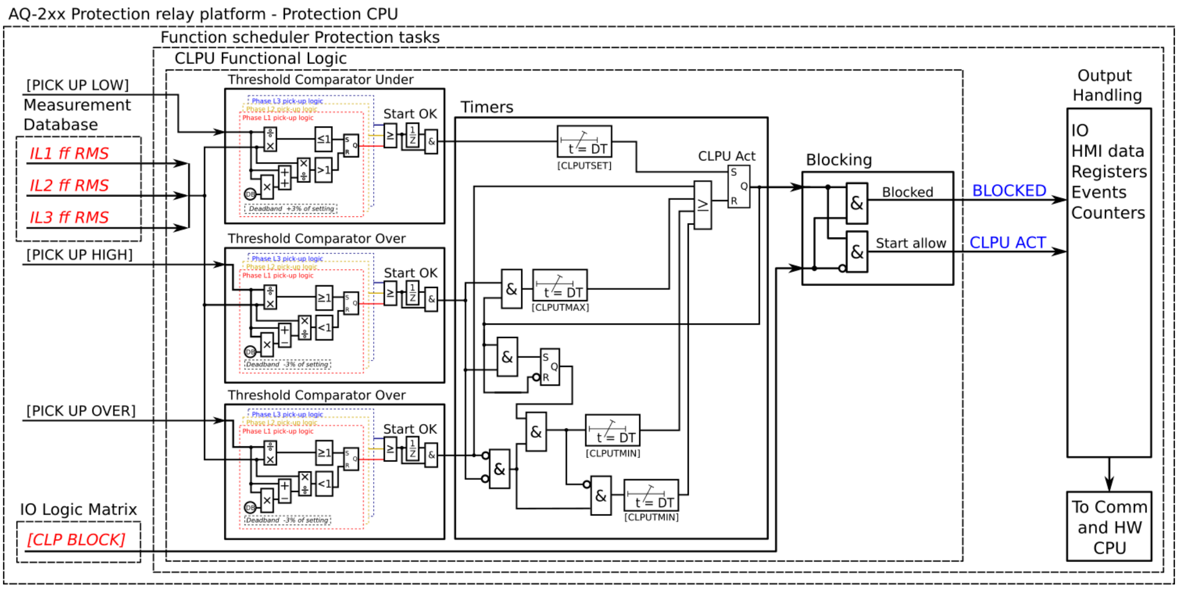
Table. 4.5.6 - 259. Event messages (instances 1-10).

Event block name	Event names
CIN1...10	Intermediate
CIN1...10	Open
CIN1...10	Close
CIN1...10	Bad

4.5.7 Cold load pick-up (CLPU)

The cold load pick-up function is used for detecting so-called cold load situations, where a loss of load diversity has occured after distribution has been re-energized. The characteristics of cold load situations vary according to the types of loads individual feeders have. This means that this function needs to be set specifically according to the load type of the feeder it is monitoring. For example, in residential areas there are relatively many thermostat-controlled devices (such as heating and cooling machinery) which normally run in asynchronous cycles. When restoring power after a longer power outage, these devices demand the full start-up power which can cause the inrush current to be significantly higher than what the load current was before the outage. This is uncommon in industrial environments since the restoring of the production process takes several hours, or even days, and the power level goes back to the level it was before the outage. However, some areas of the industrial network may find the cold load pick-up function useful.

Figure. 4.5.7 - 158. Simplified function block diagram of the cold load pick-up function.



Measured input

The function block uses fundamental frequency component of phase current measurement values.

Table. 4.5.7 - 260. Measurement inputs of the cold load pick-up function.

Signal	Description	Time base
I_{L1}RMS	Fundamental frequency component of phase L1 (A) current	5ms
I_{L2}RMS	Fundamental frequency component of phase L2 (B) current	5ms
I_{L3}RMS	Fundamental frequency component of phase L3 (C) current	5ms

General settings

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

Table. 4.5.7 - 261. General settings.

Name	Range	Default	Description
CLPU LN mode	• On • Blocked • Test • Test/ Blocked • Off	On	Set mode of CLP block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
Measurement side	• Side 1 • Side 2	Side 1	Defines which current measurement module is used by the function. Only visible when there is more than one module.
Condition	• Normal • Curr low • Overcurrent On • CLPU On • CLPU blocked	Normal	Displays the status of the function.

Pick-up settings

The I_{low}, I_{high} and I_{over} setting parameters control the the pick-up and activation of the cold load pick-up function. They define the maximum and 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. The reset ratio of 97 % is built into the function and is always relative to the setting value. The setting value is common for all measured phases. When the I_m exceeds the setting value (in single, dual or all phases) it triggers the pick-up operation of the function.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.5.7 - 262. Pick-up settings.

Name	Range	Step	Default	Description
I_{low}	0.01…40.00×In	0.01×In	0.20×In	The pick-up setting for low current detection. All measured currents must be below this setting in order for the cold load pick-up signal to be activated.

Name	Range	Step	Default	Description
I_{high}	0.01…40.00×In	0.01×In	1.20×In	The pick-up setting for high current detection. All measured currents must exceed this setting in order for the cold load pick-up signal to be activated.
I_{over}	0.01…40.00×In	0.01×In	2.00×In	The pick-up setting for overcurrent detection. If this setting is exceeded by any of the measured currents, the cold load pick-up signal is released immediately.

Read-only parameters

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

Table. 4.5.7 - 263. Information displayed by the function.

Name	Range	Description
CLPU LN behaviour	• On • Blocked • Test • Test/Blocked • Off	Displays the mode of CLP block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
CLP condition	• Normal • Curr low • Overcurrent On • CLPU On • CLPU blocked	Displays status of the control function.

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 CLPU ACT 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 CLPU ACT 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 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 behavior of the function's operating timers can be set for activation as well as for the situation monitoring and release of the cold load pick-up.

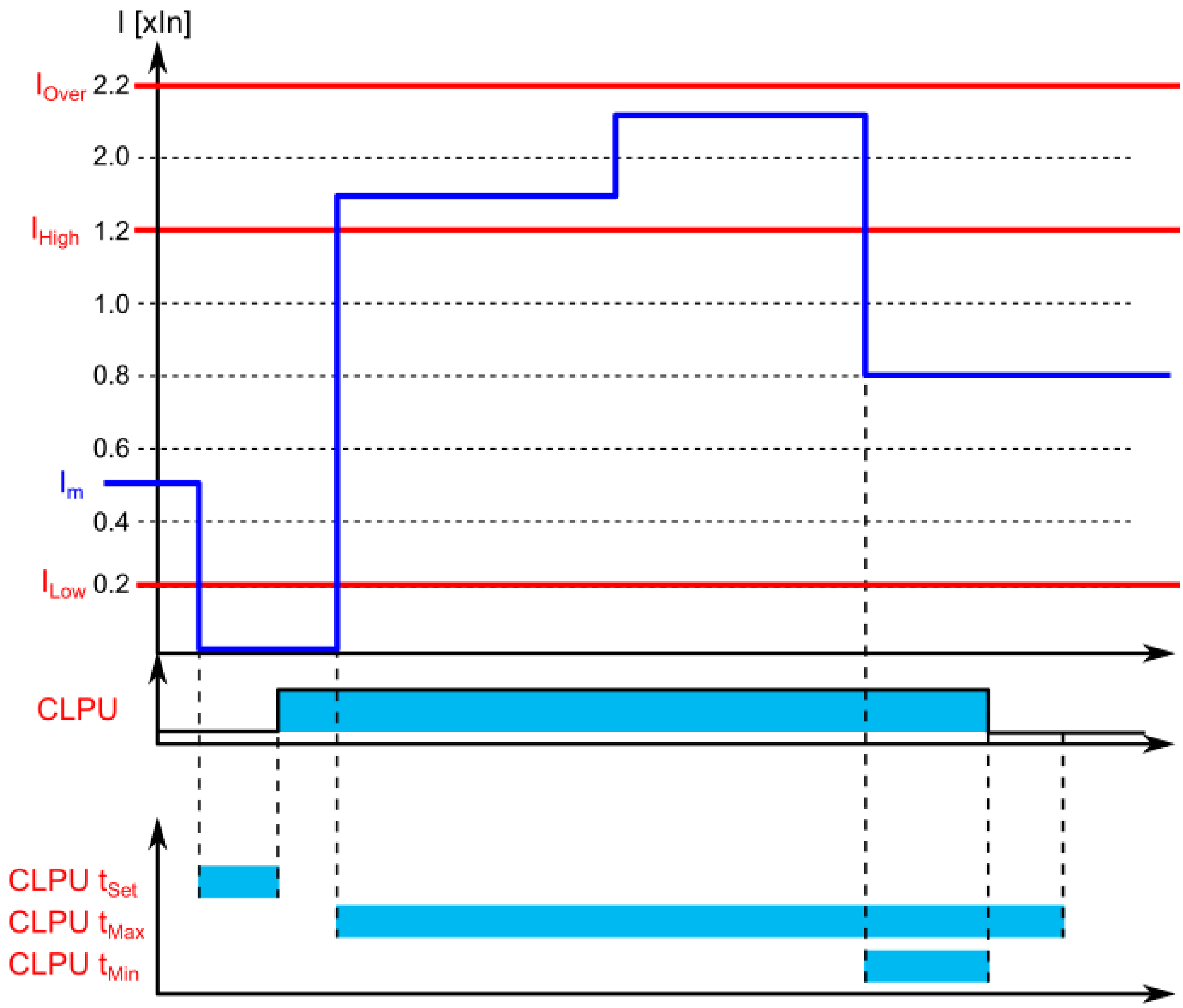
The table below presents the setting parameters for the function's time characteristics.

Table. 4.5.7 - 264. Setting parameters for operating time characteristics.

Name	Range	Step	Default	Description
T_{set}	0.000…1800.000s	0.005s	10.000s	The function's start timer which defines how long the I_{low} condition has to last before the cold load pick-up is activated.
T_{max}	0.000…1800.000s	0.005s	30.000s	The function's maximum timer which defines how long the starting condition can last and for how long the current is allowed to be over I_{high}.
T_{min}	0.000…1800.000s	0.005s	0.040s	The function's minimum timer which defines how long the starting condition has to last at the minimum. If the start-up sequence includes more than one inrush situation, this parameter may be used to prolong the cold load pick-up time over the first inrush. Additionally, this parameter operates as the "reclaim" time for the function in case the inrush current is not immediately initiated in the start-up sequence.

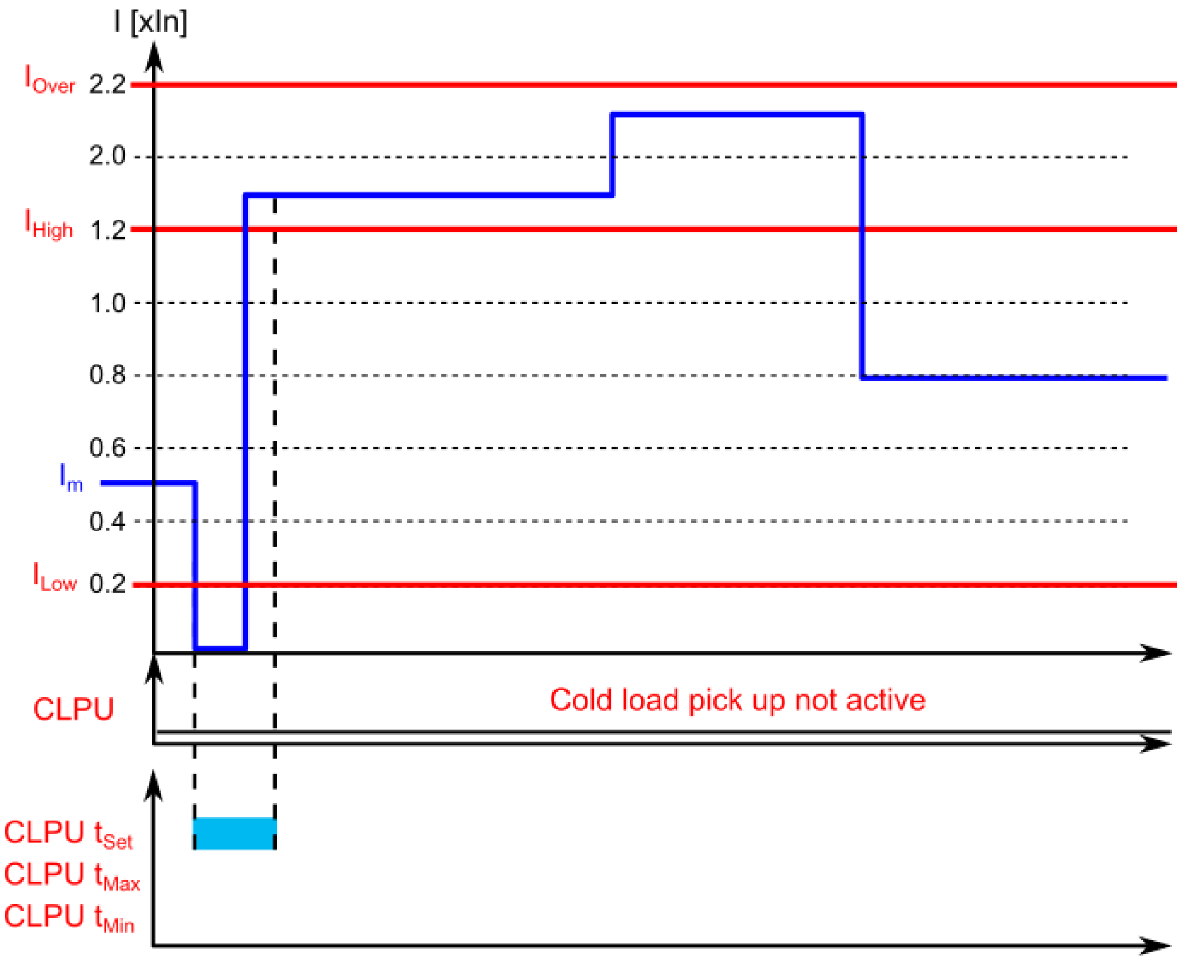
The six examples below showcase some typical cases with the cold load pick-up function.

Figure. 4.5.7 - 159. Example of timers and pick-up parameters (normal CLPU situation).



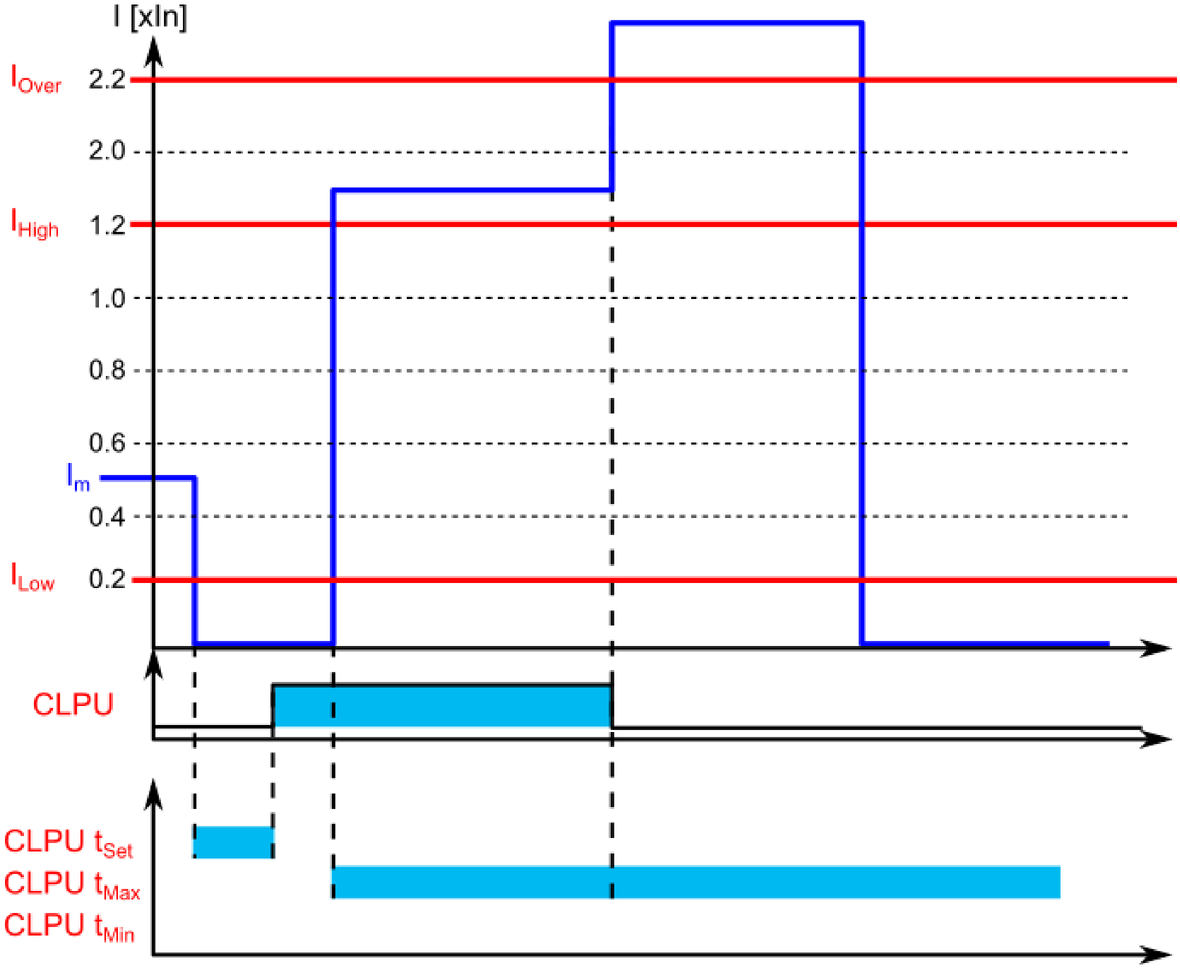
In the example above, the cold load pick-up function activates after the measured current dips below the I_{low} setting and has been there for T_{set} amount of time. When the current exceeds the I_{high} setting value, a timer starts counting towards the T_{max} time. The pick-up current is cleared before the the counter reaches the T_{max} time, when the measured current goes between of I_{low} and the I_{high}. This is when the start-up condition is considered to be over. The cold load pick-up signal can be prolonged beyond this time by setting the T_{min} to a value higher than 0.000 s.

Figure. 4.5.7 - 160. Example of timers and pick-up parameters (no cold load pick-up, I_{low} too short).



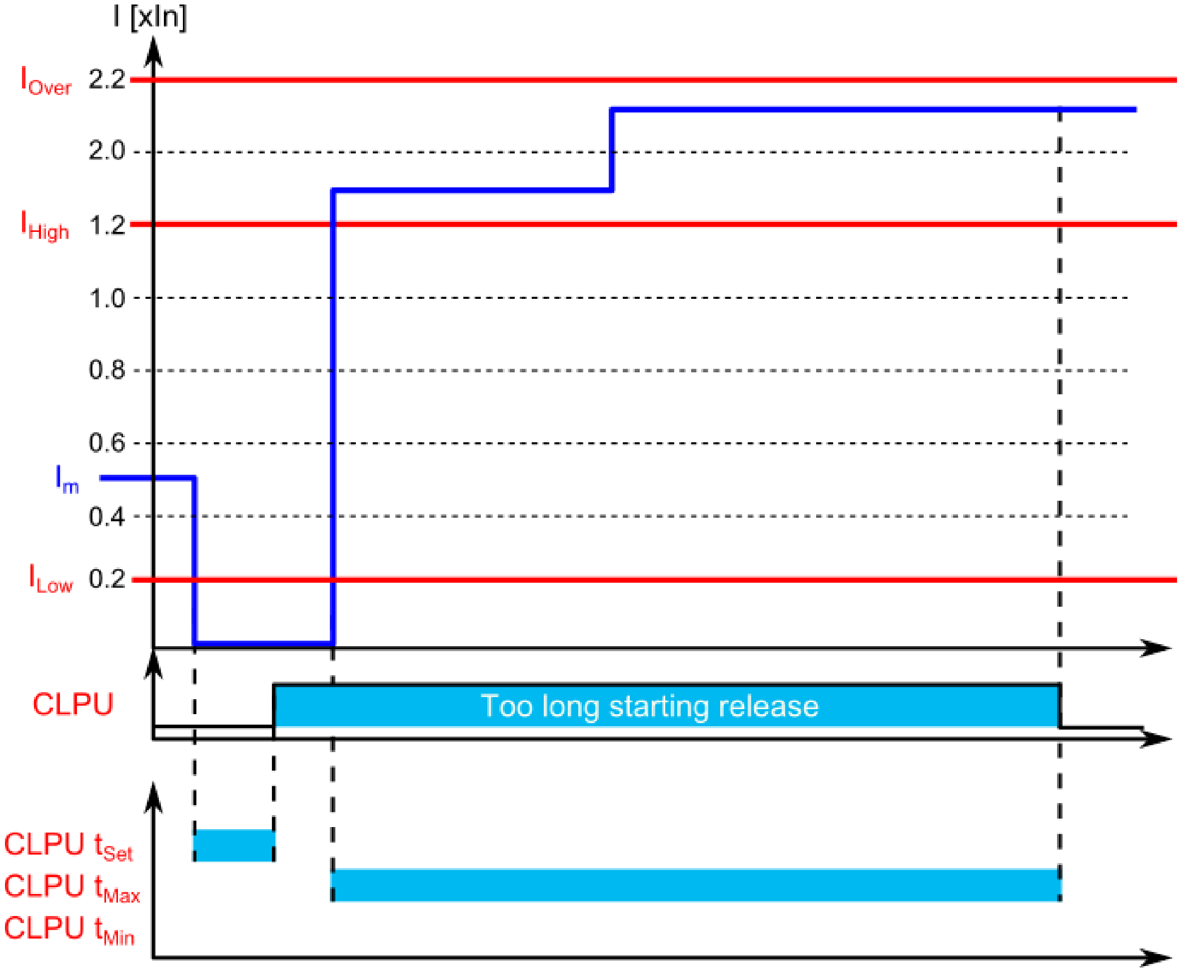
In the example above, the cold load pick-up function does not activate even when the measured current dips below the I_{low} setting, because the T_{set} is not exceeded and therefore no cold load pick-up signal is issued. If the user wants the function to activate within a shorter period of time, the T_{set} parameter can be se to a lower value. If the user wants no delay, the T_{set} can be zero seconds and the operation will be immediate.

Figure. 4.5.7 - 161. Example of timers and pick-up parameters (activated pick-up and instant release due to overcurrent).



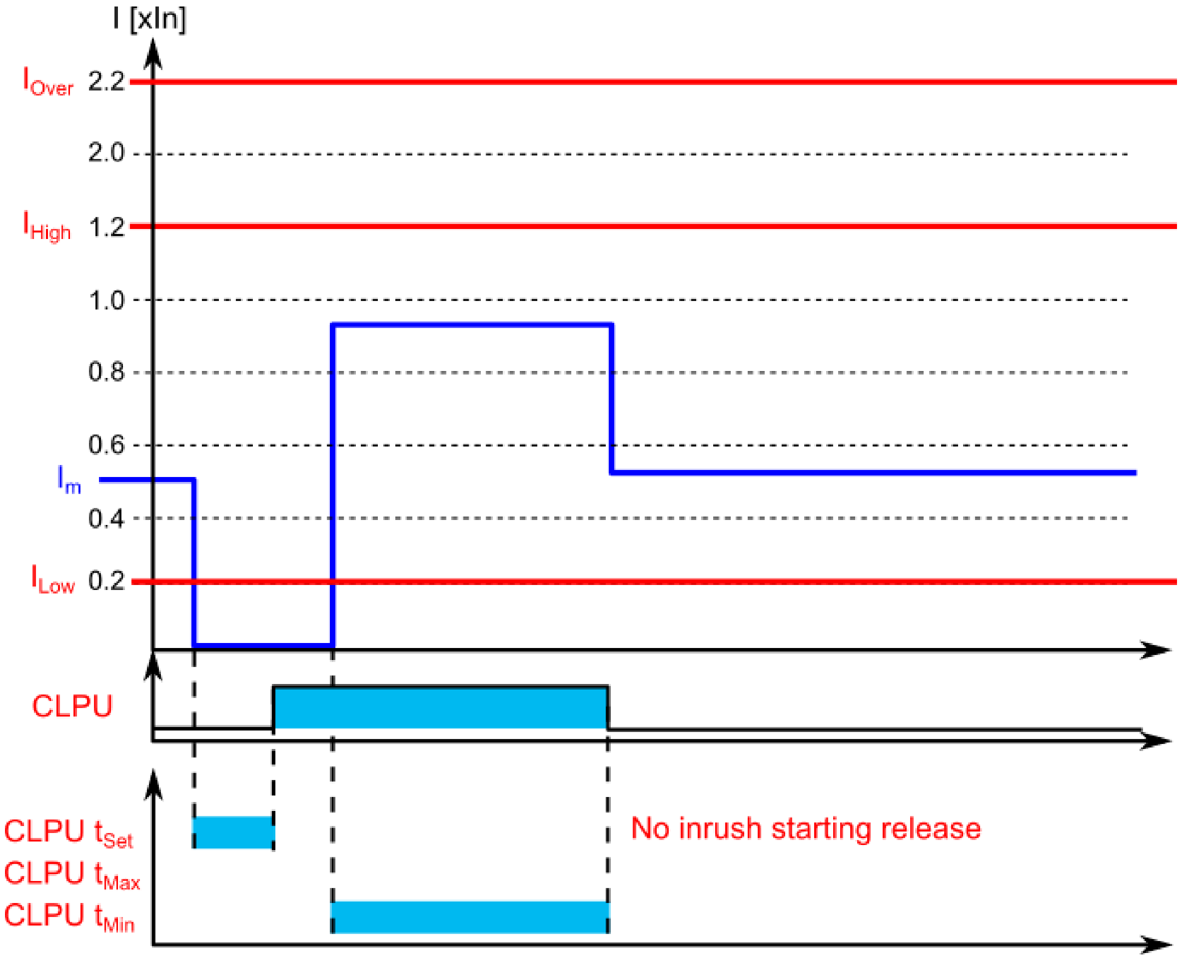
In the example above, the cold load pick-up function activates after the measured current dips below the I_{low} setting and has been there for T_{set} amount of time. When the I_m exceeds the I_{high} setting, a counter starts counting towards the T_{max} time. The measured current exceeds the I_{over} setting during the start-up situation and causes the cold load pick-up signal to be released immediately.

Figure. 4.5.7 - 162. Example of timers and pick-up parameters (activated pick-up and instant release due to too long starting).



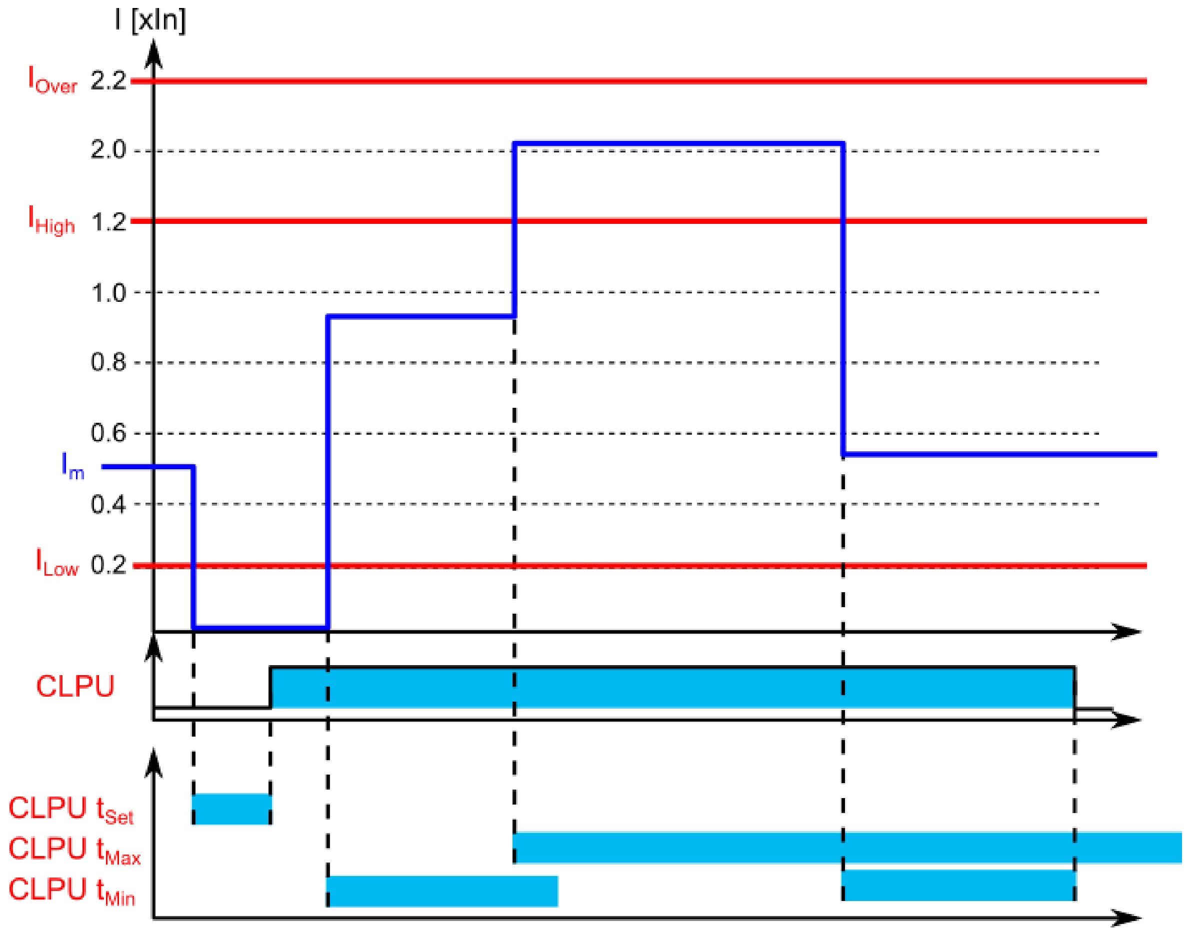
In the example above, the cold load pick-up function activates after the measured current has stayed below the I_{low} setting for a T_{set} amount of time. When the current exceeds the I_{high} setting, a timer starts counting towards the T_{max} time. The measured current stays above the I_{high} setting until the T_{max} is reached, which causes the release of the cold load pick-up signal.

Figure. 4.5.7 - 163. Example of timers and pick-up parameters (no inrush current detected in the starting).



In the example above, the cold load pick-up function activates after the measured current has stayed below the I_{low} setting for a T_{set} amount of time. The current stays between the I_{low} setting and the I_{high} setting, so the cold load pick-up signal is active for T_{min} time. As no inrush current is detected during that time, the signal is released.

Figure. 4.5.7 - 164. Example of timers and pick-up parameters (an inrush current detected during T_{min} time).



In the example above, the cold load pick-up function activates after the measured current has stayed below the I_{low} setting for a T_{set} amount of time. The current increases to between the I_{low} setting and the I_{high} setting, which causes a counter to start counting towards the T_{min} time. Before the counter reaches T_{min}, the current exceeds the I_{high} setting, which causes a counter to start counting towards the T_{max} time. The cold load pick-up signal remains active until the T_{max} has been reached, or until the start-up is over and the T_{min} time is over.

Events and registers

The cold load pick-up function (abbreviated "CLP" in event block names) generates events and registers from the status changes in the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the CLPU ACT and BLOCKED events.

Table. 4.5.7 - 265. Event messages.

Event block name	Event names
CLP1	LowStart ON
CLP1	LowStart OFF
CLP1	HighStart ON

Event block name	Event names
CLP1	HighStart OFF
CLP1	LoadNormal ON
CLP1	LoadNormal OFF
CLP1	Overcurrent ON
CLP1	Overcurrent OFF
CLP1	CLPUActivated ON
CLP1	CLPUActivated OFF
CLP1	Block ON
CLP1	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. 4.5.7 - 266. Register content.

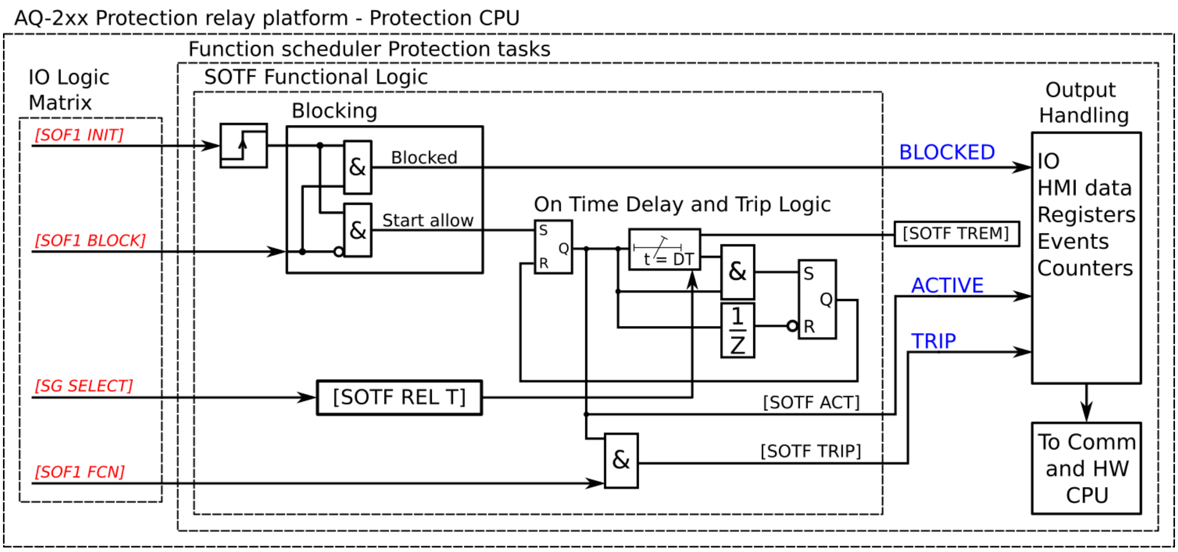
Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
L1/L2/L3 current	Phase currents on trigger time
Time to CLPUact	Time remaining before the function is active
CLPU active time	The time the function has been active before starting
Start-up time	Recorded starting time
Releasing time of CLPU	Reclaim time counter
Setting group in use	Setting group 1...8 active

4.5.8 Switch-on-to-fault (SOTF)

The switch-on-to-fault (SOTF) function is used for speeding up the tripping when the breaker is closed towards a fault or forgotten earthing to reduce the damage in the fault location. The function can be used to control protection functions, or it can be used to directly trip a breaker if any of the connected protection functions starts during the set SOTF time. The operation of the function is instant after the conditions are met and any one signal connected to the "*Function input*" input activates.

The function can be initiated by a digital input, or by a circuit breaker "Close" command connected to the "*SOTF activate input*" input. The duration of the SOTF-armed condition can be set by the "Release time for SOTF" setting parameter; it can be changed if the application so requires through setting group selection.

Figure. 4.5.8 - 165. Simplified function block diagram of the switch-on-to-fault function.



Input signals

The function block does not use analog measurement inputs. Instead, its operation is based entirely on binary signal statuses.

Table. 4.5.8 - 267. Input signals.

Input	Description
Activate input	The digital input or logic signal for the function to arm and start calculating the SOTF time. Any binary signal can be used to activate the function and start the calculation. The rising edge of the signal is considered as the start of the function.
Block input	The input for blocking the function. Any binary signal can be used to block the function from starting.
Function input	The function input activates the function's instant trip if applied when the function is calculating the SOTF time.

Settings

The switch-on-to-fault function has one setting and it determines how long the function remains active after it has been triggered. If the inputs receive any of the set signals during this time, the function's trip is activated.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.5.8 - 268. Settings of the function.

Name	Range	Default	Description
SOTF LN mode	• On • Blocked • Test • Test/Blocked • Off	On	Set mode of SOF block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.

Name	Range	Default	Description
SOTF force status to	• Normal • Blocked • Active • Trip	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.
Release time for SOTF	0.000…1800.000s	1.000s	The time the function is active after triggering.

Read-only parameters

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

Table. 4.5.8 - 269. Information displayed by the function.

Name	Range	Description
SOTF LN behaviour	• On • Blocked • Test • Test/Blocked • Off	Displays the mode of SOF block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
SOTF condition	• Normal • Init • Active • Trip • Blocked	Displays status of the control function.

Function blocking

The function can be blocked by activating the BLOCK input. This prevents the function's active time from starting.

Events and registers

The switch-on-to-fault function (abbreviated "SOF" in event block names) generates events and registers from the status changes in the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the INIT, BLOCKED, ACTIVE and TRIP events.

Table. 4.5.8 - 270. Event messages.

Event block name	Event names
SOF1	SOTF Init ON
SOF1	SOTF Init OFF

Event block name	Event names
SOF1	SOTF Block ON
SOF1	SOTF Block OFF
SOF1	SOTF Active ON
SOF1	SOTF Active OFF
SOF1	SOTF Trip ON
SOF1	SOTF Trip OFF

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

Table. 4.5.8 - 271. Register content.

Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
Used SG	Setting group 1...8 active
SOTF remaining time	The time remaining of the set release time.
SOTF been active time	The time the function has been active.

4.5.9 Synchrocheck (ΔV/Δa/Δf; 25)

Checking the synchronization is important to ensure the safe closing of the circuit breaker between two systems. Closing the circuit breaker when the systems are not synchronized can cause several problems such as current surges which damage the interconnecting elements. The synchrocheck function has three stages: SYN1, SYN2 and SYN3. Their function and availability of these stages depend on which voltage channels are set to "SS" mode or not. Voltage measurement settings are located at *Measurements → Transformers → VT module*. When synchroswitching is used, the function automatically closes the breaker when both sides of the breaker are synchronized.

When only U3 or U4 voltage measurement channel has been set to "SS" mode:

- SYN1 – Supervises the synchronization condition between the channel set to "SS" mode and the selected system voltage (UL1, UL2, UL3, UL12, UL23 or UL31).
- SYN2 – Not active and not visible.
- SYN3 – Not active and not visible.

When both U3 and U4 have been set to "SS" mode:

- SYN1 – Supervises the synchronization condition between the U3 channel and the selected system voltage (UL12, UL23 or UL31).
- SYN2 – Supervises the synchronization condition between the U4 channel and the selected system voltage (UL12, UL23 or UL31).
- 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. 4.5.9 - 166. Example connection of the synchrocheck function (3LN+U4 mode, SYN1 in use, UL1 as reference voltage).

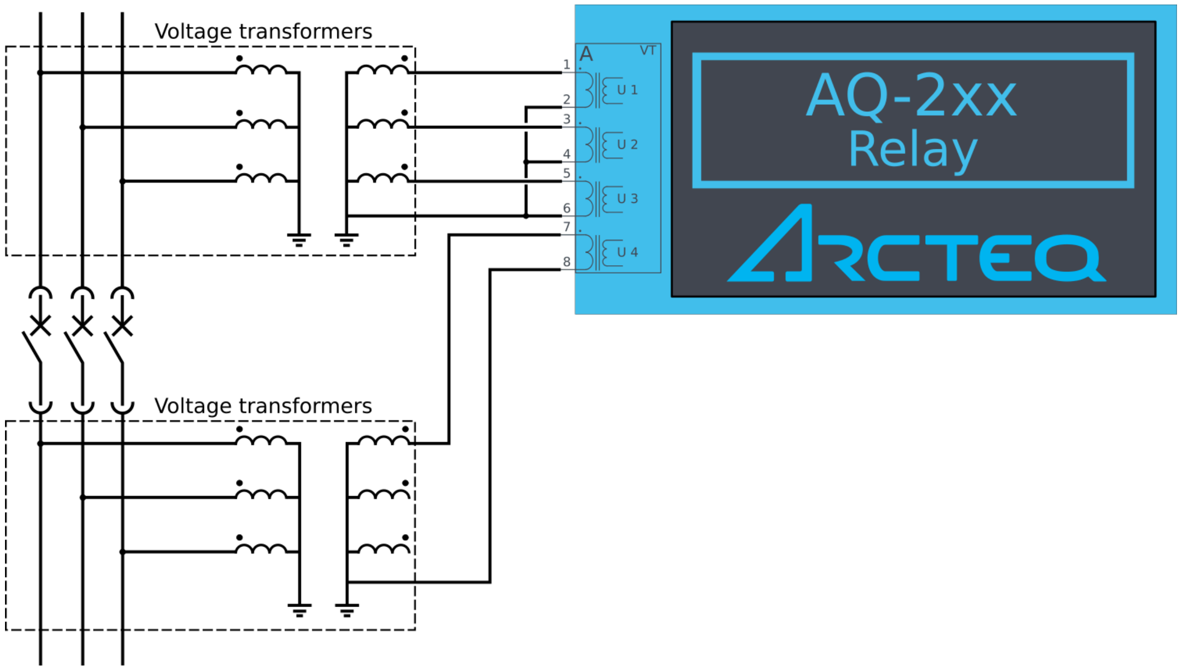


Figure. 4.5.9 - 167. Example connection of the synchrocheck function (2LL+U0+U4 mode, SYN1 in use, UL12 as reference voltage).

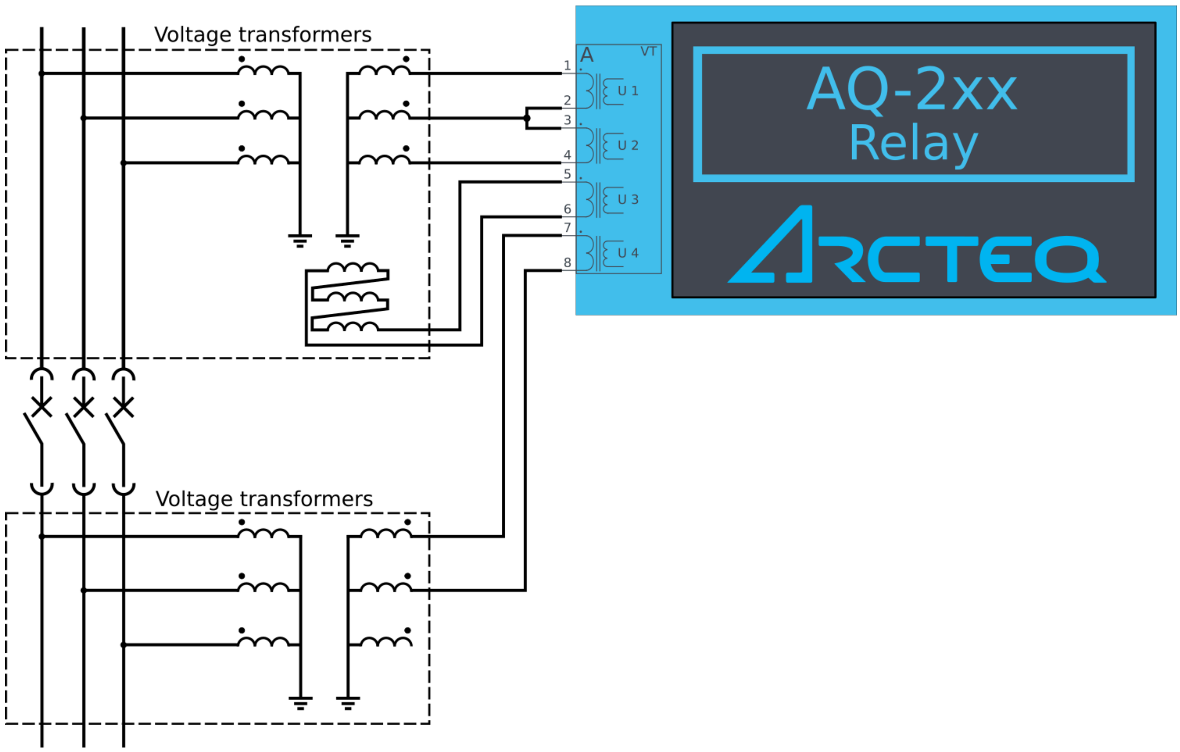


Figure. 4.5.9 - 168. Example connection of the synchrocheck function (2LL+U3+U4 mode, SYN3 in use, UL12 as reference voltage).

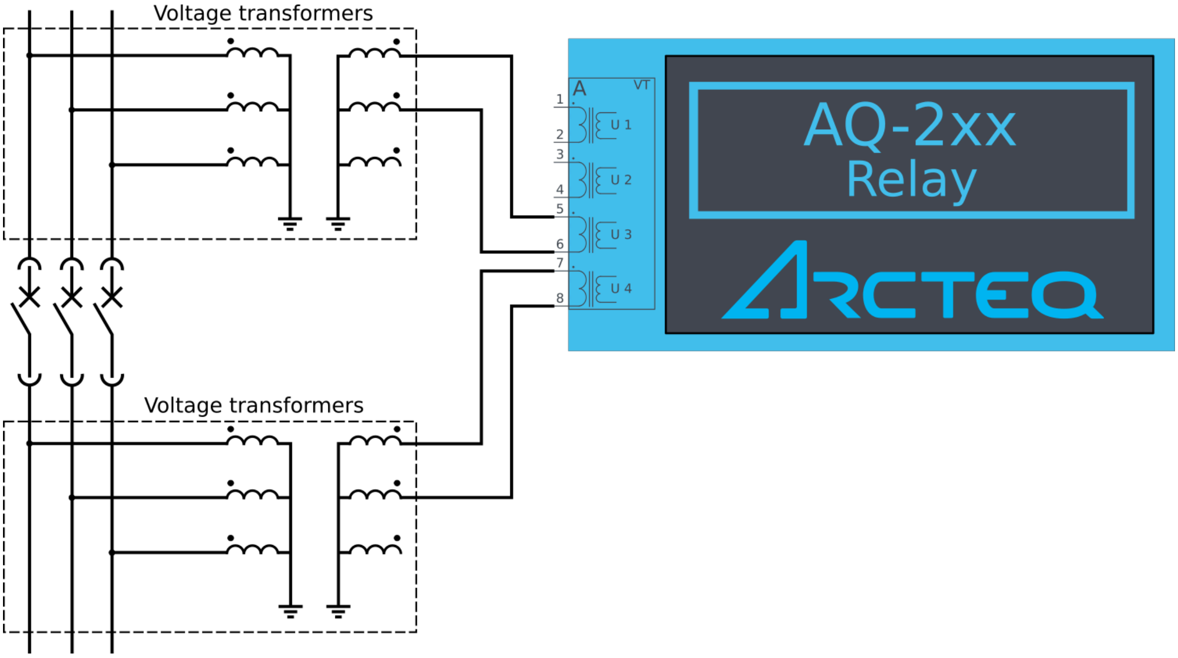


Figure. 4.5.9 - 169. Example application (synchrocheck over one breaker, with 3LL and 3LN VT connections).

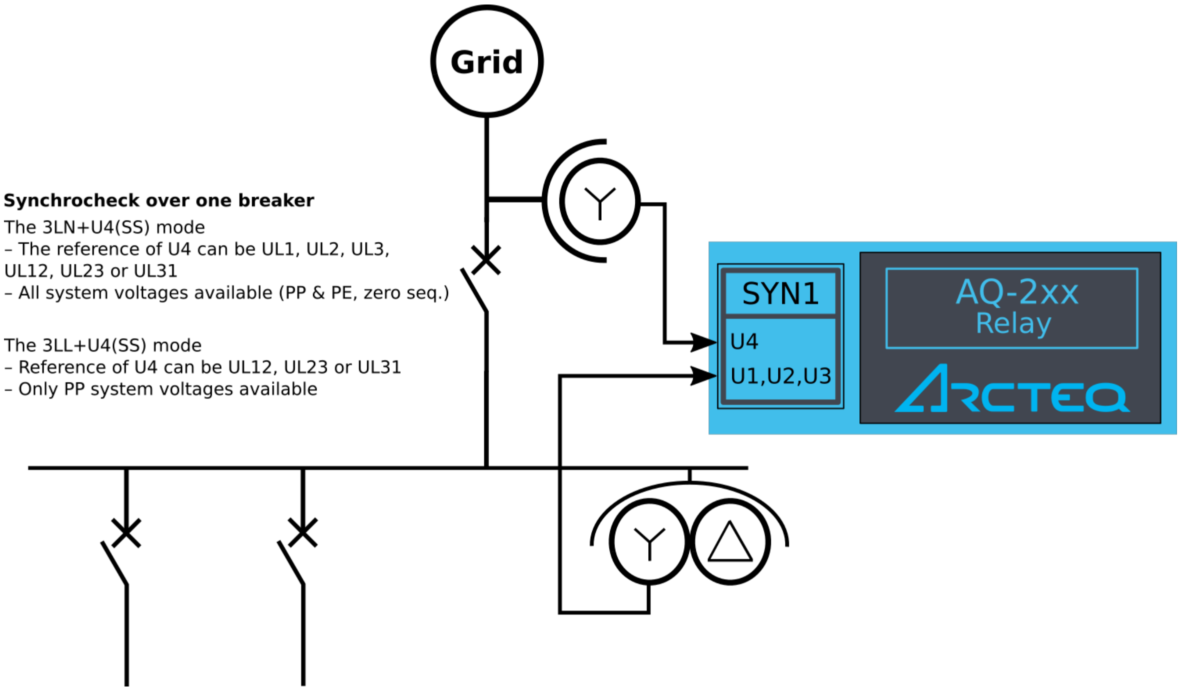


Figure. 4.5.9 - 170. Example application (synchrocheck over one breaker, with 2LL VT connection).

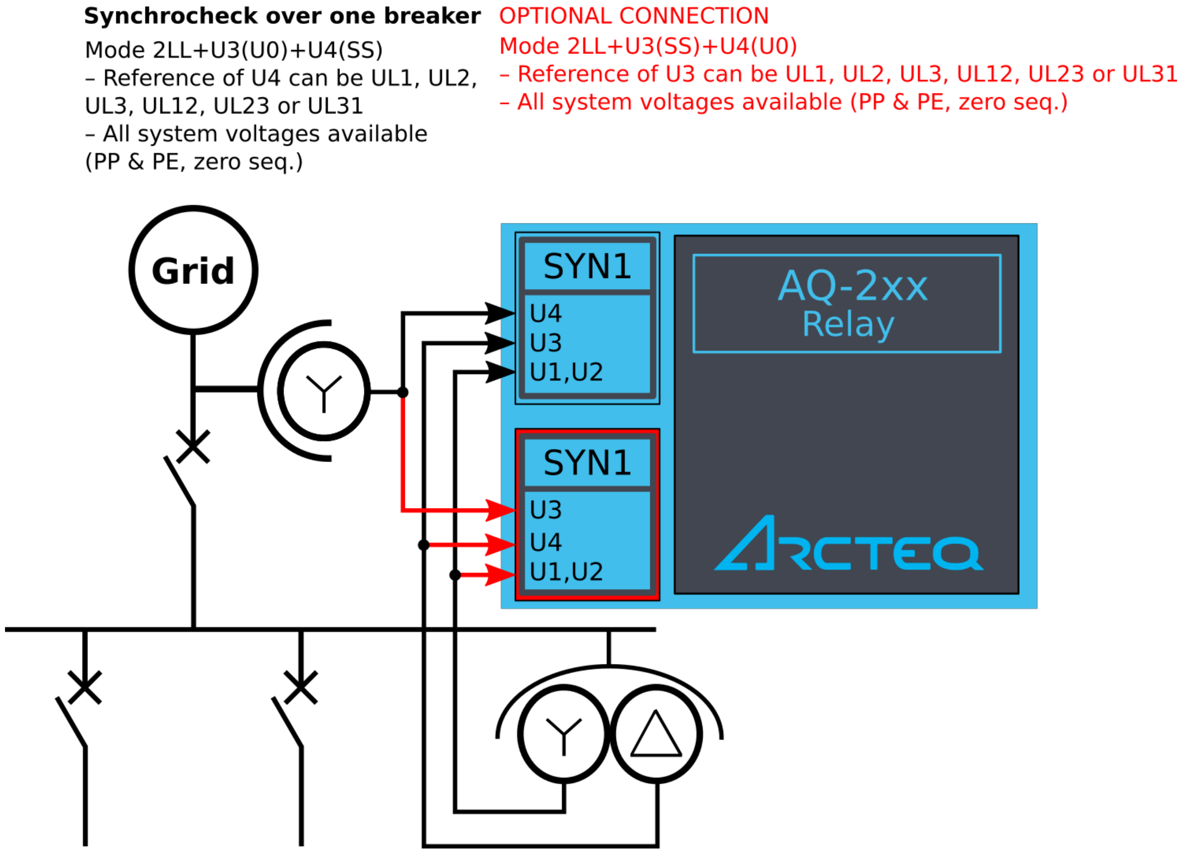


Figure. 4.5.9 - 171. Example application (synchrocheck over two breakers, with 2LL VT connection).

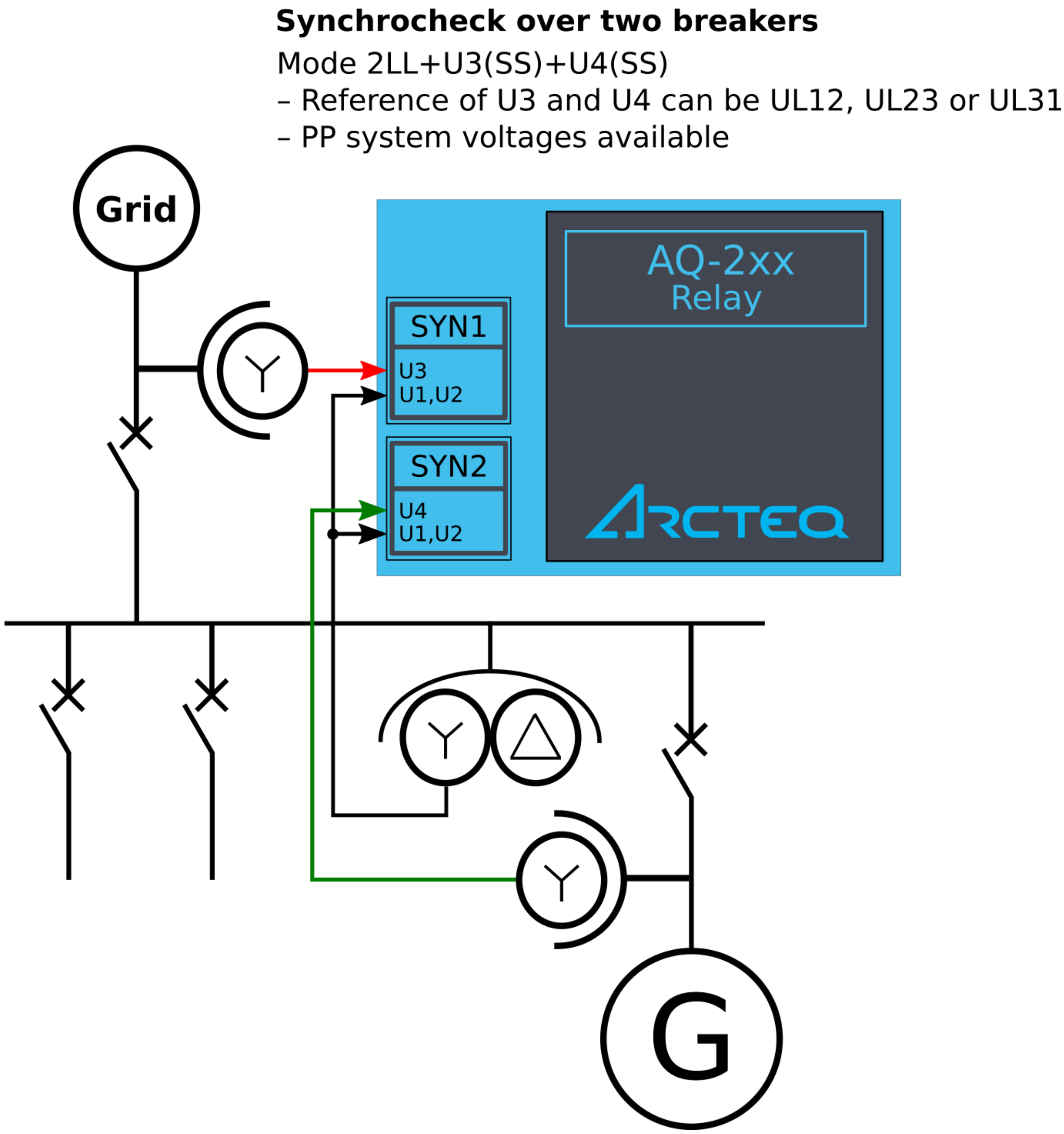
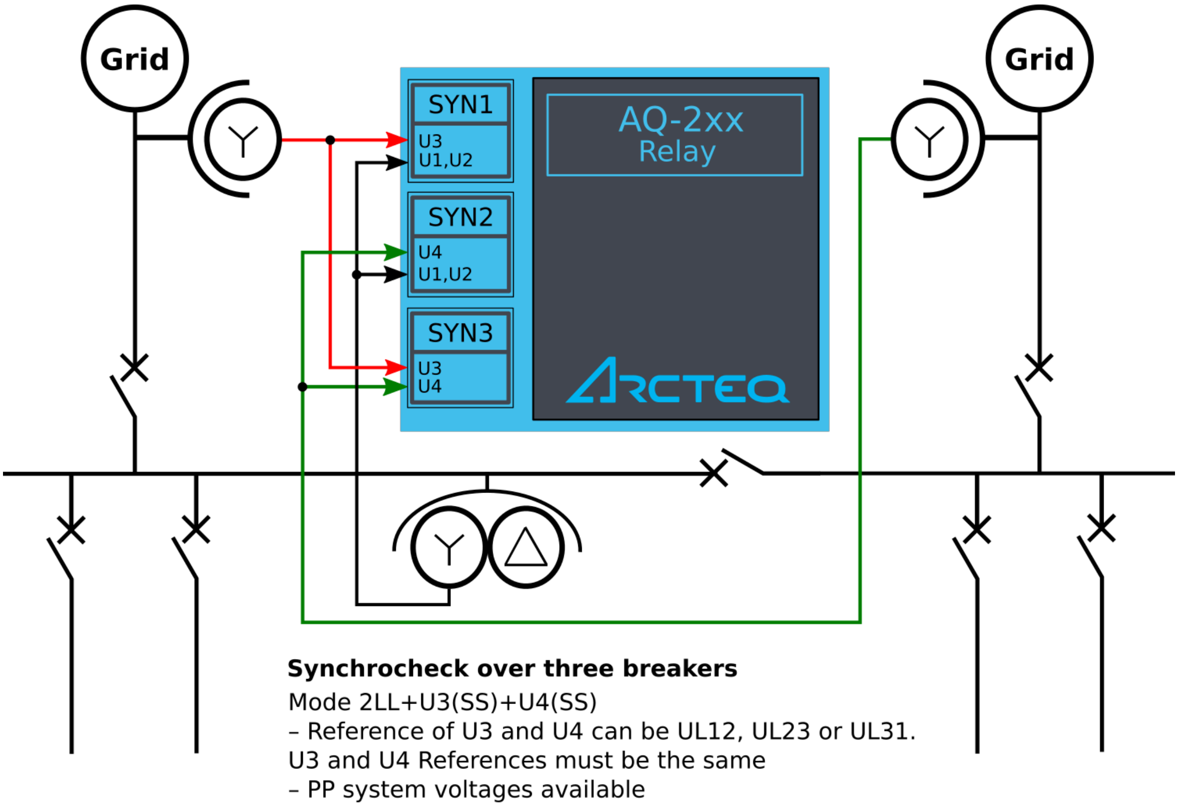


Figure. 4.5.9 - 172. Example application (synchrocheck over three breakers, with 2LL+U3+U4 connection).



NOTICE!
When synchrocheck is used over three breakers, SYN1 and SYN2 must have the same reference voltage.

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.

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. 4.5.9 - 173. System states.

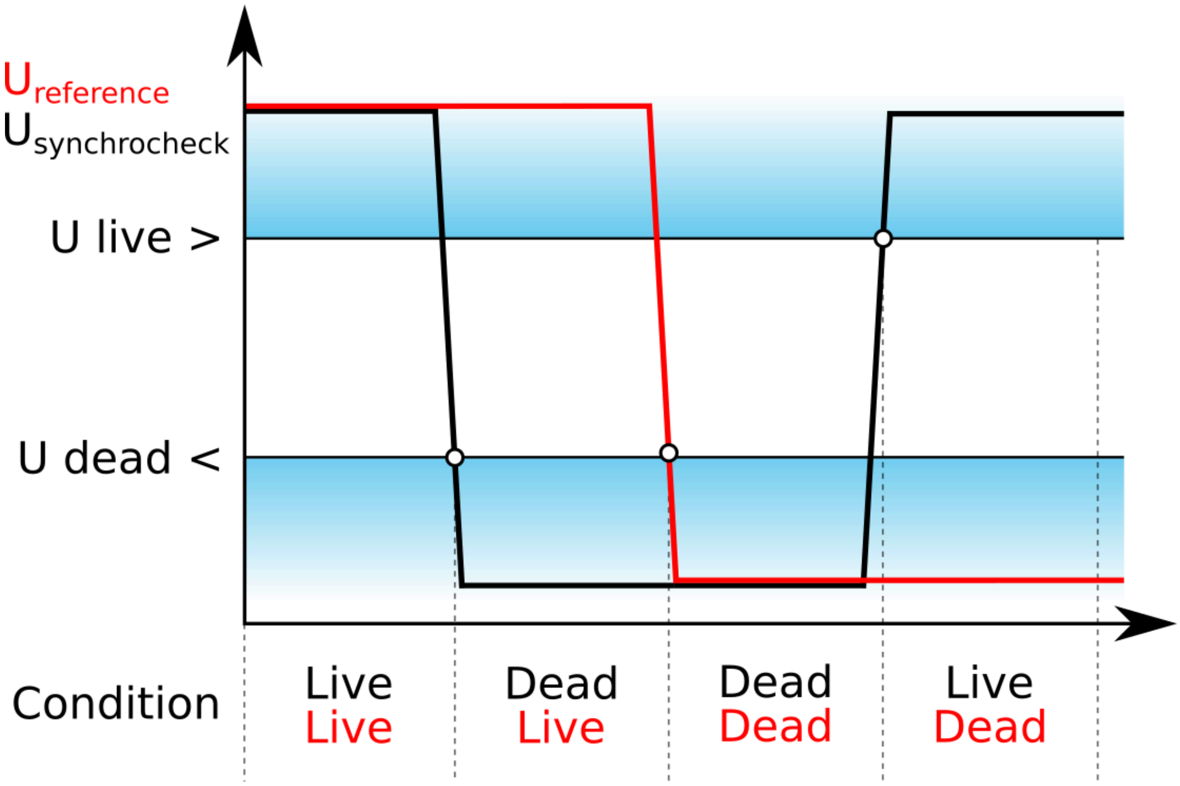


Figure. 4.5.9 - 174. Simplified function block diagram of the SYN1 and SYN2 function.

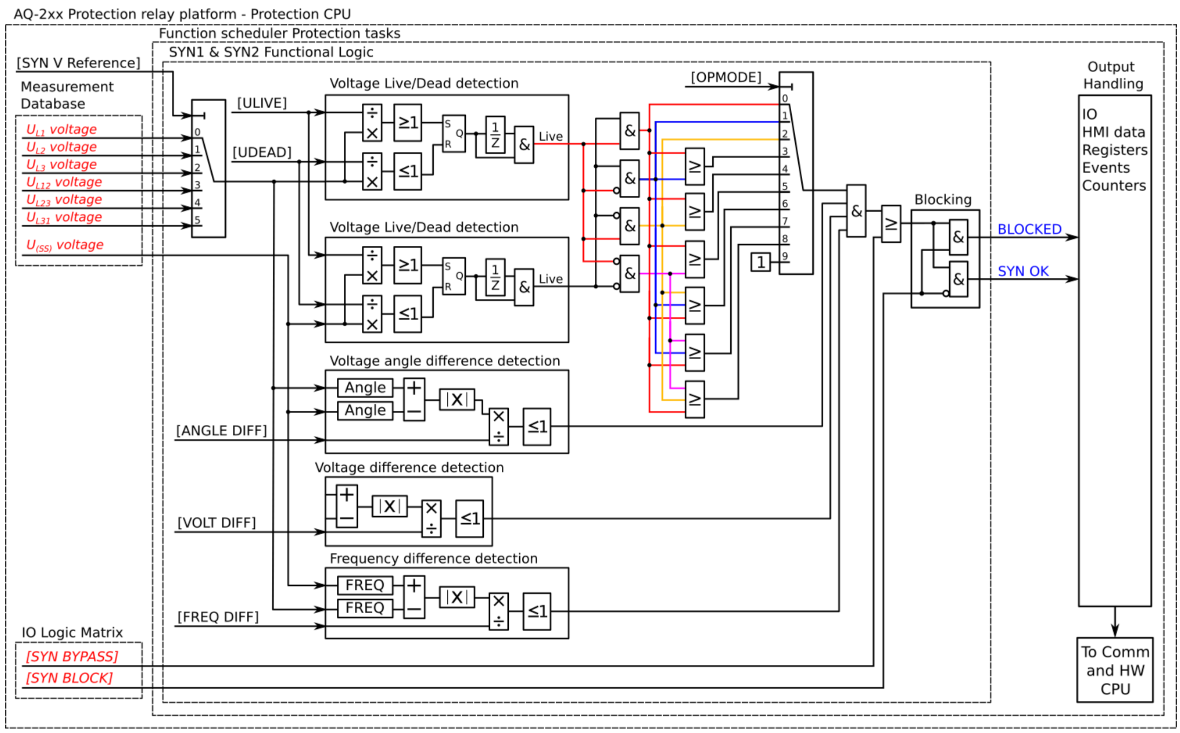
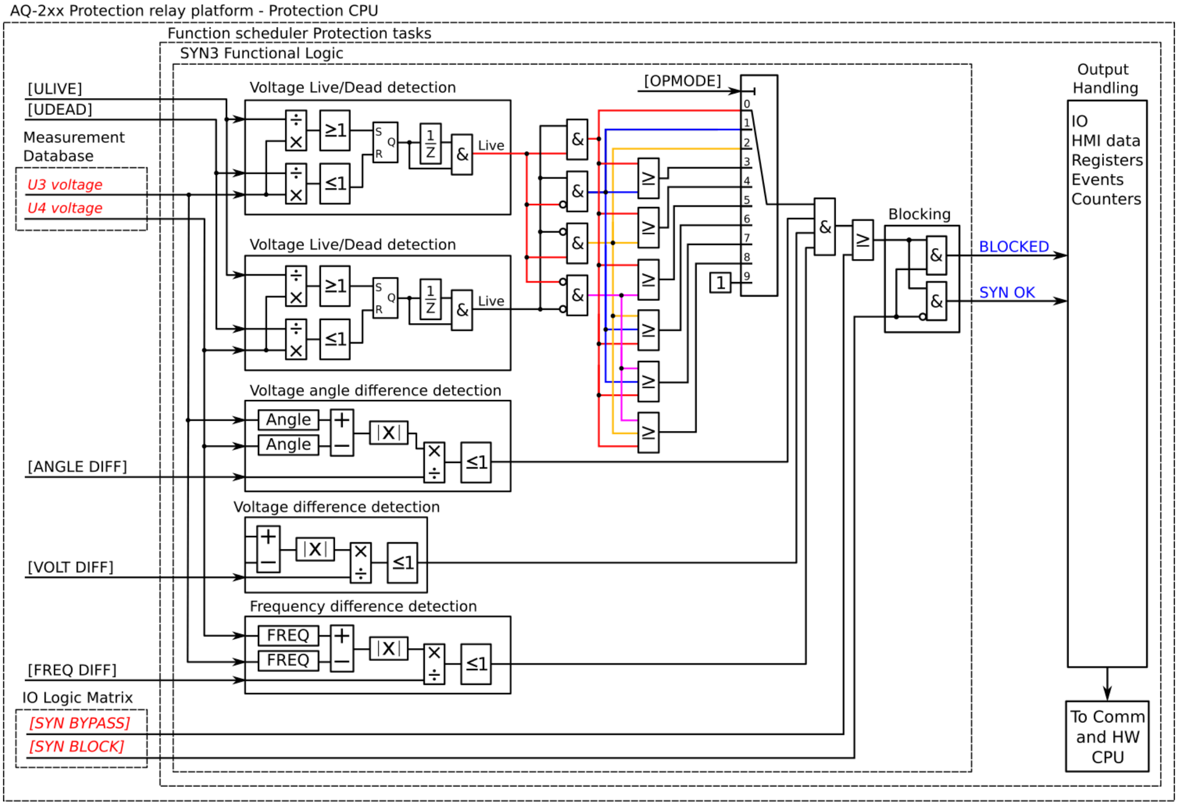


Figure. 4.5.9 - 175. Simplified function block diagram of the SYN3 function.



Measured input

The function block uses user selected voltage channels. The function monitors frequency, angle and fundamental frequency component value of the selected channels.

Table. 4.5.9 - 272. Measurement inputs of the synchrocheck function.

Signal	Description	Time base
U_1RMS	Fundamental frequency component of U_1/V voltage channel	5ms
U_2RMS	Fundamental frequency component of U_2/V voltage channel	5ms
U_3RMS	Fundamental frequency component of U_3/V voltage channel	5ms
U_4RMS	Fundamental frequency component of U_4/V voltage channel	5ms

Read-only parameters

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

Table. 4.5.9 - 273. Information displayed by the function.

Name	Range	Step	Description
dV / da / df LN behaviour	• On • Blocked • Test • Test/ Blocked • Off	-	Displays the mode of SYN block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
SYN condition	• SYN1 Blocked • SYN1 Ok • SYN1 Bypass • SYN1 Vcond Ok • SYN1 Vdiff Ok • SYN1 Adiff Ok • SYN1 fdiff Ok	-	Displays status of the control function.
SYN volt status	• Dead Dead • Live Dead • Dead Live • Live Live • Undefined • Not monitored	-	Displays the voltage status of both sides.
SYN Mag diff	-120...120%Un	0.01%Un	Displays voltage difference between the two measured voltages.
SYN Ang diff	-360'...360deg	0.01deg	Displays angle difference between the two measured voltages.
SYN Freq diff	-75...75Hz	0.001Hz	Displays frequency difference between the two measured voltages.
SYN Switch status	• Still • Departing • Enclosing	-	Displays the synchroswitching status. This parameter is visible when "SYN Switching" parameter has been set to "Use SynSW".
Estimated BRK closing time	0...360s	0.005s	Estimated time left to breaker closing.
Networks rotating time	0...360s	0.005s	Estimated time how long it takes for the network to rotate fully.
Networks placement atm	-360...360deg	0.001deg	Networks placement in degrees.

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.

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. 4.5.9 - 274. General settings.

Name	Range	Step	Default	Description
dV / da / df LN mode	• On • Blocked • Test • Test/Blocked • Off	-	On	Set mode of SYN block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
SYN(1,2,3) Status Force to	• Normal • SYN1 Blocked • SYN1 Ok • SYN2 Blocked • SYN2 Ok • SYN3 Blocked • SYN3 Ok	-	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.
System voltages are measured on	• Bus, Line is reference • Line, Bus is reference	-	Bus, Line is reference	Defines which voltage is the reference when determining dead/live status of voltages.
Use SYNx	• No • Yes	-	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.
SYNx Start check	• Always • On start	-	Always	Selects synchrocheck start behaviour. If "On start" is selected "SYNx START" input must be active for synchrochecking to begin. "SYNx START" input signal can be defined at *IO → Input control* menu. If "Always" is selected "SYNx START" input is not needed for synchrochecking to start.
SYN1 V Reference	• Not in use • UL12 • UL23 • UL31 • UL1 • UL2 • UL3	-	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(SS) - 2LL+U3(U0)+U4(SS) - 2LL+U3(SS)+U4(U0) Reference options 0...3 available: - 3LL+U4(SS) - 2LL+U3(Not in use)+U4(SS) - 2LL+U3(SS)+U4(Not in use)

Name	Range	Step	Default	Description
SYN2 V Reference	• Not in use • UL12 • UL23 • UL31	-	Not in use	Selects the reference voltage of the stage. SYN2 is available when both U3 and U4 have been set to SS mode.
SYN3 V Reference	• Not in use • U3–U4	-	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.
SYNx Switching	• Not in use • Use SynSW	-	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.
SYNx Switch bk time	0.000...1800.000s	0.005s	0.05s	Estimated time between a close command given to a breaker and the breaker entering the closed state. This setting 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.
SYNx Switching object	• Object 1 • Object 2 • Object 3 • Object 4 • Object 5	-	Object 1	When synchroswitching is enabled, this parameter defines which object receives the breaker's closing command. This setting is only visible when "SYNx Switching" is activated.
Estimated BRK closing time	0.000…360.000s	0.005s	-	Displays the estimated time until networks are synchronized.
Networks rotating time	0.000…360.000s	0.005s	-	Displays the time it takes for both sides of the network to fully rotate.
Networks placement atm	-360.000…360.000deg	0.001deg	-	Indicates the angle difference between the two sides of the breaker at the moment.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.5.9 - 275. Synchrocheck stage settings.

Name	Range	Step	Default	Description
SYNx U conditions	• LL only • LD only • DL only • LL & LD • LL & DL • LL & DD • LL & LD & DL • LL & LD & DD • LL & DL & DD • Bypass	-	LL only	Determines the allowed states of the supervised systems. L = Live D = Dead
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. Not in use when set to 0%Un
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…90.00deg	0.01deg	3deg	The maximum allowed angle difference between the systems.
SYNx freq diff <	0.05…0.50Hz	0.01Hz	0.1Hz	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 the status changes in the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs can be used for direct I/O controlling and user logic programming.

The function offers three (3) independent stages; the events are segregated for each stage operation.

Table. 4.5.9 - 276. Event messages.

Event block name	Event names
SYN1	SYN1 Blocked On
SYN1	SYN1 Blocked Off
SYN1	SYN1 Ok On
SYN1	SYN1 Ok Off
SYN1	SYN1 Bypass On
SYN1	SYN1 Bypass Off
SYN1	SYN1 Volt condition OK
SYN1	SYN1 Volt cond not match

Event block name	Event names
SYN1	SYN1 Volt diff Ok
SYN1	SYN1 Volt diff out of setting
SYN1	SYN1 Angle diff Ok
SYN1	SYN1 Angle diff out of setting
SYN1	SYN1 Frequency diff Ok
SYN1	SYN1 Frequency diff out of setting
SYNX1	SYN1 Voltage difference Ok On
SYNX1	SYN1 Voltage difference Ok Off
SYNX1	SYN1 Angle difference Ok On
SYNX1	SYN1 Angle difference Ok Off
SYNX1	SYN1 Frequency difference Ok On
SYNX1	SYN1 Frequency difference Ok On
SYNX1	SYN1 Live Live Condition On
SYNX1	SYN1 Live Live Condition Off
SYNX1	SYN1 Live Dead Condition On
SYNX1	SYN1 Live Dead Condition Off
SYNX1	SYN1 Dead Live Condition On
SYNX1	SYN1 Dead Live Condition Off
SYNX1	SYN1 Dead Dead Condition On
SYNX1	SYN1 Dead Dead Condition On
SYNX1	SYN1 Voltage Difference too high Vbus > Vline On
SYNX1	SYN1 Voltage Difference too high Vbus > Vline Off
SYNX1	SYN1 Voltage Difference too high Vline > Vbus On
SYNX1	SYN1 Voltage Difference too high Vline > Vbus Off
SYNX1	SYN1 Frequency Difference too high fbus > fline On
SYNX1	SYN1 Frequency Difference too high fbus > fline Off
SYNX1	SYN1 Frequency Difference too high fline > fbus On
SYNX1	SYN1 Frequency Difference too high fline > fbus Off
SYNX1	SYN1 Angle Difference too high a bus leads a line On
SYNX1	SYN1 Angle Difference too high a bus leads a line Off
SYNX1	SYN1 Angle Difference too high a line leads a bus On

Event block name	Event names
SYNX1	SYN1 Angle Difference too high a line leads a bus Off
SYNX1	SYN1 Bus voltage Live On
SYNX1	SYN1 Bus voltage Live Off
SYNX1	SYN1 Bus voltage Dead On
SYNX1	SYN1 Bus voltage Dead Off
SYNX1	SYN1 Line voltage Live On
SYNX1	SYN1 Line voltage Live Off
SYNX1	SYN1 Line voltage Dead On
SYNX1	SYN1 Line voltage Dead 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. 4.5.9 - 277. Register content.

Name	Range
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
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.

4.5.10 Milliampere output control

The milliamp current loop is the prevailing process control signal in many industries. It is an ideal method of transferring process information because 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

AQ-200 series supports 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.

Table. 4.5.10 - 278. Main settings (output channels).

Name		Range	Default	Description
mA option card 1	Enable mA output channels 1 and 2	• Disabled • Enabled	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	• Disabled • Enabled	Disabled	Enables and disables the outputs of the mA output card 2.
	Enable mA output channels 7 and 8			

Table. 4.5.10 - 279. Settings for mA output channels.

Name	Range	Step	Default	Description
Enable mA output channel	• Disabled • Enabled	-	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	• Currents • Voltages • Powers • Impedance and admittance • Other	-	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	$-10^7 \ldots 10^7$	0.001	0	The first input point in the mA output control curve.
Scaled mA output value 1	0.0000…24.0000mA	0.0001mA	0mA	The mA output value when the measured value is equal to or less than Input value 1.

Name	Range	Step	Default	Description
Input value 2	$-10^7 \ldots 10^7$	0.001	1	The second input point in the mA output control curve.
Scaled mA output value 2	0.0000…24.0000mA	0.0001mA	0mA	The mA output value when the measured value is equal to or greater than Input value 2.

Figure. 4.5.10 - 176. Example of the effects of mA output channel settings.

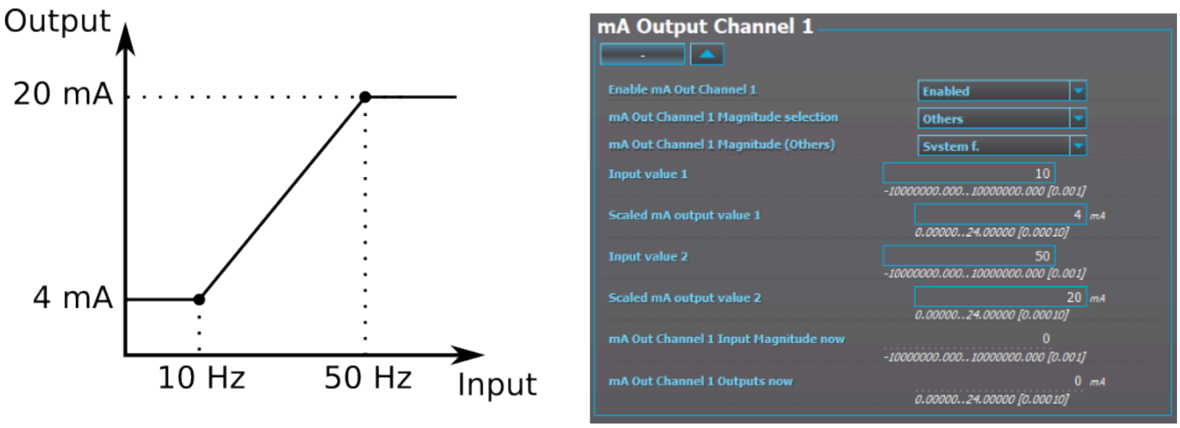


Table. 4.5.10 - 280. Hardware indications.

Name	Range	Description
Hardware in mA output channels 1...4 Hardware in mA output channels 5...8	• None • Slot A • Slot B • Slot C • Slot D • Slot E • Slot F • Slot G • Slot H • Slot I • Slot J • Slot K • Slot L • Slot M • Slot N • Too many cards installed	Indicates the option card slot where the mA output card is located.

Table. 4.5.10 - 281. Measurement values reported by mA output cards.

Name	Range	Step	Description
mA in Channel 1	0.0000…24.0000mA	0.0001mA	Displays the measured mA value of the selected input channel.
mA in Channel 2			
mA Out Channel Input Magnitude now	$-10^7 \ldots 10^7$	0.001	Displays the input value of the selected mA output channel at that moment.

Name	Range	Step	Description
mA Out Channel Outputs now	0.0000…24.0000mA	0.0001mA	Displays the output value of the selected mA output channel at that moment.

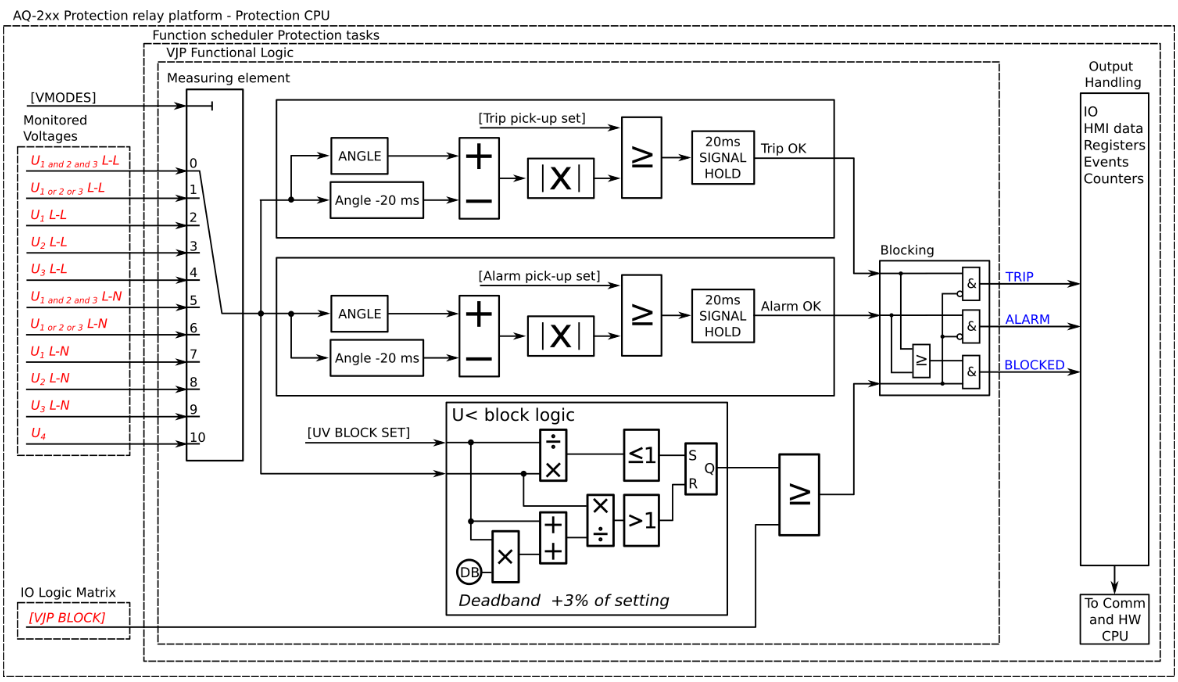
4.5.11 Vector jump (Δφ; 78)

Distribution systems may include different kinds of distributed power generation sources, such as wind farms and diesel or fuel generators. When a fault occurs in the distribution system, it is usually detected and isolated by the protection system closest to the faulty point, resulting in the electrical power system shutting dow either partially or completely. The remaining distributed generators try to deliver the power to the part of the distribution system that has been disconnected from the grid, and usually an overload condition can be expected. Under such overload conditions, it is normal to have a drop in voltage and frequency. This overload results in the final system disconnection from the islanding generator(s). The disconnection depends greatly on the ratio between the power generation and the demand of the islanded system. When any power is supplied to a load only from distributed generators, (due to the opening of the main switch), the situation is called an isolated island operation or an islanded operation of the electrical distribution network.

The vector jump control function is suitable to detect most islanding situations and to switch off the mains breaker in order to let the generator only supply loads according to their rated power value. Therefore, an overload does not cause any mechanical stress to the generator unit(s). The vector jump function should be located either on the mains side of the operated breaker or on the islanding generator side.

The vector jump function is used for instant tripping and has only one operating stage. The function has an algorithm which follows the samples of chosen measured voltages (64 samples/cycle). The reference voltage used can be all or any of the phase-to-phase or phase-to-neutral voltages.

Figure. 4.5.11 - 177. Simplified function block diagram of the Δφ function.



Measured input

The function block uses phase-to-phase or phase-to-neutral voltages and always uses complex measurement from samples.

Table. 4.5.11 - 282. Measurement inputs of the vector jump function.

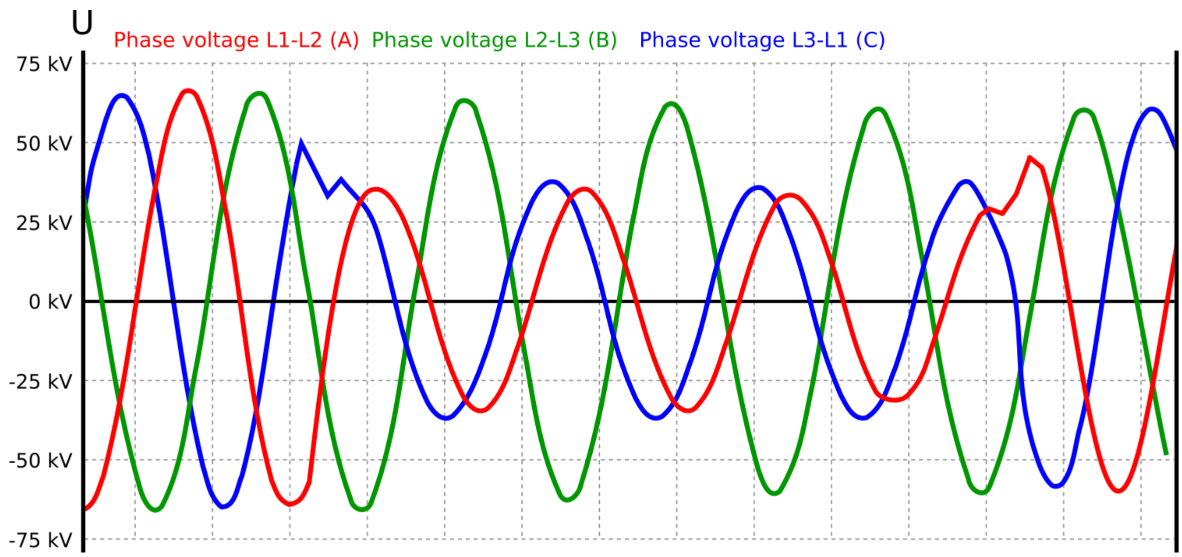
Signal	Description	Time base
U_1 CMPLX	The complex vector of U_1/V voltage channel	5ms
U_2 CMPLX	The complex vector of U_2/V voltage channel	5ms
U_3 CMPLX	The complex vector of U_3/V voltage channel	5ms
U_4 CMPLX	The complex vector of U_4/V voltage channel	5ms

Pick-up settings

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

When a fault appears in the power system and some areas are disconnected, normally the remaining generators connected to the network must supply the area disconnected from the utility side supply. This results in an instantaneous demand of power that the generators must tackle. The excitation and the mechanical systems cannot answer such a huge demand of power quickly even if there were enough reserve power. The worst of the situation is received by the rotors of the generator units: they suffer a torsion torque that can even break the rotor and cause subsequent damage not only for the generator but for the entire power plant too.

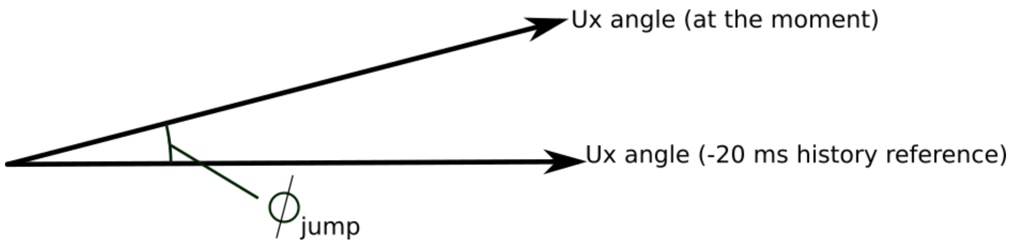
Figure. 4.5.11 - 178. Generator islanding.



As can be seen in the example above, only phase-to-phase voltages L1-L2 and L3-L1 have been reduced, while voltage L2-L3 remains the same. This means that the problem occured in phase L1 of the network. The voltage level is not reduced to zero, nor is the voltage in any phase is totally lost. The phases without the fault condition remain normal with the same value. On the other hand, the frequency can sag as can be seen in the figure above.

The *Δα* setting parameter controls the pick-up of the vector jump function. This defines the minimum allowed rapid measured voltage angle change before action from the function. The function constantly calculates the ratio between the $\Delta\alpha_{set}$ and the measured magnitude ($\Delta\alpha_m$) for each of the selected voltages. The function's stage trip signal lasts for 20 ms and automatically resets after that time has passed. The setting value is common for all measured amplitudes.

Figure. 4.5.11 - 179. Vector jump from the function's point of view.



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. 4.5.11 - 283. General settings of the function.

Name	Range	Default	Description
Δα LN mode	• On • Blocked • Test • Test/ Blocked • Off	On	Set mode of VJP block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
Δα force status to	• Normal • Blocked • Trip • Alarm	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.
Available stages	• Trip • Trip and alarm	Trip	Defines if alarm is included with trip or not.
Monitored voltages	• System all P-P Voltages • System any P-P Voltage • System L12 Voltage • System L23 Voltage • System L31 Voltage • System all P-E voltages • System any P-E voltage • System L1 Voltage • System L2 Voltage • System L3 Voltage • U4 Voltage	System any P-P Voltage	Defines the monitored voltage channel(s)

Table. 4.5.11 - 284. Pick-up settings.

Name	Range	Step	Default	Description
Pick-up setting Δα (lead or lag) Trip	0.05…30.00°	0.01°	5°	Pick-up setting for trip signal
Pick-up setting Δα (lead or lag) Alarm	0.05…30.00°	0.01°	5°	Pick-up setting for alarm signal
Undervoltage block limit % < Un	0.01…100.00%U_n	0.01%U_n	95%U_n	Block setting. When measured voltage is below this setting the function is blocked.

Read-only parameters

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

Table. 4.5.11 - 285. Information displayed by the function.

Name	Range	Step	Description
Δα > LN behaviour	• On • Blocked • Test • Test/ Blocked • Off	-	Displays the mode of UEX block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
Δα > condition	• Normal • Blocked • Trip • Alarm	-	Displays status of the protection function.
Voltage meas selected	• Selection Ok • Selection not available	-	Displays validity of the voltage channel(s) selected in "Monitored voltages" parameter.
Δα > U1 Angle difference	-360...360deg	0.01deg	Displays the angle difference between present time and 20 ms ago.
Δα > U2 Angle difference			
Δα > U3 Angle difference			
Δα > U1meas/ set	-360...360p.u.	0.01p.u.	Displays the ratio between the measured voltage and undervoltage block limit setting.
Δα > U2meas/ set			
Δα > U3meas/ set			

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 ALARM or 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.

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 vector jump function (abbreviated "VJP" in event block names) generates events and registers from the status changes in the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the ALARM, TRIP and BLOCKED events.

Table. 4.5.11 - 286. Event messages.

Event block name	Event names
VJP1	Block ON
VJP1	Block OFF
VJP1	Trip ON
VJP1	Trip OFF
VJP1	Alarm ON
VJP1	Alarm 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 ALARM, TRIP or BLOCKED. The table below presents the structure of the function's register content.

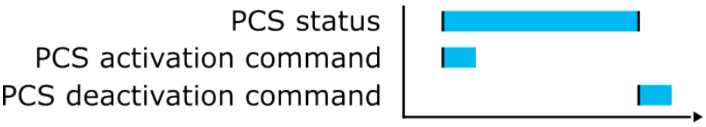
Table. 4.5.11 - 287. Register content.

Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
Fault type	L1(2), L2(3), L3(1) and U4
Trip Δα meas / dataset	Trip angle difference
Alarm Δα meas / dataset	Alarm angle difference

Register	Description
Setting group in use	Setting group 1...8 active

4.5.12 Programmable control switch

The programmable control switch is a control function that controls its binary output signal. This output signal can be controlled locally from the device's mimic (displayed as a box in the mimic) or remotely from the RTU. The main purpose of programmable control switches is to block or enable function and to change function properties by changing the setting group. However, this binary signal can also be used for any number of other purposes, just like all other binary signals. Once a programmable control switch has been activated or disabled, it remains in that state until given a new command to switch to the opposite state (see the image below). The switch cannot be controlled by an auxiliary input, such as digital inputs or logic signals; it can only be controlled locally (mimic) or remotely (RTU).



Settings.

These settings can be accessed at *Control → Device I/O → Programmable control switch*.

Table. 4.5.12 - 288. Settings.

Name	Range	Default	Description
Switch name	-	Switchx	The user-settable name of the selected switch. The name can be up to 32 characters long.
Access level for Mimic control	• User • Operator • Configurator • Super user	Configurator	Determines which access level is required to be able to control the programmable control switch via the Mimic.

Events

The programmable control switch function (abbreviated "PCS" in event block names) generates events from the status changes in the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp. The function offers five (5) independent switches. The function's output signals can be used for direct I/O controlling and user logic programming.

Table. 4.5.12 - 289. Event messages.

Event block name	Event names
PCS	Switch 1 ON
PCS	Switch 1 OFF
PCS	Switch 2 ON
PCS	Switch 2 OFF

Event block name	Event names
PCS	Switch 3 ON
PCS	Switch 3 OFF
PCS	Switch 4 ON
PCS	Switch 4 OFF
PCS	Switch 5 ON
PCS	Switch 5 OFF

4.5.13 User buttons

AQ-250 devices have twelve (12) physical user buttons in the front panel of the device. The main purpose of user buttons is to block or enable functions and to change function properties by changing the setting group. However, this binary signal can also be used for any number of other purposes, just like all other binary signals. Push buttons have two operation modes: "Press release" and "Toggle On/Off". In "Press release" mode the push button status is active while the button is pressed down. In "Toggle On/Off" mode push button status toggles between "On" and "Off". Each button has a user configurable LED at the top left corner of the button. The LED can be configured to activate red, orange or green color from button status or any other logical binary signal.

General user button settings and LED activation settings can be set at *Control → Device IO → User-button Settings*.

NOTICE!
Status of push button output can only be controlled from the AQ-200 device front panel i.e. can't be controlled remotely. Therefore it is recommended to use "a virtual button" (programmable control switches or logical inputs) if a toggleable signal must be controlled both locally and remotely.

Table. 4.5.13 - 290. User button settings

Name	Range	Step	Default	Description
User editable description 1...12	-	-	BTN1...12	Description of the button. If "Function button" view has been added to the "Carousel design", these descriptions are used for the buttons.
Mode of Push-button	Press release Toggle On/Off	-	Press release	Defines the operation mode of the button. In "Press release" mode the button signal is active while the button is pressed down. In "Toggle On/Off" mode the button signal changes status between "On" and "Off" each time the button is pressed.

Table. 4.5.13 - 291. User button output signals

Signal name	Description
Status Push-button 1...12 On	"On" status of each push-button
Status Push-button 1...12 Off	"Off" status of each push-button

4.5.14 Analog input scaling curves

Sometimes when measuring with RTD inputs, milliampere inputs and digital inputs the measurement might be inaccurate because the signal coming from the source is inaccurate. One common example of this is tap changer location indication signal not changing linearly from step to step. If the output difference between the steps are not equal to each other, measuring the incoming signal accurately is not enough. "Analog input scaling curves" menu can be used to take these inaccuracies into account.

Analog input scaling curve settings can be found at *Measurement → AI(mA, DI volt) scaling* menu.

Currently following measurements can be scaled with analog input scaling curves:

- RTD inputs and mA inputs in "RTD & mA input" option cards
- mA inputs in "4x mA output & 1x mA input" option cards
- mA input in "4x mA input & 1x mA output" option cards
- Digital input voltages

Table. 4.5.14 - 292. Main settings (input channel).

Name	Range	Step	Default	Description
Analog input scaling	• Disabled • Activated	-	Disabled	Enables and disables the input.
Scaling curve 1...10	• Disabled • Activated	-	Disabled	Enables and disables the scaling curve and the input measurement.
Curve 1...10 input signal select	• S7 mA Input • S8 mA Input • S15 mA Input • S16 mA Input • DI1...DI20 Voltage • RTD S1...S16 Resistance • mA In 1 (I card 1) • mA In 2 (I card 2) • mA In 1 (T card 1) • mA In 2 (T card 1) • mA In 3 (T card 1) • mA In 4 (T card 1) • mA In 1 (T card 2) • mA In 2 (T card 2) • mA In 3 (T card 2) • mA In 4 (T card 2)	-	S7 mA Input	Defines the measurement used by scaling curve.

Name	Range	Step	Default	Description
Curve 1...10 input signal filtering	• No • Yes	-	No	Enables calculation of the average of received signal.
Curve 1...10 input signal filter time constant	0.005...3800.000 s	0.005 s	1 s	Time constant for input signal filtering. This parameter is visible when "Curve 1...4 input signal filtering" has been set to "Yes".
Curve 1...10 input signal out of range set	• No • Yes	-	No	Enables out of range signals. If input signal is out of minimum and maximum limits, "ASC1...4 input out of range" signal is activated.
Curve1...10 input minimum	-1 000 000.00...1 000 000.00	0.00001	0	Defines the minimum input of the curve. If input is below the set limit, "ASC1...4 input out of range" is activated.
Curve 1...10 input	-1 000 000.00...1 000 000.00	0.00001	-	Displays the input measurement received by the curve.
Curve1...10 input maximum	-1 000 000.00...1 000 000.00	0.00001	0	Defines the maximum input of the curve. If input is above the set limit, "ASC1...4 input out of range" is activated.
Curve1...10 output	-1 000 000.00...1 000 000.00	0.00001	-	Displays the output of the curve.

The input signal filtering parameter calculates the average of received 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 "ASC1...10 input out of range" signal, which can be used inside logic or with other functions of the device. 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 signal falls below the set input minimum limit, or when it exceeds the input maximum limit.

If for some reason the 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. 4.5.14 - 293. Output settings and indications.

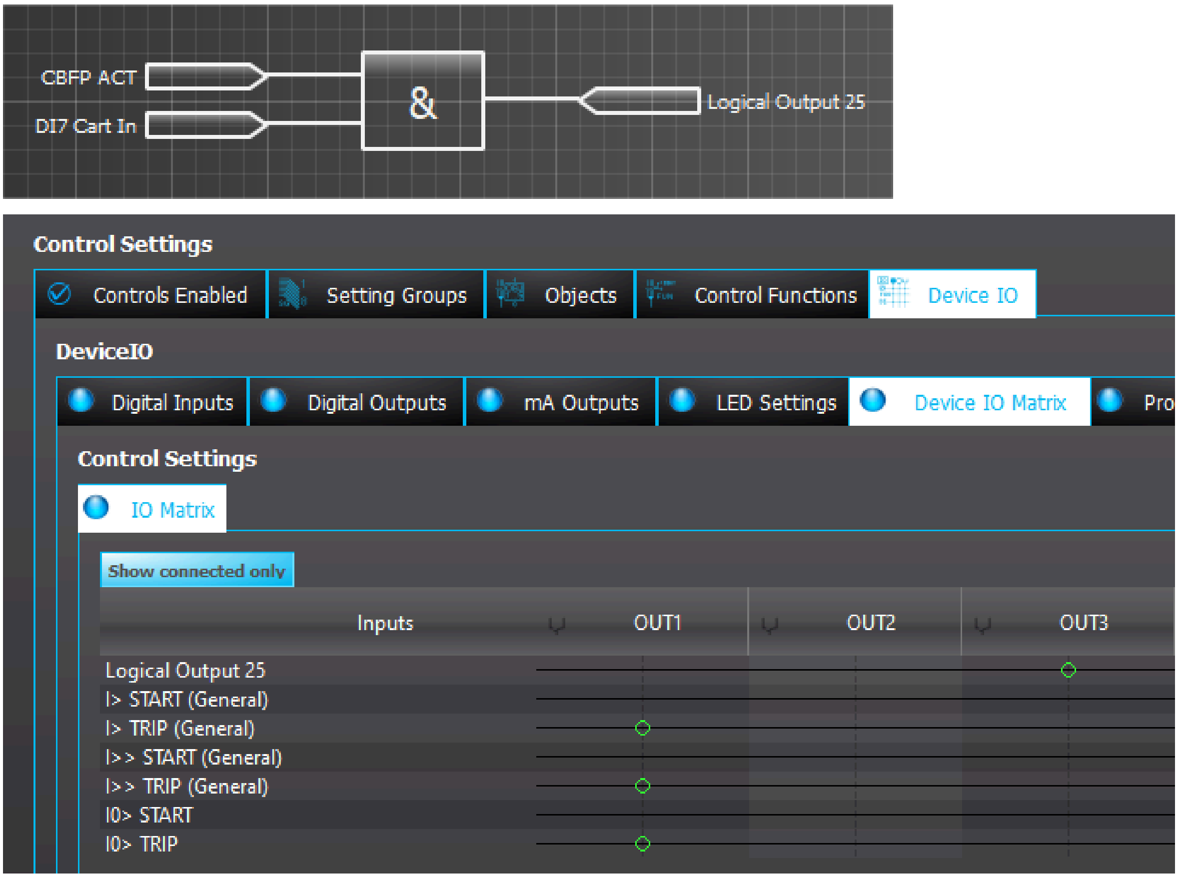
Name	Range	Step	Default	Description
Curve 1...10 update cycle	5...10 000ms	5ms	150ms	Defines the length of the input measurement update cycle. If the user wants a fast operation, this setting should be fairly low.

Name	Range	Step	Default	Description
Scaled value handling	• Floating point • Integer out (Floor) • Integer (Ceiling) • Integer (Nearest)	-	Floating point	Rounds the milliampere signal output as selected.
Input value 1	0...4000	0.000 01	0	The measured 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 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	• Not used • Used	-	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.

4.5.15 Logical outputs

Logical outputs are used for sending binary signals out from a logic that has been built in the logic editor. Logical signals can be used for blocking functions, changing setting groups, controlling digital outputs, activating LEDs, etc. The status of logical outputs can also be reported to a SCADA system. 64 logical outputs are available. The figure below presents a logic output example where a signal from the circuit breaker failure protection function controls the digital output relay number 3 ("OUT3") when the circuit breaker's cart status is "In".

Figure. 4.5.15 - 180. Logic output example. Logical output is connected to an output relay in matrix.



Logical output descriptions

Logical outputs can be given a description. The user defined description are displayed in most of the menus:

- logic editor
- matrix
- block settings
- event history
- disturbance recordings
- etc.

Table. 4.5.15 - 294. Logical output user description.

Name	Range	Default	Description
User editable description LO1...64	1...31 characters	Logical output 1...64	Description of the logical output. This description is used in several menu types for easier identification.

NOTICE!
After editing user descriptions the event history will start to use the new description only after resetting the HMI. HMI can be reset from *General → Device info → HMI restart*.

Events

The logical outputs (abbreviated "LOGIC" in event block names) generates events from the status changes in the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp. The function's output signals can be used for direct I/O controlling and user logic programming.

Table. 4.5.15 - 295. Event messages.

Event block name	Event names
LOGIC1	Logical out 1...32 ON
LOGIC1	Logical out 1...32 OFF
LOGIC3	Logical out 33...64 ON
LOGIC3	Logical out 33...64 OFF

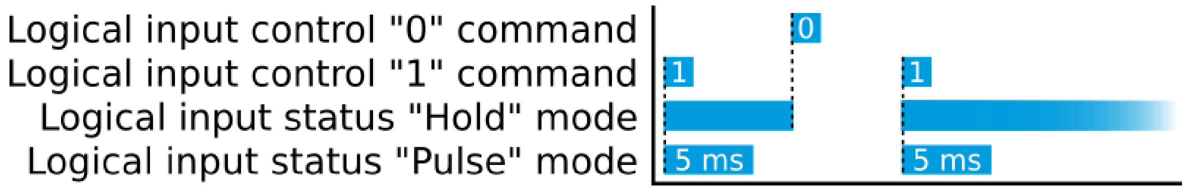
4.5.16 Logical inputs

Logical inputs are binary signals that a user can control manually to change the behavior of the AQ-200 unit or to give direct control commands. Logical inputs can be controlled with a virtual switch built in the mimic and from a SCADA system. Logical inputs are volatile signals: their status will always return to "0" when the AQ-200 device is rebooted. 32 logical inputs are available.

Logical inputs have two modes available: Hold and Pulse. When a logical input which has been set to "Hold" mode is controlled to "1", the input will switch to status "1" and it stays in that status until it is given a control command to go to status "0" or until the device is rebooted. When a logical input which has been set to "Pulse" mode is controlled to "1", the input will switch to status "1" and return back to "0" after 5 ms.

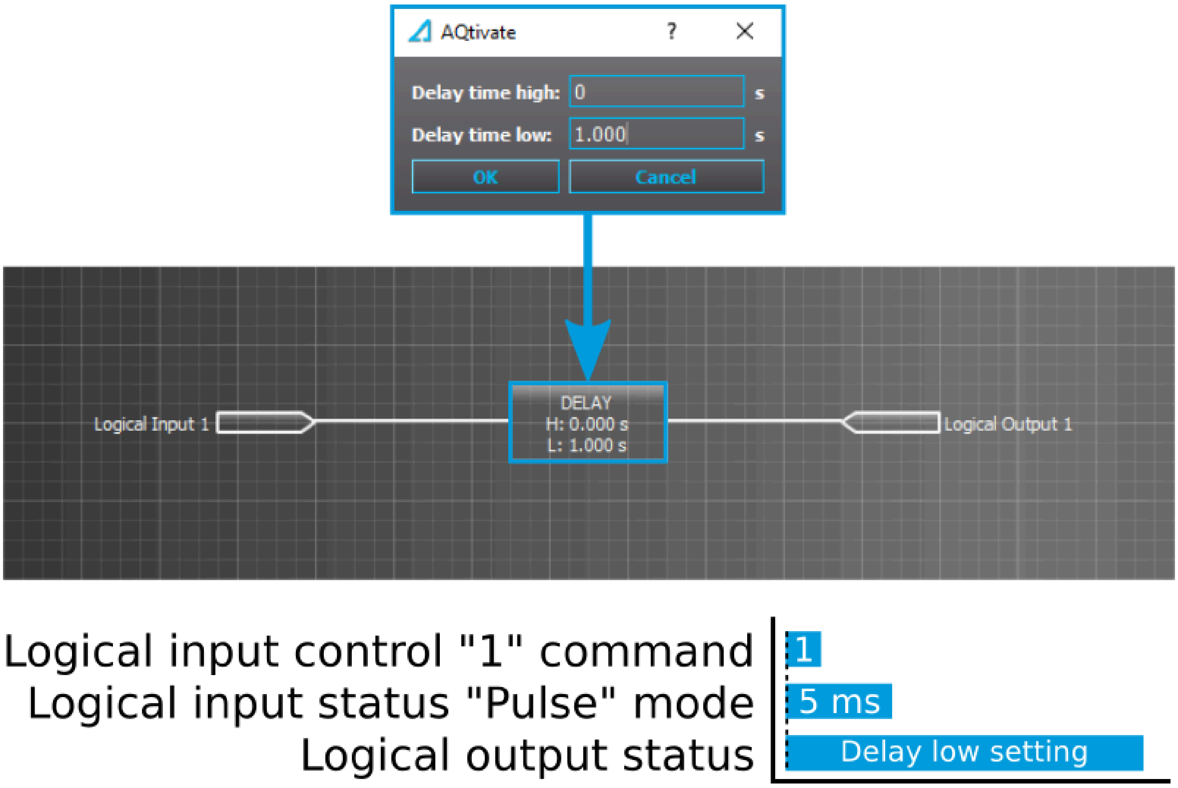
The figure below presents the operation of a logical input in Hold mode and in Pulse mode.

Figure. 4.5.16 - 181. Operation of logical input in "Hold" and "Pulse" modes.



A logical input pulse can also be extended by connecting a DELAY-low gate to a logical output, as has been done in the example figure below.

Figure. 4.5.16 - 182. Extending a logical input pulse.



Logical input descriptions

Logical inputs can be given a description. The user defined description are displayed in most of the menus:

- logic editor
- matrix
- block settings
- event history
- disturbance recordings
- etc.

Table. 4.5.16 - 296. Logical input user description.

Name	Range	Default	Description
User editable description LI1...32	1...31 characters	Logical input 1...32	Description of the logical input. This description is used in several menu types for easier identification.

NOTICE!
After editing user descriptions the event history will start to use the new description only after resetting the HMI. HMI can be reset from *General* → *Device info* → *HMI restart*.

Events

The logical outputs (abbreviated "LOGIC" in event block names) generates events from the status changes in the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp. The function's output signals can be used for direct I/O controlling and user logic programming.

Table. 4.5.16 - 297. Event messages.

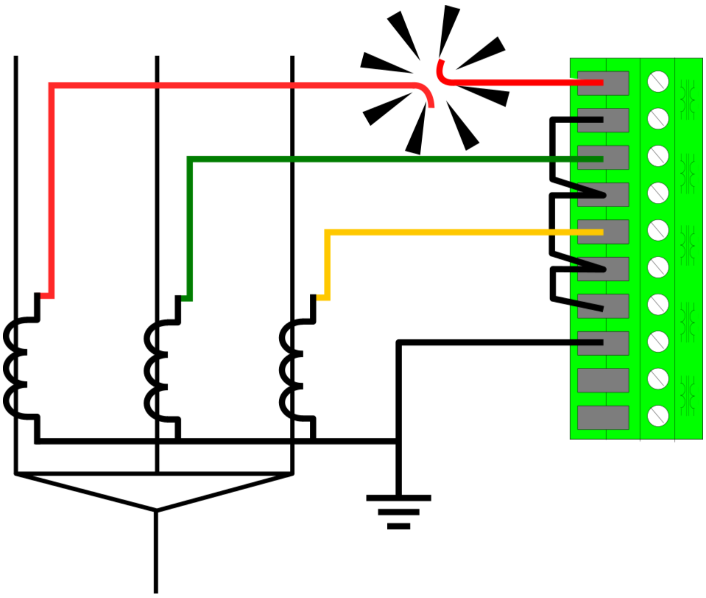
Event block name	Event names
LOGIC2	Logical in 1...32 ON
LOGIC2	Logical in 1...32 OFF

4.6 Monitoring functions

4.6.1 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.

Figure. 4.6.1 - 183. Secondary circuit fault in phase L1 wiring.



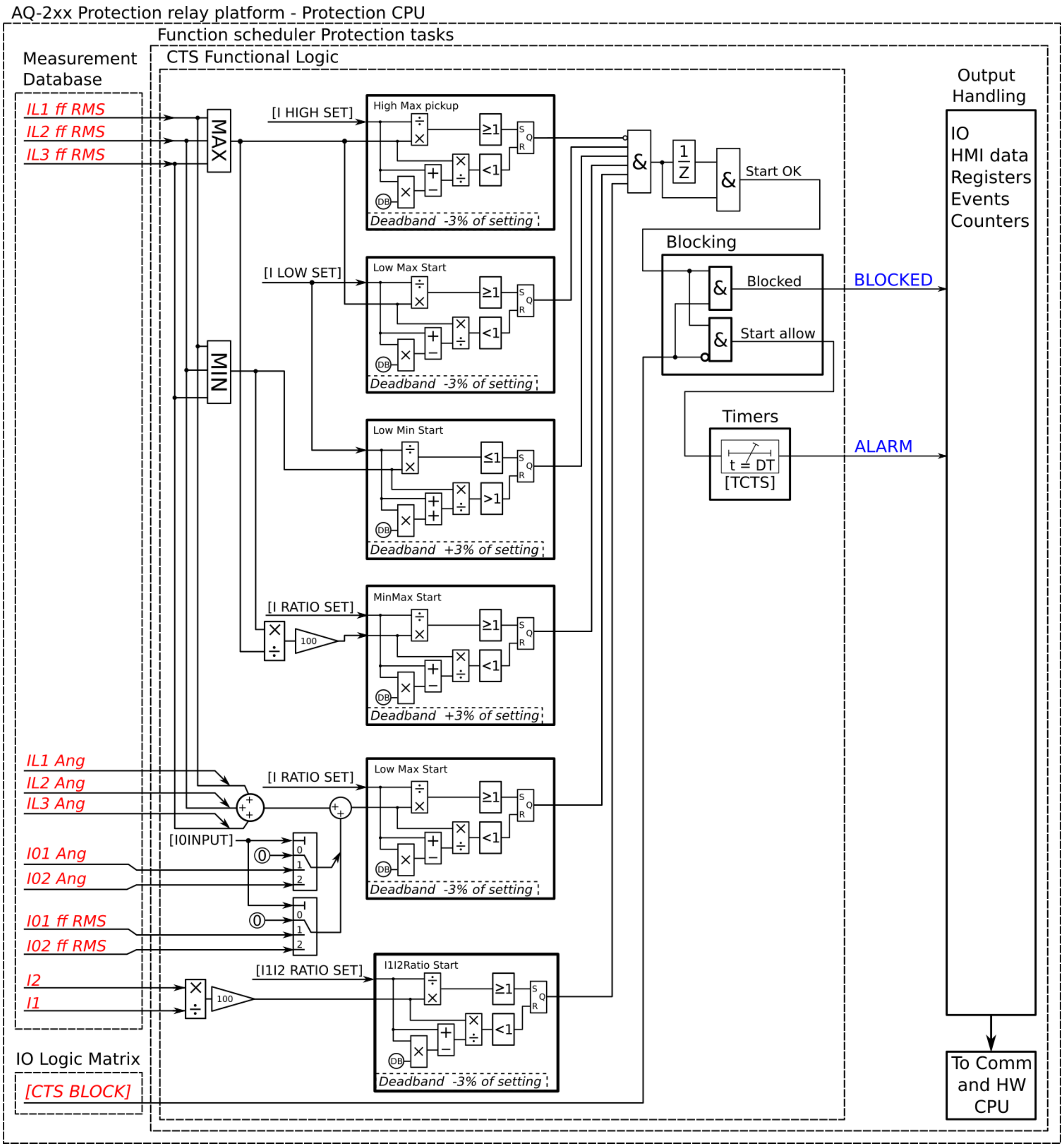
The function constantly monitors the instant values and the key calculated magnitudes of the phase currents. Additionally, the residual current circuit can be monitored if the residual current is measured from a dedicated residual current CT. The user can enable and disable the residual circuit monitoring at will.

The 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.

Figure. 4.6.1 - 184. Simplified function block diagram of the CTS function.



Measured input

The function block uses fundamental frequency component of phase current measurement values and residual current measurement values. The function supervises the angle of each current measurement channel. Positive sequence current and negative sequence currents are calculated from the phase currents. The user can select what is used for the residual current measurement: nothing, the I01 channel, or the I02 channel.

Table. 4.6.1 - 298. Measured inputs of the CTS function.

Signal	Description	Time base
I_{L1}RMS	Fundamental frequency component of phase L1 (A) current	5ms
I_{L2}RMS	Fundamental frequency component of phase L2 (B) current	5ms
I_{L3}RMS	Fundamental frequency component of phase L3 (C) current	5ms
I_{01}RMS	Fundamental frequency component of residual input I01	5ms
I_{02}RMS	Fundamental frequency component of residual input I02	5ms

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. 4.6.1 - 299. General settings of the function.

Name	Range	Default	Description
CTS LN mode	• On • Blocked • Test • Test/ Blocked • Off	On	Set mode of CTS block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
CTS force status to	• Normal • Alarm • Blocked	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.
I0 input selection	• Not in use • I01 • I02	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".
I0 direction	• Add • Subtract	Add	Defines the polarity of residual current channel connection.
Compensate natural unbalance	• - • Comp	-	When activated while the line is energized, the currently present calculated residual current is compensated to 0.

Pick-up settings

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 and maximum 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 % and 103% are 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 currents) it triggers the pick-up operation of the function.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.6.1 - 300. 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…1800.000s	0.005s	0.5s	Determines the delay between the activation of the function and the alarm.

Read-only parameters

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

Table. 4.6.1 - 301. Information displayed by the function.

Name	Range	Step	Description
CTS LN behaviour	• On • Blocked • Test • Test/ Blocked • Off	-	Displays the mode of CTS block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.

Name	Range	Step	Description
Uncompensated residual unbalance Pri	• Normal • Start • Trip • Blocked	-	Displays the natural unbalance of current after compensating it with *Compensate natural unbalance* parameter.
Natural unbalance ang	-360.00...360.00 deg	0.01 deg	Displays the natural unbalance of angle after compensating it with *Compensate natural unbalance* parameter.
Measured current difference Isum, I0	0.00...50.00 xIn	0.01 xIn	Current difference between summed phases and residual current.
Measured angle difference Isum, I0	-360...360 deg	0.01 deg	Angle difference between summed phases and residual current.

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 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. 4.6.1 - 185. All works properly, no faults.

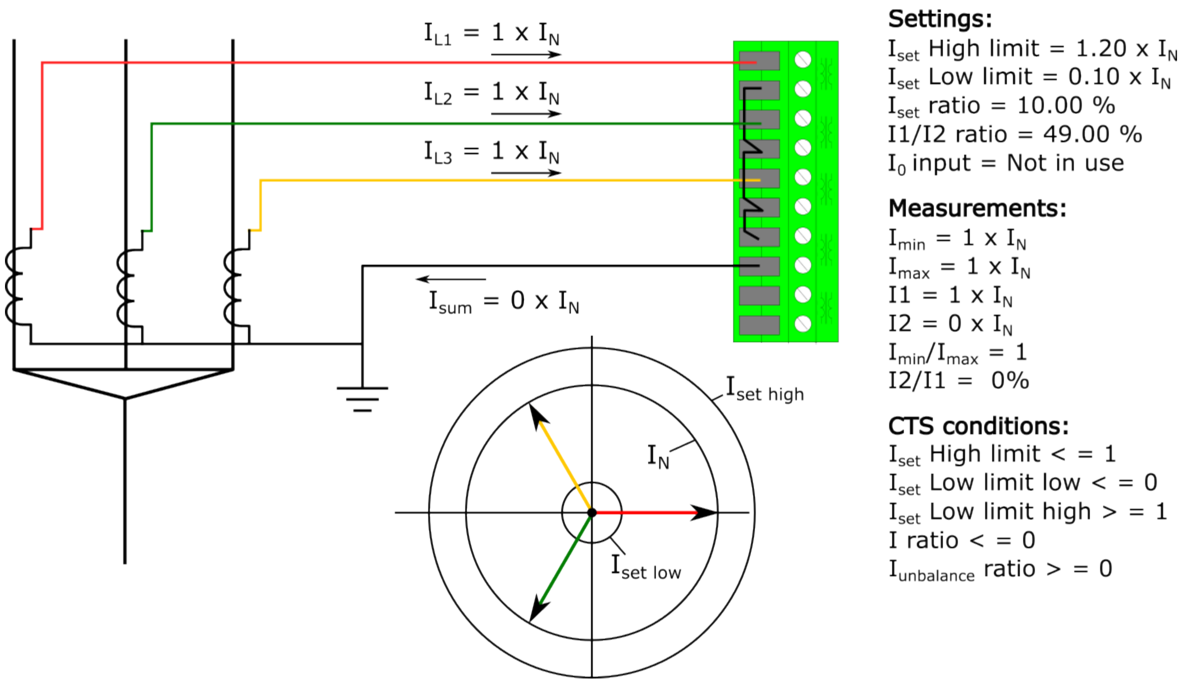
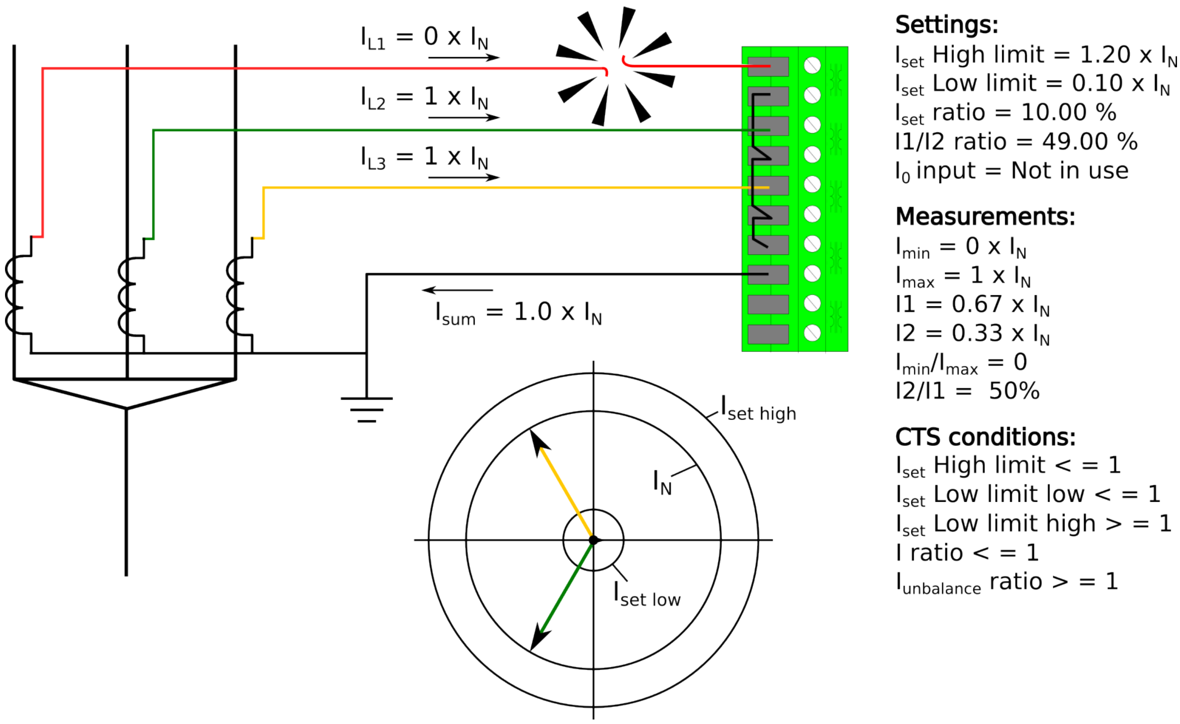
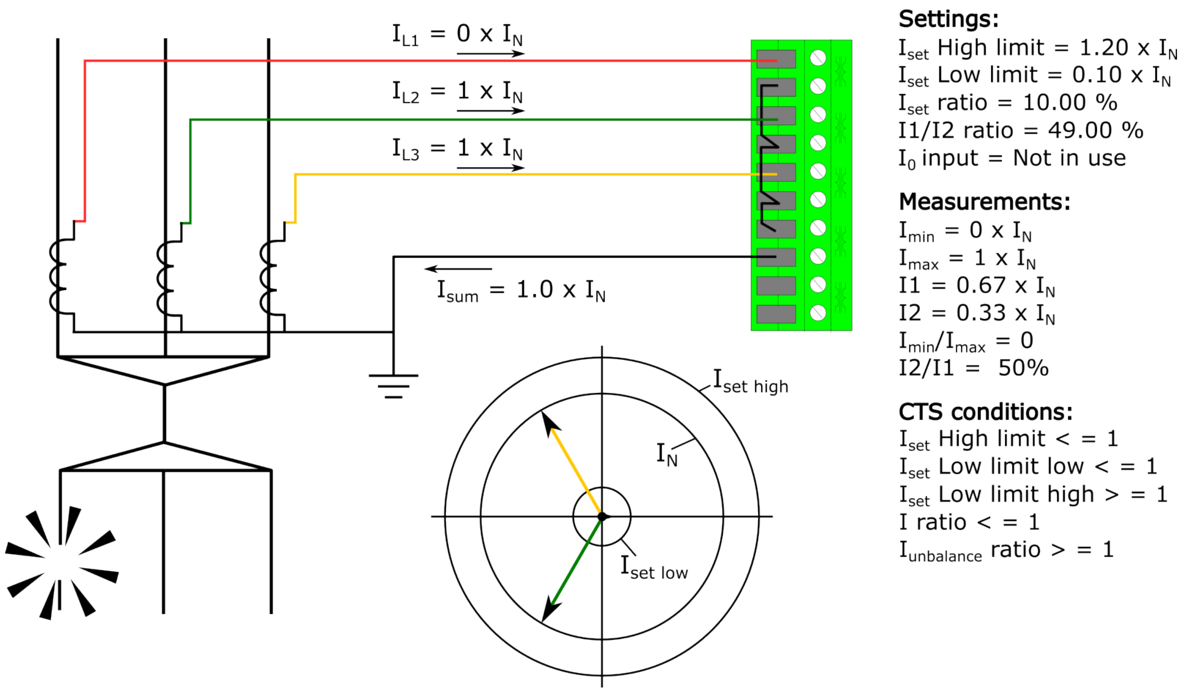


Figure. 4.6.1 - 186. Secondary circuit fault in phase L1 wiring.



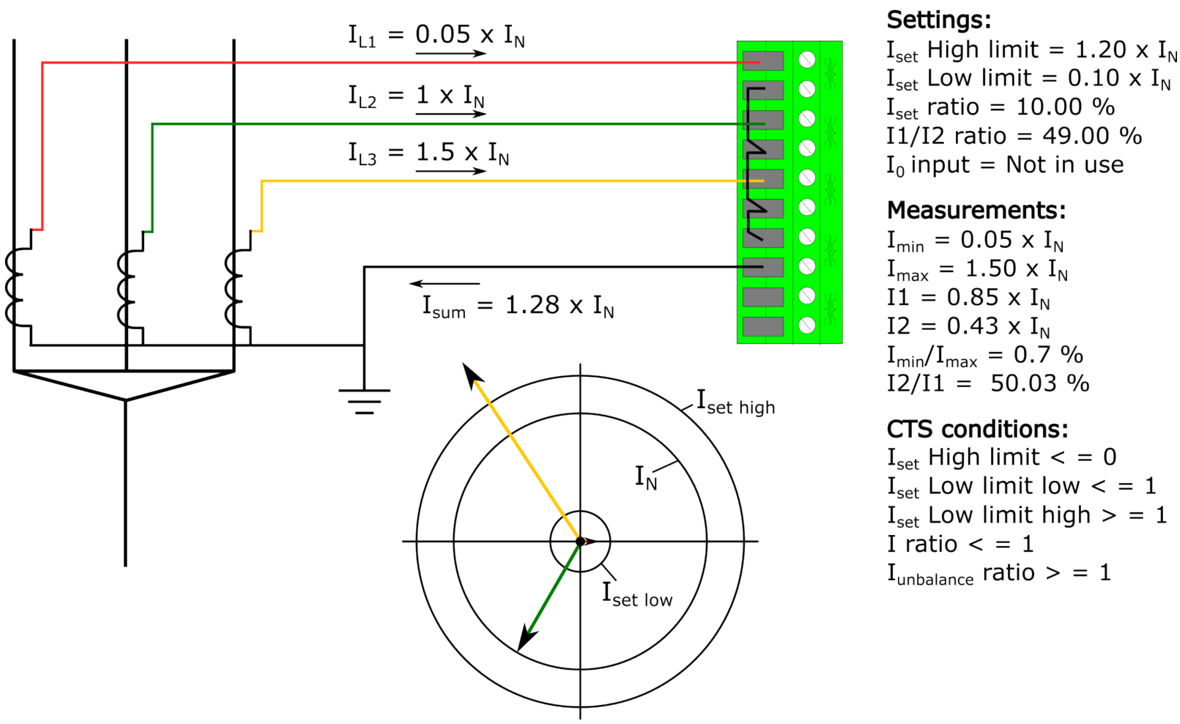
When a fault is detected and all conditions are met, the CTS timer starts counting. If the situation continues until the set time has passed, the function issues an alarm.

Figure. 4.6.1 - 187. Primary circuit fault in phase L1 wiring.



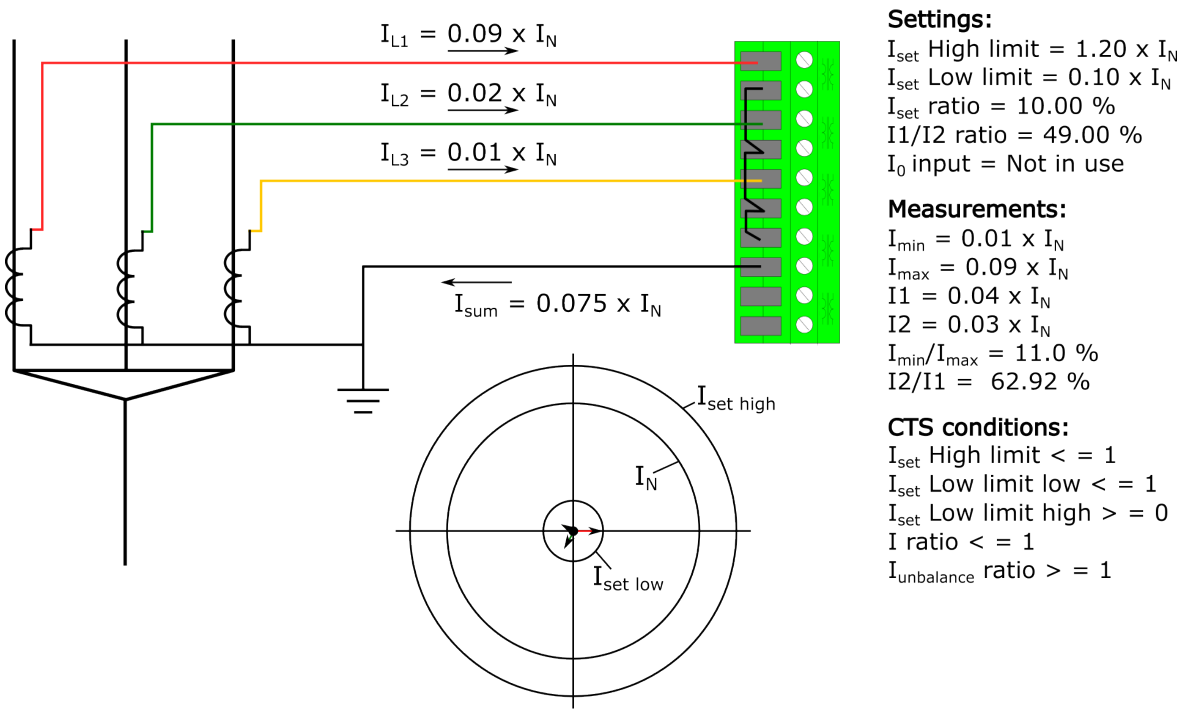
In this example, distinguishing between a primary fault and a secondary fault is impossible. However, the situation meets the function's activation conditions, and if this state (secondary circuit fault) continues until the set time has passed, the function issues an alarm. This means that the function supervises both the primary and the secondary circuit.

Figure. 4.6.1 - 188. 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.

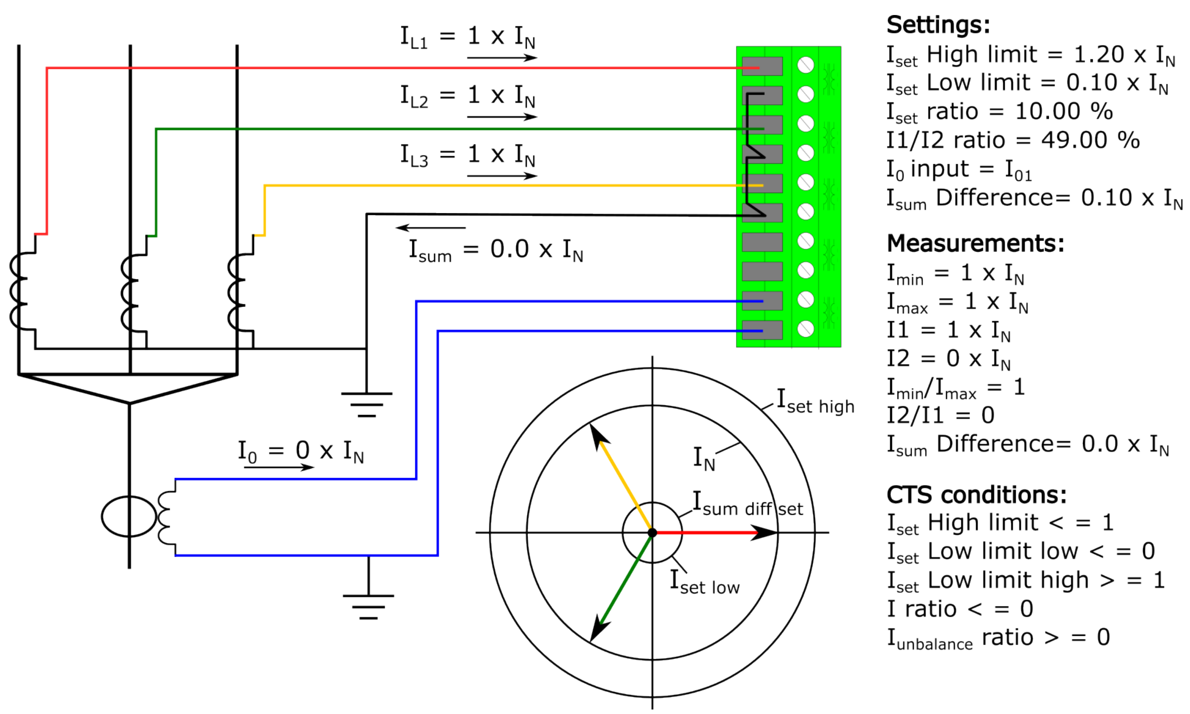
Figure. 4.6.1 - 189. Low current and heavy unbalance.



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.

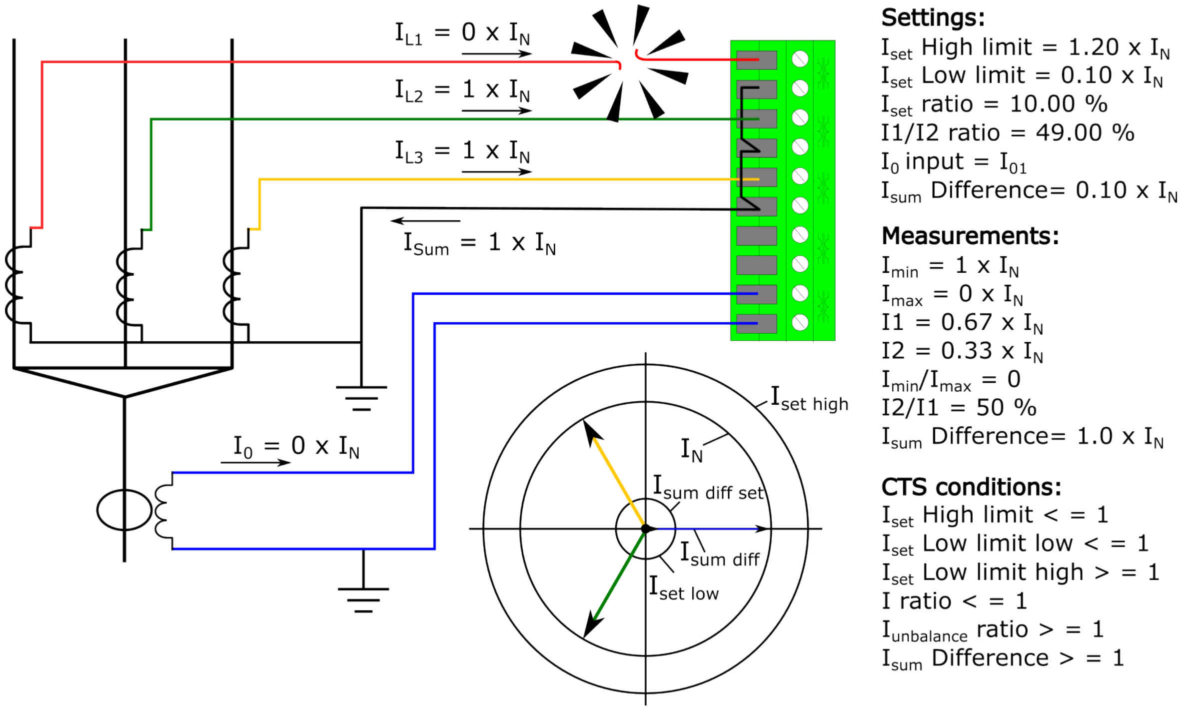
If the *I_{set} high limit* and *I_{set} low limit* setting parameters are adjusted according to the application's normal behavior, the operation of the function can be set to be very sensitive for broken circuit and conductor faults.

Figure. 4.6.1 - 190. Normal situation, residual current also measured.



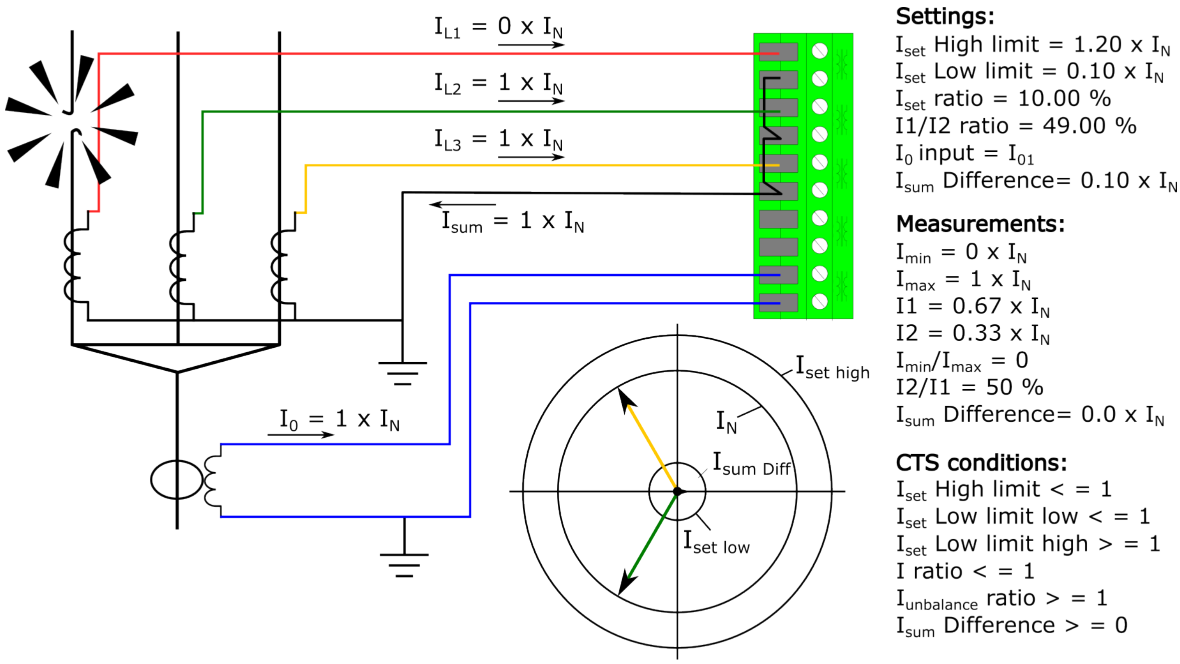
When the residual condition is added with the "I0 input selection", the sum of the current and the residual current are compared against each other to verify the wiring condition.

Figure. 4.6.1 - 191. Broken secondary phase current wiring.



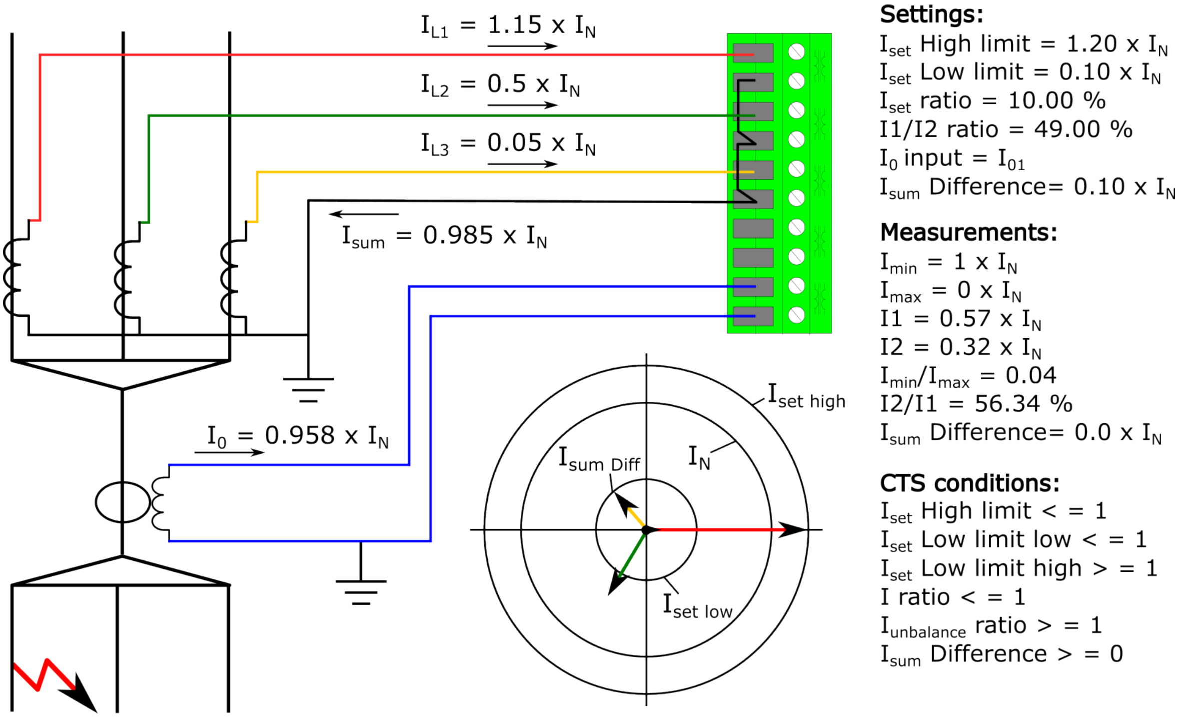
When phase current wire is broken all of the conditions are met in the CTS and alarm shall be issued in case if the situation continues until the set alarming time is met.

Figure. 4.6.1 - 192. 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. 4.6.1 - 193. 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 the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp. The function offers two (2) independent stages.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the CTS ALARM and BLOCKED events.

Table. 4.6.1 - 302. Event messages.

Event block name	Event names
CTS1	Alarm ON
CTS1	Alarm OFF
CTS1	Block ON
CTS1	Block OFF
CTS2	Alarm ON
CTS2	Alarm OFF
CTS2	Block ON
CTS2	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. 4.6.1 - 303. Register content.

Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
Trigger currents	The phase currents (L1, L2 & L3), the residual currents (I01 & I02), and the sequence currents (I1 & I2) on trigger time.
Time to CTSact	Time remaining before alarm activation.
Fault type	The status code of the monitored current.
Setting group in use	Setting group 1...8 active

4.6.2 Voltage transformer supervision (60)

Voltage transformer supervision is used to detect errors in the secondary circuit of the voltage transformer wiring and during fuse failure. This signal is mostly used as an alarming function or to disable functions that require adequate voltage measurement.

Figure. 4.6.2 - 194. Secondary circuit fault in phase L1 wiring.

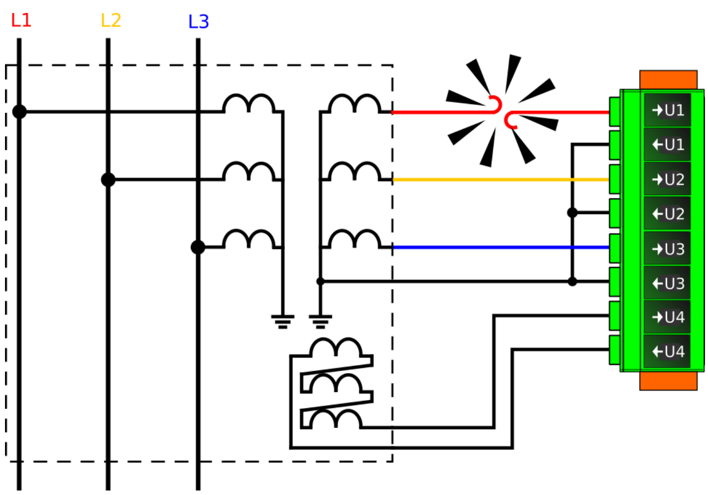
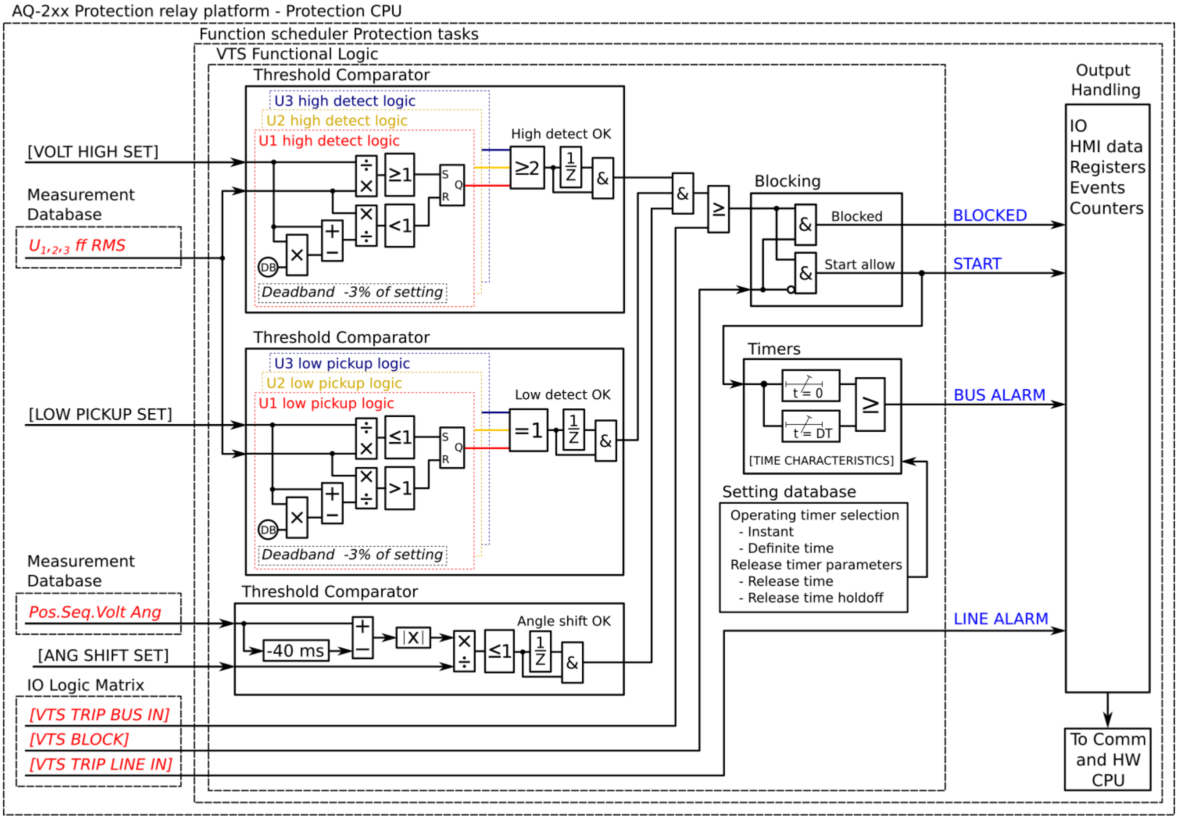


Figure. 4.6.2 - 195. Simplified function block diagram of the VTS function.



Measured input

The function block uses fundamental frequency component of voltage measurement channels. The function uses calculated positive, negative and zero sequence voltages. The function also monitors the angle of each voltage channel.

Table. 4.6.2 - 304. Measurement inputs of the voltage transformer supervision function.

Signal	Description	Time base
U_1RMS	Fundamental frequency component of U_1/V voltage measurement	5ms
U_2RMS	Fundamental frequency component of U_2/V voltage measurement	5ms
U_3RMS	Fundamental frequency component of U_3/V voltage measurement	5ms
U_4RMS	Fundamental frequency component of U_4/V voltage measurement	5ms

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. 4.6.2 - 305. General settings of the function.

Name	Range	Default	Description
VTS LN mode	• On • Blocked • Test • Test/ Blocked • Off	On	Set mode of VTS block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
VTS force status to	• Normal • Start • VTLinefail • VTBusfail • Blocked	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.

Pick-up settings

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.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.6.2 - 306. 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 one the measured voltages is below low pickup value and two of the measured voltages exceed high detect value the function's pick-up activates.
Voltage high detect	0.01…1.10×U_n	0.01×U_n	0.80×U_n	
Angle shift limit	2.00…90.00deg	0.10deg	5.00deg	If the difference between the present angle and the angle 40 ms before is below the set value, the function's pick-up is blocked.
Bus fuse fail check	• No • Yes	-	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	• No • Yes	-	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*).

The voltage transformer supervision can also report several different states of the measured voltage. These can be seen in the function's *INFO* menu.

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.

Read-only parameters

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

Table. 4.6.2 - 307. Information displayed by the function.

Name	Range	Step	Description
VTS LN behaviour	• On • Blocked • Test • Test/Blocked • Off	-	Displays the mode of VTS block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
VTS condition	• Normal • Start • VTLinefail • VTBusfail • Blocked	-	Displays status of the monitoring function.
Bus voltages	• Bus dead • Bus Live VTS Ok SEQ Ok • Bus Live VTS Ok SEQ Rev • Bus Live VTS Ok SEQ Undef • Bus Live VTS problem	-	Displays the status of bus voltages.
Expected operating time	0.000...1800.000s	0.005s	Displays the expected operating time when a fault occurs.
Time remaining to trip	-1800.000...1800.000s	0.005s	When the function has detected a fault and counts down time towards a operation, this displays how much time is left before operation occurs.

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 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 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 voltage transformer supervision function (abbreviated "VTS" in event block names) generates events and registers from the status changes in the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the START, ALARM BUS, ALARM LINE and BLOCKED events.

Table. 4.6.2 - 308. Event messages.

Event block name	Event names
VTS1	Bus VT fail Start ON
VTS1	Bus VT fail Start OFF
VTS1	Bus VT fail Trip ON
VTS1	Bus VT fail Trip OFF
VTS1	Bus VT fail Block ON
VTS1	Bus VT fail Block OFF
VTS1	Line VT fail ON
VTS1	Line VT fail OFF
VTS1	Bus Fuse fail ON
VTS1	Bus Fuse fail OFF
VTS1	Line Fuse fail ON

Event block name	Event names
VTS1	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. 4.6.2 - 309. Register content.

Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
Volt 1, 2, 3, 4 status	• No voltage • Voltage OK • Low voltage
System status	• Bus dead • Bus live, VTS OK, Seq. OK • Bus live, VTS OK, Seq. reversed • Bus live, VTS OK, Seq. undefined • Bus live, VTS fault
Input A, B, C, D angle diff	0.00...360.00deg
Trip time remaining	Time remaining to alarm 0...1800s
Setting group in use	Setting group 1...8 active

4.6.3 Current 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 (RMS).

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. 4.6.3 - 196. THD calculation formulas.

$$THD_P = \frac{{I_{x2}}^2 + {I_{x3}}^2 + {I_{x4}}^2 \ldots {I_{x31}}^2}{{I_{x1}}^2}$$

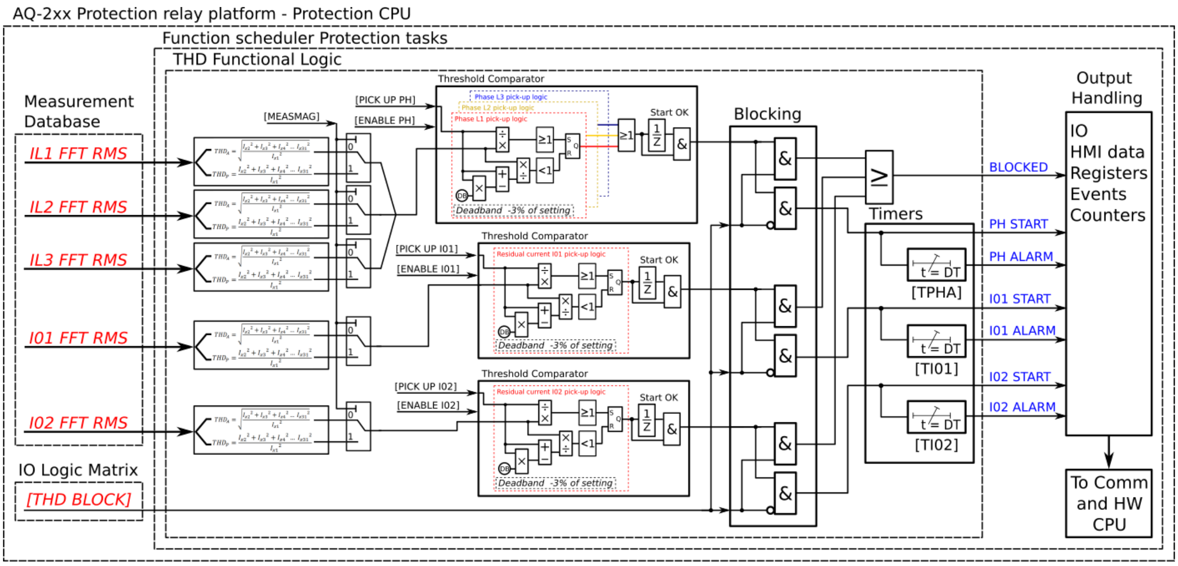
, where
I = measured current,
x= measurement input,
n = harmonic number

$$THD_A = \sqrt{\frac{{I_{x2}}^2 + {I_{x3}}^2 + {I_{x4}}^2 \ldots {I_{x31}}^2}{{I_{x1}}^2}}$$

, 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.

Figure. 4.6.3 - 197. Simplified function block diagram of the total harmonic distortion monitor function.



Measured input

The function block uses phase and residual current measurement channels. 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.

Table. 4.6.3 - 310. Measurement inputs of the total harmonic distortion monitor function.

Signal	Description	Time base
I_{L1}FFT	FFT measurement of phase L1 (A) current	5ms
I_{L2}FFT	FFT measurement of phase L2 (B) current	5ms
I_{L3}FFT	FFT measurement of phase L3 (C) current	5ms
I_{01}FFT	FFT measurement of residual I01 current	5ms
I_{02}FFT	FFT measurement of residual I02 current	5ms

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. 4.6.3 - 311. General settings.

Name	Range	Default	Description
THD> LN mode	• On • Blocked • Test • Test/ Blocked • Off	On	Set mode of THD block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
THD> in side	• CT1 • CT2	CT1	Defines which current measurement module the function uses.
Measurement magnitude	• Amplitude • Power	Amplitude	Defines which available measured magnitude the function uses.

Pick-up settings

The *Phase$_{THD}$*, *I01$_{THD}$*and *I02$_{THD}$* setting parameters control the the pick-up and activation of the function. They define the maximum allowed measured current THD 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 calculated THD for each of the three phases. The reset ratio of 97 % is built into the function and is always relative to the setting value. The setting value is common for all measured phases. When the calculated THD exceeds the pick-up value (in single, dual or all phases), it triggers the pick-up operation of the function.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.6.3 - 312. Pick-up settings.

Name	Range	Step	Default	Description
Enable phase THD alarm	• Enabled • Disabled	-	Enabled	Enables and disables the THD alarm function from phase currents.
Enable I01 THD alarm	• Enabled • Disabled	-	Enabled	Enables and disables the THD alarm function from residual current input I01.

Name	Range	Step	Default	Description
Enable I02 THD alarm	• Enabled • Disabled	-	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.

Read-only parameters

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

Table. 4.6.3 - 313. Information displayed by the function.

Name	Range	Description
THD> LN behaviour	• On • Blocked • Test • Test/ Blocked • Off	Displays the mode of THD block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
THD condition	• Normal • Start • Alarm • Blocked	Displays status of the monitoring function.

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 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

This function supports definite time delay (DT). The following table presents the setting parameters for the function's time characteristics.

Table. 4.6.3 - 314. Settings for operating time characteristics.

Name	Range	Step	Default	Description
Phase THD alarm delay	0.000…1800.000s	0.005s	10.000s	Defines the delay for the alarm timer from the phase currents' measured THD.
I01 THD alarm delay	0.000…1800.000s	0.005s	10.000s	Defines the delay for the alarm timer from the residual current I01's measured THD.
I02 THD alarm delay	0.000…1800.000s	0.005s	10.000s	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 events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the START, ALARM and BLOCKED events.

Table. 4.6.3 - 315. Event messages.

Event block name	Event names
THD1	THD Start Phase ON
THD1	THD Start Phase OFF
THD1	THD Start I01 ON
THD1	THD Start I01 OFF
THD1	THD Start I02 ON
THD1	THD Start I02 OFF
THD1	THD Alarm Phase ON
THD1	THD Alarm Phase OFF
THD1	THD Alarm I01 ON
THD1	THD Alarm I01 OFF
THD1	THD Alarm I02 ON
THD1	THD Alarm I02 OFF
THD1	Blocked ON
THD1	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 START, ALARM and BLOCKED. The table below presents the structure of the function's register content.

Table. 4.6.3 - 316. Register content.

Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
L1h, L2h, L3h Fault THD	Start/Alarm THD of each phase.
Setting group in use	Setting group 1...8 active.

4.6.4 Voltage total harmonic distortion (THD)

The voltage total harmonic distortion (THD) function is used for monitoring the content of the voltage 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 (RMS).

Harmonics can be caused by different sources in electric networks such as electric machine drives, thyristor controls, etc. The function's monitoring of the voltage 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 voltage magnitudes as well as the harmonic content of the monitored signals up to the 31st harmonic component. The user can set the alarming limits 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. 4.6.4 - 198. THD calculation formulas.

$$THD_P = \frac{{U_{x2}}^2 + {U_{x3}}^2 + {U_{x4}}^2 \ldots {U_{x31}}^2}{{U_{x1}}^2}$$

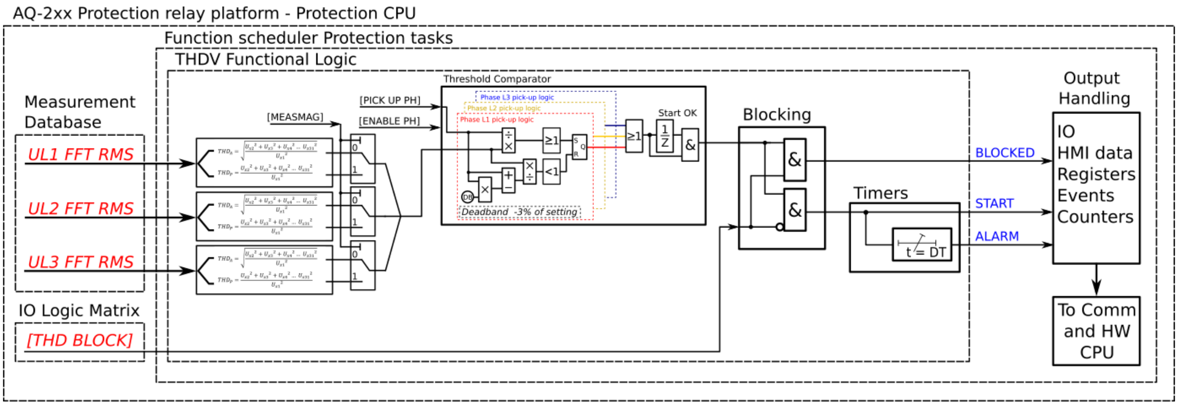
, where
U = measured voltage,
x= measurement input,
n = harmonic number

$$THD_A = \sqrt{\frac{{U_{x2}}^2 + {U_{x3}}^2 + {U_{x4}}^2 \ldots {U_{x31}}^2}{{U_{x1}}^2}}$$

, where
U = measured voltage,
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.

Figure. 4.6.4 - 199. Simplified function block diagram of the total harmonic distortion monitor function.



Measured input

The function block uses analog voltage measurement values. The function always uses FFT measurement of the whole harmonic specter of 32 components from each measured voltage channel. From these measurements the function calculates either the amplitude ratio or the power ratio.

Table. 4.6.4 - 317. Measurement inputs of the total harmonic distortion monitor function.

Signal	Description	Time base
U_1FFT	FFT measurement of U_1/V voltage channel	5ms
U_2FFT	FFT measurement of U_2/V voltage channel	5ms
U_3FFT	FFT measurement of U_3/V voltage channel	5ms

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. 4.6.4 - 318. General settings.

Name	Range	Default	Description
THDV> LN mode	• On • Blocked • Test • Test/ Blocked • Off	On	Set mode of THDV block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
Measurement magnitude	• Amplitude • Power	Amplitude	Defines which available measured magnitude the function uses.

Pick-up settings

The THDV pick-up setting parameter controls the the pick-up and activation of the function. They define the maximum allowed measured voltage THD before action from the function. Before the function activates alarm signals, their corresponding pick-up elements need to be activated with the setting parameter *Enable THD alarm*. The function constantly calculates the ratio between the setting values and the calculated voltage THD. The reset ratio of 97 % is built into the function and is always relative to the setting value. The setting value is common for all measured phases. When the calculated THD exceeds the pick-up value (in single, dual or all phases), it triggers the pick-up operation of the function.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.6.4 - 319. Pick-up settings.

Name	Range	Step	Default	Description
Enable THDV alarm	• Enabled • Disabled	-	Enabled	Enables and disables the THD alarm function.
THDV pick-up	0.10…100.00%	0.01%	10.00%	The pick-up setting for the THD alarm element from the phase voltages. At least one of the phases' measured THD value has to exceed this setting in order for the alarm signal to activate.

Read-only parameters

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

Table. 4.6.4 - 320. Information displayed by the function.

Name	Range	Description
THDV> LN behaviour	• On • Blocked • Test • Test/ Blocked • Off	Displays the mode of THDV block. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
THDV condition	• Normal • Start • Alarm • Blocked	Displays status of the monitoring function.

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 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

This function supports definite time delay (DT). The following table presents the setting parameters for the function's time characteristics.

Table. 4.6.4 - 321. Settings for operating time characteristics.

Name	Range	Step	Default	Description
THDV alarm delay	0.000…1800.000s	0.005s	10.000s	Defines the delay for the alarm timer from the phase voltages' measured THD.

Events and registers

The voltage total harmonic distortion monitor function (abbreviated "THDV" in event block names) generates events and registers from the status changes in the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the START, ALARM and BLOCKED events.

Table. 4.6.4 - 322. Event messages.

Event block name	Event names
THDV1	Voltage THD Start ON
THDV1	Voltage THD Start OFF
THDV1	Voltage THD Alarm ON
THDV1	Voltage THD Alarm OFF
THDV1	Voltage Blocked ON
THDV1	Voltage 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 START, ALARM and BLOCKED. The table below presents the structure of the function's register content.

Table. 4.6.4 - 323. Register content.

Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss

Register	Description
Event	Event name
UL1, UL2, UL3 THDV	Start/Alarm Voltage THD of each phase.
Setting group in use	Setting group 1...8 active.

4.6.5 Fault locator (21FL)

The fault locator function is used for recording an estimated distance to the point where a fault has occurred. It is mostly used in directional overcurrent protection or distance protection applications but can be also triggered by other protections. The function can be used if all three phase currents and three phase voltages have been connected to the device. The triggering signals, the triggering current and "Reactance per km" must be set in the configuration.

Measured input

Function block uses fundamental frequency component of current and voltage measurements to calculate phase-to-phase or phase-to-ground loop impedances.

Table. 4.6.5 - 324. Measurement inputs of the 21FL function.

Signal	Description	Time base
I_{L1}RMS	Fundamental frequency component of phase L1 (A) current measurement	5ms
I_{L2}RMS	Fundamental frequency component of phase L2 (B) current measurement	5ms
I_{L3}RMS	Fundamental frequency component of phase L3 (C) current measurement	5ms
U_1RMS	Fundamental frequency component of U_1/V voltage measurement	5ms
U_2RMS	Fundamental frequency component of U_2/V voltage measurement	5ms
U_3RMS	Fundamental frequency component of U_3/V voltage measurement	5ms
U_4RMS	Fundamental frequency component of U_4/V voltage measurement	5ms

Fault locator triggering

The "Trig fault locator" input defines which signal triggers the fault locator. This can be any binary signal generated by the unit. Typically, a TRIP signal of a protection function or the "Open" status of the breaker is used as the triggering input.

Several conditions have to be met before the fault locator can trigger and record the distance to a fault. First, when receiving a triggering signal, the function checks if the calculation is blocked. The calculation blocking signals are determined by the "Block calculation" matrix set by the user. Next, the function checks if any phase-to-earth voltages are available. If there are no available voltages, the function can only record phase-to-phase impedance loops. If there are available voltages, the function can also record phase-to-neutral impedance loops. Depending on the measured phase currents at the moment the triggering signal was received, the recorded impedance loop is selected from the available options. See the table "Required current conditions" for more information on which conditions have to be met to trigger impedance recording.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.6.5 - 325. Pick-up settings.

Name	Range	Step	Default	Description
Trigger current>	0.0…40.0×I_n	0.1×I_n	1×I_n	Sets the trigger current. Affects which impedance loop is recorded, if anything is recorded at all (see the table below).
Reactance per km	0.000…5.000Ω/km	0.001Ω/km	0.125Ω/km	This setting helps calculate the distance to a fault.

Table. 4.6.5 - 326. Required current conditions.

Currents over limit	P-E voltages available	P-E voltages not available
	Recorded impedance	
I_{L1}, I_{L2}, I_{L3}	X_{L12}	X_{L12}
I_{L1}, I_{L2}	X_{L12}	X_{L12}
I_{L2}, I_{L3}	X_{L23}	X_{L23}
I_{L1}, I_{L3}	X_{L31}	X_{L31}
I_{L1}	X_{L1}	No trigger
I_{L2}	X_{L2}	No trigger
I_{L3}	X_{L3}	No trigger

If no current measurement requirements are fulfilled when the function receives a triggering signal, the function will not record impedance at all.

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 active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further.

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

The fault locator function (abbreviated "FLX" in event block names) generates events and registers from the status changes in the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp. The function also provides a resettable cumulative counter for the fault locator triggering events.

Table. 4.6.5 - 327. Event messages.

Event block name	Event names
FLX1	Flocator triggered ON
FLX1	Flocator triggered OFF
FLX1	Flocator Calculation ON
FLX1	Flocator Calculation 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. 4.6.5 - 328. Register content.

Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
Fault type	• L1-L2 • L2-L3 • L3-L1 • L1-N • L2-N • L3-N • L1-L2-L3
Fault direction	• Not detected • Forward • Reverse
Fault reactance	In ohms (Ω)
Fault current	In per-unit value
Fault current	In primary value
Fault distance	In kilometers (km)
Setting group in use	Setting group 1...8 active.

4.6.6 Disturbance recorder (DR)

The disturbance recorder is a high-capacity (64 MB permanent flash memory) 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 95 digital channels simultaneously with the twenty (20) measured analog channels. Maximum capacity of recordings is 100.

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.

Table. 4.6.6 - 329. 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_{L12} (VT card 1)
U2(3)VT1	Line-to-neutral U_{L2} or line-to-line voltage U_{L23} (VT card 1)
U3(1)VT1	Line-to-neutral U_{L3} or line-to-line voltage U_{L31} (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 1)
IL1"'	Phase current I_{L1} (CT card 3)
IL2"'	Phase current I_{L2} (CT card 3)
IL3"'	Phase current I_{L3} (CT card 3)

Signal	Description
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_{L12} (VT card 2)
UL2(3)VT2	Line-to-neutral U_{L2} or line-to-line voltage U_{L23} (VT card 2)
UL3(1)VT2	Line-to-neutral U_{L3} or line-to-line voltage U_{L31} (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 residual 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. A fine signal is capable of sampling at very low currents and with high accuracy but cuts off at higher currents. Table below lists performance of both channels with fine and coarse gain.

Table. 4.6.6 - 330. Residual current channel performance with coarse or residual gain.

Channel	Coarse gain range	Fine gain range	Fine gain peak
I01	0...150 A	0...10 A	15 A
I02	0...75 A	0...5 A	8 A

Table. 4.6.6 - 331. 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

Signal	Description	Signal	Description
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

Signal	Description	Signal	Description
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

Signal	Description	Signal	Description
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 device.
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. 4.6.6 - 332. 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)

Signal	Description	Signal	Description
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.

NOTICE!
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. 4.6.6 - 333. Recorder control settings.

Name	Range	Description
Recorder enabled	• Enabled • Disabled	Enables and disables the disturbance recorder function.
Recorder status	• Recorder ready • Recording triggered • Recording and storing • Storing recording • Recorder full • Wrong config	Indicates the status of recorder.

Name	Range	Description
Clear record+	0…2^{32}-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	• - • Trig	Triggers disturbance recording manually. This parameter will return back to "-" automatically.
Clear all records	• - • Clear	Clears all disturbance recordings.
Clear newest record	• - • Clear	Clears the newest stored disturbance recording.
Clear oldest record	• - • Clear	Clears the oldest stored disturbance recording.
Max. number of recordings	0…100	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...1800.000s	Displays the maximum length of a single recording.
Max. location of the pre-trigger	0.000...1800.000s	Displays the highest pre-triggering time that can be set with the settings currently in use.
Recordings in memory	0…100	Displays how many recordings are stored in the memory.

Table. 4.6.6 - 334. 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. 4.6.6 - 335. Recorder settings.

Name	Range	Default	Description
Recording length	0.100...1800.000s	1s	Sets the length of a recording.
Recording mode	• FIFO • Keep olds	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	• 64s/c • 32s/c • 16s/c • 8s/c	64s/c	Selects the sample rate of the disturbance recorder in samples per cycle. The samples are saved from the measured wave according to this setting.

Name	Range	Default	Description
Digital channel samples	5ms (fixed)	5 ms(fixed)	The fixed sample rate of the recorded digital channels.
Pretriggering time	0.2...30.0s	0.2s	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	• Disabled • Enabled	Disabled	Enables and disables the automatic transfer of recordings. The recordings are taken from the device's protection CPU and transferred to the device's FTP directory in the communication CPU; the FTP client then automatically loads the recordings from the device and 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 server of the device. 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. When a recording has been sent to the FTP server of the device, it is no longer accessible through setting tools *Disturbance recorder → Get DR files* command.
Recorder digital channels	0…95 freely selectable channels	-	Selects the digital channel for recording. Please see the list of all available digital channels in the section titled "Analog and digital recording channels".

NOTICE!
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 device, 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 setting tool software or device 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 6.0 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 5 (ie. how long is recorded before the I> TRIP signal) and the post-triggering time is 1 s

The image below shows how these settings are placed in the setting tool.

Figure. 4.6.6 - 200. Disturbance recorder settings.

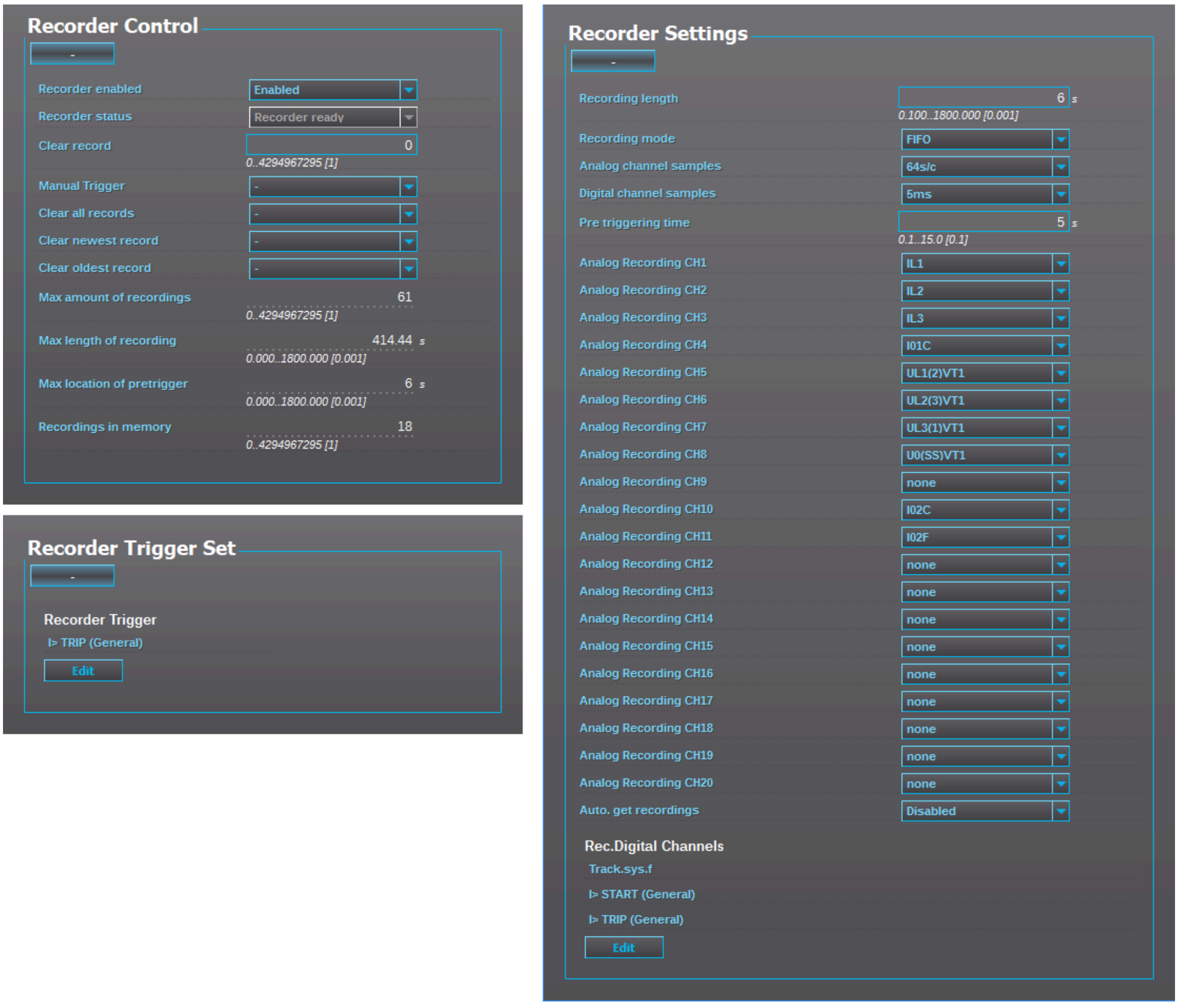
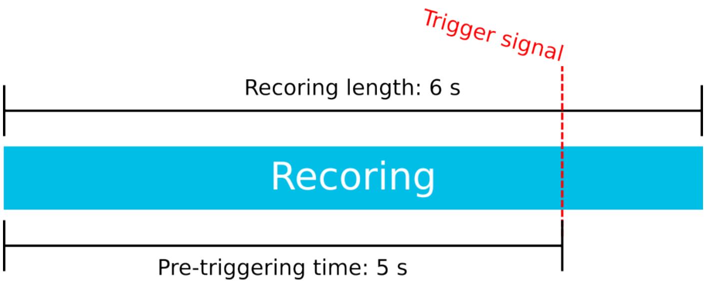
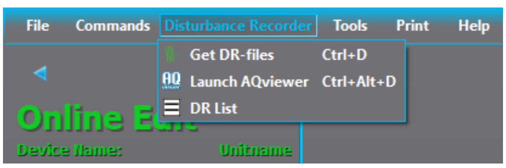


Figure. 4.6.6 - 201. Effects of recording length and pre-triggering time signals. This example is based on the settings shown above.



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 software instructions can be found in AQtivate 200 Instruction manual (arcteq.fi./downloads/).

Events

The disturbance recorder function (abbreviated "DR" in event block names) generates events and registers from the status changes in the events listed below. Events cannot be masked off. The events triggered by the function are recorded with a time stamp.

Table. 4.6.6 - 336. Event messages.

Event block name	Event names
DR1	Recorder triggered ON
DR1	Recorder triggered OFF
DR1	Recorder memory cleared
DR1	Oldest record cleared
DR1	Recorder memory full ON
DR1	Recorder memory full OFF
DR1	Recording ON
DR1	Recording OFF
DR1	Storing recording ON
DR1	Storing recording OFF
DR1	Newest record cleared

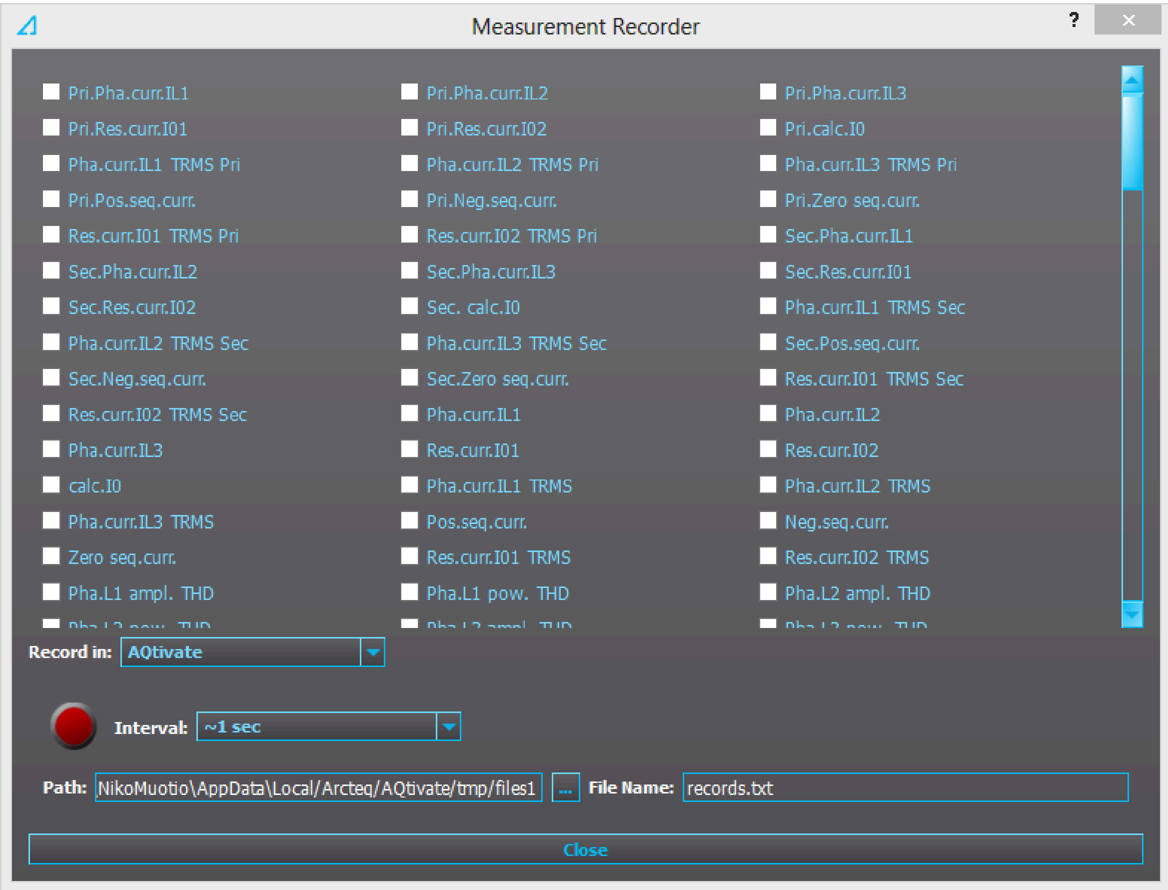
4.6.7 Event logger

Event logger records status changes of protection functions, digital inputs, logical signals etc. Events are recorded with a timestamp. The time stamp resolution is 1 ms. Up to 15 000 events can be stored at once. When 15 000 events have been recorded, the event history will begin to remove the oldest events to make room for new events. You can find more information about event masks in the selected function's "Events" tab. Event masks determine what is recorded into the event history; they are configured in each function's individual settings in the *Protection*, *Control* and *Monitoring* menu. Event history is accessible with PC setting tool (*Tools → Events and Logs → Event history*) and from the device HMI if "Events" view has been configured with Carousel designer in PC setting tool.

Event overload detection

Continuous generation of a high number of nuisance events may have adverse effects on the operation and communication capabilities of the device. A high number of nuisance events may end up being generated due to mistakes in configuration and/or installation. For example, mistakes in logic configuration or RTD sensor wiring, in conjunction with suitable event mask settings may generate an excessive number of unintended events. Event overload detector looks for a condition where over 200 events are being generated inside one (1) second window (more than 1 event every 5 milliseconds on average). If such a condition is detected, further events are blocked and an IRF (Internal Relay Fault-message) is issued. The event blocking is released and the IRF can be cleared after 5 seconds if the overload condition has been corrected. Other device operations, such as protection and communication, remain available even during the event overload condition.

4.6.8 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 check boxes. In order for the measurement recorder to activate, a connection to a device must be established via the setting tool 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 the setting tool or in the device.

If the recording is done in the setting tool, both the setting tool 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 device, only the recording interval needs to be set before recording can be started. The setting tool 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. 4.6.8 - 202. Measurement recorder values viewed with AQtivate PRO.

Table. 4.6.8 - 337. Available analog signals.

Current measurements	P-P Curr.I"L3	L1 Imp.React.Ind.E.Mvarh
Pri.Pha.Curr.IL1	P-P Curr.I"01	L1 Imp.React.Ind.E.kvarh
Pri.Pha.Curr.IL2	P-P Curr.I"02	L1 Exp/Imp React.Ind.E.bal.Mvarh
Pri.Pha.Curr.IL3	Pha.angle I"L1	L1 Exp/Imp React.Ind.E.bal.kvarh
Pri.Res.Curr.I01	Pha.angle I"L2	L2 Exp.Active Energy MWh
Pri.Res.Curr.I02	Pha.angle I"L3	L2 Exp.Active Energy kWh
Pri.Calc.I0	Res.Curr.angle I"01	L2 Imp.Active Energy MWh
Pha.Curr.IL1 TRMS Pri	Res.Curr.angle I"02	L2 Imp.Active Energy kWh
Pha.Curr.IL2 TRMS Pri	Calc.I"0.angle	L2 Exp/Imp Act. E balance MWh
Pha.Curr.IL3 TRMS Pri	I" Pos.Seq.Curr.angle	L2 Exp/Imp Act. E balance kWh
Pri.Pos.Seq.Curr.	I" Neg.Seq.Curr.angle	L2 Exp.React.Cap.E.Mvarh
Pri.Neg.Seq.Curr.	I" Zero.Seq.Curr.angle	L2 Exp.React.Cap.E.kvarh
Pri.Zero.Seq.Curr.	Voltage measurements	L2 Imp.React.Cap.E.Mvarh
Res.Curr.I01 TRMS Pri	U1Volt Pri	L2 Imp.React.Cap.E.kvarh
Res.Curr.I02 TRMS Pri	U2Volt Pri	L2 Exp/Imp React.Cap.E.bal.Mvarh
Sec.Pha.Curr.IL1	U3Volt Pri	L2 Exp/Imp React.Cap.E.bal.kvarh
Sec.Pha.Curr.IL2	U4Volt Pri	L2 Exp.React.Ind.E.Mvarh

Sec.Pha.Curr.IL3	U1Volt Pri TRMS	L2 Exp.React.Ind.E.kvarh
Sec.Res.Curr.I01	U2Volt Pri TRMS	L2 Imp.React.Ind.E.Mvarh
Sec.Res.Curr.I02	U3Volt Pri TRMS	L2 Imp.React.Ind.E.kvarh
Sec.Calc.I0	U4Volt Pri TRMS	L2 Exp/Imp React.Ind.E.bal.Mvarh
Pha.Curr.IL1 TRMS Sec	Pos.Seq.Volt.Pri	L2 Exp/Imp React.Ind.E.bal.kvarh
Pha.Curr.IL2 TRMS Sec	Neg.Seq.Volt.Pri	L3 Exp.Active Energy MWh
Pha.Curr.IL3 TRMS Sec	Zero.Seq.Volt.Pri	L3 Exp.Active Energy kWh
Sec.Pos.Seq.Curr.	U1Volt Sec	L3 Imp.Active Energy MWh
Sec.Neg.Seq.Curr.	U2Volt Sec	L3 Imp.Active Energy kWh
Sec.Zero.Seq.Curr.	U3Volt Sec	L3 Exp/Imp Act. E balance MWh
Res.Curr.I01 TRMS Sec	U4Volt Sec	L3 Exp/Imp Act. E balance kWh
Res.Curr.I02 TRMS Sec	U1Volt Sec TRMS	L3 Exp.React.Cap.E.Mvarh
Pha.Curr.IL1	U2Volt Sec TRMS	L3 Exp.React.Cap.E.kvarh
Pha.Curr.IL2	U3Volt Sec TRMS	L3 Imp.React.Cap.E.Mvarh
Pha.Curr.IL3	U4Volt Sec TRMS	L3 Imp.React.Cap.E.kvarh
Res.Curr.I01	Pos.Seq.Volt.Sec	L3 Exp/Imp React.Cap.E.bal.Mvarh
Res.Curr.I02	Neg.Seq.Volt.Sec	L3 Exp/Imp React.Cap.E.bal.kvarh
Calc.I0	Zero.Seq.Volt.Sec	L3 Exp.React.Ind.E.Mvarh
Pha.Curr.IL1 TRMS	U1Volt p.u.	L3 Exp.React.Ind.E.kvarh
Pha.Curr.IL2 TRMS	U2Volt p.u.	L3 Imp.React.Ind.E.Mvarh
Pha.Curr.IL3 TRMS	U3Volt p.u.	L3 Imp.React.Ind.E.kvarh
Pos.Seq.Curr.	U4Volt p.u.	L3 Exp/Imp React.Ind.E.bal.Mvarh
Neg.Seq.Curr.	U1Volt TRMS p.u.	L3 Exp/Imp React.Ind.E.bal.kvarh
Zero.Seq.Curr.	U2Volt TRMS p.u.	Exp.Active Energy MWh
Res.Curr.I01 TRMS	U3Volt p.u.	Exp.Active Energy kWh
Res.Curr.I02 TRMS	U4Volt p.u.	Imp.Active Energy MWh
Pha.L1 ampl. THD	Pos.Seq.Volt. p.u.	Imp.Active Energy kWh
Pha.L2 ampl. THD	Neg.Seq.Volt. p.u.	Exp/Imp Act. E balance MWh
Pha.L3 ampl. THD	Zero.Seq.Volt. p.u.	Exp/Imp Act. E balance kWh
Pha.L1 pow. THD	U1Volt Angle	Exp.React.Cap.E.Mvarh
Pha.L2 pow. THD	U2Volt Angle	Exp.React.Cap.E.kvarh
Pha.L3 pow. THD	U3Volt Angle	Imp.React.Cap.E.Mvarh

Res.I01 ampl. THD	U4Volt Angle	Imp.React.Cap.E.kvarh
Res.I01 pow. THD	Pos.Seq.Volt. Angle	Exp/Imp React.Cap.E.bal.Mvarh
Res.I02 ampl. THD	Neg.Seq.Volt. Angle	Exp/Imp React.Cap.E.bal.kvarh
Res.I02 pow. THD	Zero.Seq.Volt. Angle	Exp.React.Ind.E.Mvarh
P-P Curr.IL1	System Volt UL12 mag	Exp.React.Ind.E.kvarh
P-P Curr.IL2	System Volt UL12 mag (kV)	Imp.React.Ind.E.Mvarh
P-P Curr.IL3	System Volt UL23 mag	Imp.React.Ind.E.kvarh
P-P Curr.I01	System Volt UL23 mag (kV)	Exp/Imp React.Ind.E.bal.Mvarh
P-P Curr.I02	System Volt UL31 mag	Exp/Imp React.Ind.E.bal.kvarh
Pha.angle IL1	System Volt UL31 mag (kV)	Other measurements
Pha.angle IL2	System Volt UL1 mag	TM> Trip expect mode
Pha.angle IL3	System Volt UL1 mag (kV)	TM> Time to 100% T
Res.Curr.angle I01	System Volt UL2 mag	TM> Reference T curr.
Res.Curr.angle I02	System Volt UL2 mag (kV)	TM> Active meas curr.
Calc.I0.angle	System Volt UL3 mag	TM> T est.with act. curr.
Pos.Seq.Curr.angle	System Volt UL3 mag (kV)	TM> T at the moment
Neg.Seq.Curr.angle	System Volt U0 mag	TM> Max.Temp.Rise All.
Zero.Seq.Curr.angle	System Volt U0 mag (kV)	TM> Temp.Rise atm.
Pri.Pha.Curr.I"L1	System Volt U1 mag	TM> Hot Spot estimate
Pri.Pha.Curr.I"L2	System Volt U1 mag (kV)	TM> Hot Spot Max. All
Pri.Pha.Curr.I"L3	System Volt U2 mag	TM> Used k for amb.temp
Pri.Res.Curr.I"01	System Volt U2 mag (kV)	TM> Trip delay remaining
Pri.Res.Curr.I"02	System Volt U3 mag	TM> Alarm 1 time to rel.
Pri.Calc.I"0	System Volt U3 mag (kV)	TM> Alarm 2 time to rel.
Pha.Curr.I"L1 TRMS Pri	System Volt U4 mag	TM> Inhibit time to rel.
Pha.Curr.I"L2 TRMS Pri	System Volt U4 mag (kV)	TM> Trip time to rel.
Pha.Curr.I"L3 TRMS Pri	System Volt UL12 ang	S1 Measurement
I" Pri.Pos.Seq.Curr.	System Volt UL23 ang	S2 Measurement
I" Pri.Neg.Seq.Curr.	System Volt UL31 ang	S3 Measurement
I" Pri.Zero.Seq.Curr.	System Volt UL1 ang	S4 Measurement
Res.Curr.I"01 TRMS Pri	System Volt UL2 ang	S5 Measurement
Res.Curr.I"02 TRMS Pri	System Volt UL3 ang	S6 Measurement

Sec.Pha.Curr.I"L1	System Volt U0 ang	S7 Measurement
Sec.Pha.Curr.I"L2	System Volt U1 ang	S8 Measurement
Sec.Pha.Curr.I"L3	System Volt U2 ang	S9 Measurement
Sec.Res.Curr.I"01	System Volt U3 ang	S10 Measurement
Sec.Res.Curr.I"02	System Volt U4 ang	S11 Measurement
Sec.Calc.I"0	Power measurements	S12 Measurement
Pha.Curr.I"L1 TRMS Sec	L1 Apparent Power (S)	Sys.meas.frqs
Pha.Curr.I"L2 TRMS Sec	L1 Active Power (P)	f atm.
Pha.Curr.I"L3 TRMS Sec	L1 Reactive Power (Q)	f meas from
I" Sec.Pos.Seq.Curr.	L1 Tan(phi)	SS1.meas.frqs
I" Sec.Neg.Seq.Curr.	L1 Cos(phi)	SS1f meas from
I" Sec.Zero.Seq.Curr.	L2 Apparent Power (S)	SS2 meas.frqs
Res.Curr.I"01 TRMS Sec	L2 Active Power (P)	SS2f meas from
Res.Curr.I"02 TRMS Sec	L2 Reactive Power (Q)	L1 Bias current
Pha.Curr.I"L1	L2 Tan(phi)	L1 Diff current
Pha.Curr.I"L2	L2 Cos(phi)	L1 Char current
Pha.Curr.I"L3	L3 Apparent Power (S)	L2 Bias current
Res.Curr.I"01	L3 Active Power (P)	L2 Diff current
Res.Curr.I"02	L3 Reactive Power (Q)	L2 Char current
Calc.I"0	L3 Tan(phi)	L3 Bias current
Pha.Curr.I"L1 TRMS	L3 Cos(phi)	L3 Diff current
Pha.Curr.I"L2 TRMS	3PH Apparent Power (S)	L3 Char current
Pha.Curr.I"L3 TRMS	3PH Active Power (P)	HV I0d> Bias current
I" Pos.Seq.Curr.	3PH Reactive Power (Q)	HV I0d> Diff current
I" Neg.Seq.Curr.	3PH Tan(phi)	HV I0d> Char current
I" Zero.Seq.Curr.	3PH Cos(phi)	LV I0d> Bias current
Res.Curr.I"01 TRMS	Energy measurements	LV I0d> Diff current
Res.Curr.I"02 TRMS	L1 Exp.Active Energy MWh	LV I0d> Char current
Pha.IL"1 ampl. THD	L1 Exp.Active Energy kWh	Curve1 Input
Pha.IL"2 ampl. THD	L1 Imp.Active Energy MWh	Curve1 Output
Pha.IL"3 ampl. THD	L1 Imp.Active Energy kWh	Curve2 Input
Pha.IL"1 pow. THD	L1 Exp/Imp Act. E balance MWh	Curve2 Output

Pha.IL"2 pow. THD	L1 Exp/Imp Act. E balance kWh	Curve3 Input
Pha.IL"3 pow. THD	L1 Exp.React.Cap.E.Mvarh	Curve3 Output
Res.I"01 ampl. THD	L1 Exp.React.Cap.E.kvarh	Curve4 Input
Res.I"01 pow. THD	L1 Imp.React.Cap.E.Mvarh	Curve4 Output
Res.I"02 ampl. THD	L1 Imp.React.Cap.E.kvarh	Control mode
Res.I"02 pow. THD	L1 Exp/Imp React.Cap.E.bal.Mvarh	Motor status
P-P Curr.I"L1	L1 Exp/Imp React.Cap.E.bal.kvarh	Active setting group
P-P Curr.I"L2	L1 Exp.React.Ind.E.Mvarh	
	L1 Exp.React.Ind.E.kvarh	

4.6.9 Measurement value recorder

The measurement value recorder function records the value of the selected magnitudes at the time of a pre-defined trigger signal. A 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)
- I2> (current unbalance)
- Idir> (directional overcurrent)
- I0> (non-directional earth fault)
- I0dir> (directional earth fault)
- f<(underfrequency)
- f> (overfrequency)
- U< (undervoltage)
- U> (overvoltage)
- U1/U2 >/< (sequence voltage)
- U0> (residual voltage)
- P> (over power)
- P< (under power)
- Prev> (reverse power)
- T> (thermal overload)

Measured input

The function block uses analog current and voltage measurement values. Based on these values, the device 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.

NOTICE!
The available measurement values depend on the device 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 (RMS) 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 2^{nd} h., 3^{rd} h., 4^{th} h., 5^{th} h., 7^{th} h., 9^{th} h., 11^{th} h., 13^{th} h., 15^{th} h., 17^{th} h., 19^{th} h.	The magnitudes of phase current components: Fundamental, 2^{nd} harmonic, 3^{rd} harmonic, 4^{th} harmonic, 5^{th} harmonic 7^{th}, harmonic 9^{th}, harmonic 11^{th}, harmonic 13^{th}, harmonic 15^{th}, harmonic 17^{th}, harmonic 19^{th} harmonic current.
I1, I2, I0Z	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**

Currents	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. 4.6.9 - 338. Reported values.

Name	Range	Description
Tripped stage	• - • I> Trip • I>> Trip • I>>> Trip • I>>>> Trip • IDir> Trip • IDir>> Trip • IDir>>> Trip • IDir>>>> Trip • U> Trip • U>> Trip • U>>> Trip • U>>>> Trip • U< Trip • U<< Trip • U<<< Trip • U<<<< Trip • I0> TRIP • I0>> Trip • I0>>> Trip • I0>>>> Trip • I0Dir> Trip • I0Dir>> Trip • I0Dir>>> Trip • I0Dir>>>> Trip • f> Trip • f>> Trip • f>>> Trip • f>>>> Trip • f< Trip • f<< Trip • f<<< Trip • f<<<< Trip • P> Trip • P< Trip • Prev> Trip • T> Trip • I2> Trip • I2>> Trip • I2>>> Trip • I2>>>> Trip • U1/2 > Trip • U1/2 >> Trip • U1/2 >>> Trip • U1/2 >>>> Trip • U0> Trip • U0>> Trip • U0>>> Trip • U0>>>> Trip	The tripped stage.
Overcurrent fault type	• A-G • B-G • A-B • C-G • A-C • B-C • A-B-C	The overcurrent fault type.

Name	Range	Description
Voltage fault type	• A(AB) • B(BC) • A-B(AB-BC) • C(CA) • A-C(AB-CA) • B-C(BC-CA) • A-B-C • Overfrequency • Underfrequency • Overpower • Underpower • Reversepower • Thermal overload • Unbalance • Harmonic overcurrent • Residual overvoltage	The voltage fault type.
Magnitude 1…8	0.000…1800.000 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 status changes in the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp.

Table. 4.6.9 - 339. Event messages.

Event block name	Event name
VREC1	Recorder triggered ON
VREC1	Recorder triggered OFF

5 Communication

5.1 Connections menu

"Connections" menu is found under "Communication" menu. It contains all basic settings of ethernet port and RS-485 serial port included with every AQ-200 device as well as settings of communication option cards.

Table. 5.1 - 340. Ethernet settings.

Name	Range	Description
IP address	0.0.0.0...255.255.255.255	Set IP address of the ethernet port in the back of the AQ-200 series device.
Netmask	0.0.0.0...255.255.255.255	Set netmask of the ethernet port in the back of the AQ-200 series device.
Gateway	0.0.0.0...255.255.255.255	Set gateway of the ethernet port in the back of the AQ-200 series device.
MAC-Address	00-00-00-00-00-00...FF-FF-FF-FF-FF-FF	Indication of MAC address of the AQ-200 series device.
Storm Protection	• Disable • Enable	When enabled, the Storm protection functionality of the internal switch in the device is enabled. This functionality aims to protect the device from excess ethernet traffic caused by storm situation. When enabled, the packet rate allowed to pass through on the ingress port towards the device, is limited to 150 packets per second. Multicast packets are also included in the packet limit.
Double Ethernet card mode	• Switch • HSR • PRP	If the device has a double ethernet option card it is possible to choose its mode.
COM A and Ethernet option card connection	• Block all • Allow both directions • Allow COM A to option card • Allow option card to COM A	If the device has ethernet option card it is possible to determine the allowed direction of data.
Double Ethernet link events	• Disable • Enable	Disables or enables "Double Ethernet Link A down" and "Double Ethernet Link B down" logic signals and events.
Double Ethernet PRP ports	• AB • BA	LanA and LanB port assigment for communication cards that support PRP.

Virtual Ethernet enables the device to be connected to multiple different networks simultaneously via one physical Ethernet connection. Virtual Ethernet has its own separate IP address and network configurations. All Ethernet-based protocol servers listen for client connections on the IP addresses of both the physical Ethernet and the Virtual Ethernet.

Table. 5.1 - 341. Virtual Ethernet settings.

Name	Description
Enable virtual adapter (No / Yes)	Enable virtual adapter. Off by default.
IP address	Set IP address of the virtual adapter.
Netmask	Set netmask of the virtual adapter.
Gateway	Set gateway of the virtual adapter.

AQ-200 series devices are always equipped with an RS-485 serial port. In the software it is identified as "Serial COM1" port.

Table. 5.1 - 342. Serial COM1 settings.

Name	Range	Description
Bitrate	• 9600bps • 19200bps • 38400bps	Bitrate used by RS-485 port.
Databits	7...8	Databits used by RS-485 port.
Parity	• None • Even • Odd	Paritybits used by RS-485 port.
Stopbits	1...2	Stopbits used by RS-485 port.
Protocol	• None • ModbutRTU • ModbusIO • IEC103 • SPA • DNP3 • IEC101	Communication protocol used by RS-485 port.

AQ-200 series supports communication option card type that has serial fiber ports (Serial COM2) an RS-232 port (Serial COM3).

Table. 5.1 - 343. Serial COM2 settings.

Name	Range	Description
Bitrate	• 9600bps • 19200bps • 38400bps	Bitrate used by serial fiber channels.
Databits	7...8	Databits used by serial fiber channels.
Parity	• None • Even • Odd	Paritybits used by serial fiber channels.
Stopbits	1...2	Stopbits used by serial fiber channels.

Name	Range	Description
Protocol	• None • ModbutRTU • ModbusIO • IEC103 • SPA • DNP3 • IEC101	Communication protocol used by serial fiber channels.
Echo	• Off • On	Enable or disable echo.
Idle Light	• Off • On	Idle light behaviour.

Table. 5.1 - 344. Serial COM3 settings.

Name	Range	Description
Bitrate	• 9600bps • 19200bps • 38400bps	Bitrate used by RS-232 port.
Databits	7...8	Databits used by RS-232 port.
Parity	• None • Even • Odd	Paritybits used by RS-232 port.
Stopbits	1...2	Stopbits used by RS-232 port.
Protocol	• None • ModbutRTU • ModbusIO • IEC103 • SPA • DNP3 • IEC101	Communication protocol used by RS-232 port.

5.2 Time synchronization

Time synchronization source can be selected with "Time synchronization" parameter at *Communication → Synchronization → General*.

Table. 5.2 - 345. General time synchronization source settings.

Name	Range	Description
Time synchronization source	• Internal • External NTP • External serial • IRIG-B • PTP	Selection of time synchronization source.

5.2.1 Internal

If no external time synchronization source is available the mode should be set to "internal". This means that the AQ-200 device clock runs completely on its own. Time can be set to the device with AQtivate setting tool with *Commands → Sync Time* command or in the clock view from the HMI. When using *Sync time* command AQtivate sets the time to device the connected computer is currently using. Please note that the clock doesn't run when the device is powered off.

5.2.2 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. 5.2.2 - 346. 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.
NTP version	3...4	Defines the NTP version used.

Table. 5.2.2 - 347. Status.

Name	Range	Description
NTP quality for events	• No sync • 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...4294967295	Displays the number of messages processed by the NTP protocol.

Additionally, the time zone of the device can be set by connecting to the device and the selecting the time zone at *Commands → Set time zone* in AQtivate setting tool.

5.2.3 PTP

PTP, Precision Time Protocol, is a higher accuracy synchronization protocol for Ethernet networks. Accuracy of microsecond level can be achieved. Time protocol is compliant with IEEE 1588-2008, also known as PTP Version 2 and supports the power profiles as specified in IEEE C37.238-2011, 2017 and IEC61850-9-3 (2016) standards.

In a PTP network the devices can have different roles. There is a Grandmaster clock that is the clock source, normally connected to GPS. Most devices take the role of an Ordinary clock which receive synchronization from the Grandmaster clock. In the PTP network there can also be Boundary and Transparent clock roles, these are most often PTP enabled switches that can redistribute time or compensate for their delays.

BMCA, Best Master Clock Algorithm, is an algorithm that PTP devices use to determine the best clock source. This is utilized in network segments where there are 2 Grandmaster clocks or in situations where there are no Grandmaster available. In these situations the devices make a selection which device will act as the clock source. In these cases without GPS synchronized clock source, the accuracy between the devices is still high.

Settings

Select PTP as the time synchronization source from *Communication → Synchronization → General* menu.

The following settings are available in *Communication → Synchronization → PTP* menu.

Table. 5.2.3 - 348. PTP time synchronization settings.

Name	Range	Description
Power profile	• None • IEEE C37-238-2011 • IEC61850-9-3 • IEEE C37-238-2017	Defines used power profile.
Role	• Auto (Default) • Master • Slave	In Auto mode, the device can take both the role of a clock source and clock consumer. In Master mode the device is forced to concider itself to be a clock source. In Slave mode the device is forced to be a clock consumer.
Mechanism	• P2P (Default) • E2E	Delay measurement mechanism used. Peer-to-peer can utilize the PTP enabled switches as transparent ro boundary clocks while End-to-end must be used if non-PTP enabled switches are found in the network.
Domain number	0...255	PTP devices can be set to belong to a grouping called domain. Devices in same domain is primearly being synchronized together.
Log announce interval		Mean time interval between successive announce messages.
Log delayReq interval		The minimum permitted mean time interval between successive Delay_Req messages
Log sync interval		Mean time interval between successive sync messages
Sync receipt timeout		Number of sync intervals that must pass without receipt of an sync message before the occurrence of the event SYNC_RECEIPT_TIMEOUT_EXPIRES
Announce receipt timeout		Number of announce intervals that must pass without receipt of an announce message before the occurrence of the event ANNOUNCE_RECEIPT_TIMEOUT_EXPIRES
Clock class		The traceability, synchronization state and expected performance of the time or frequency distributed by the Grandmaster PTP Instance
Clock accuracy		The expected accuracy of a PTP Instance when it is the Grandmaster PTP Instance, or in the event it becomes the Grandmaster PTP Instance

Name	Range	Description
Priority 1		Priority setting used in the execution of the best master clock algorithm. Lower values take precedence
Priority 2		Priority setting used in the execution of the best master clock algorithm. Lower values take precedence
VLAN enable	• Disabled • Enabled	Enable VLAN header for PTP communication
VLAN priority	0...7	Priority setting for VLAN
VLAN ID	0...4095	VLAN identification setting
Reconfigure PTP	• - • Reconfigure	Parameter to trig reconfiguration of the PTP application

Status indications

The following status indications are available in *Communication → Synchronization → PTP* menu.

Table. 5.2.3 - 349. PTP status indications

Name	Description
State	State of the PTP application (Master, Slave, Listening).
Best master	Identification of best master in network. Id consist of MAC address plus id number.
Last receive	Time when last synchronization frame was received.
Message sent	Diagnostic message counter.
Message receive	Diagnostic message counter.
PTP timesource	Diagnostic number describing the current time source.

5.3 Communication protocols

5.3.1 IEC 61850

The user can enable the IEC 61850 protocol in device models that support this protocol at *Communication → Protocols → IEC61850*. AQ-21x frame units support Edition 1 of IEC 61850. AQ-25x frame units support both Edition 1 and 2 of IEC 61850. The following services are supported by IEC 61850 in Arcteq devices:

- Up to six data sets (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', 'Select before operate with normal security, 'Direct with enhanced security' and 'Select before operate with enhanced sequrity' control sequences)
- Disturbance recording file transfer
- GOOSE
- Time synchronization

The device's current IEC 61850 setup can be viewed and edited with the IEC61850 tool (*Tools → Communication → IEC 61850*).

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. 5.3.1 - 350. General settings.

Name	Range	Step	Default	Description
Enable IEC 61850	• Disabled • Enabled	-	Disabled	Enables and disables the IEC 61850 communication protocol.
Reconfigure IEC 61850	• - • Reconfigure	-	-	Reconfigures IEC 61850 settings.
IP port	0…65 535	1	102	Defines the IP port used by the IEC 61850 protocol. The standard (and default) port is 102.
IEC61850 edition	• Ed1 • Ed2	-	-	Displays the IEC61850 edition used by the device. Edition can be chosen by loading a new CID file at *Tools → Communication → IEC 61850* with *Open* button.
Control Authority switch	• Remote Control • Station Level Control	-	Remote Control	The device can be set to allow object control via IEC 61850 only from clients that are of category Station level control. This would mean that other Remote control clients would not be allowed to control. In Remote control mode all IEC 61850 clients of both remote and station level category are allowed to control objects.
Ethernet port	• All • COM A • Double ethernet card	-	All	Determines which ports use IEC61850. Parameter is visible if double ethernet option card is found in the device.
Configure GOOSE Subscriber from CID file allowed	• Disabled • Allowed	-	Disabled	In edition 2 of IEC 61850 GOOSE subscriber configuration is a part of the CID file. Determines if it is possible to import published GOOSE settings of another device with a CID file and set them to GOOSE input at *Tools → Communication → IEC 61850 → GOOSE subscriptions*.
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.

Name	Range	Step	Default	Description
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	Determines the integration time of the protocol. If this parameter is set to "0 ms", no integration time is in use.
GOOSE Ethernet port	• All • COM A • Double ethernet card	-	All	Determines which ports can use GOOSE communication. Visible if double ethernet option card is found in the device.

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).

5.3.1.1 Logical device mode and logical node mode

Every protection block has its own behavior (LNBeh). This behavior is determined using a combination of the protection block's mode (LNMod) and the device's mode (LDMod).

In IEC68150 mode,

- LNMod can be reported and controlled through Mod data object in all logical nodes.
- LNBeh can be reported through Beh data object in all logical nodes.
- LDMod is only visible through logical node zero's Mod data object (LLN0.Mod).

Mode and behavior values

There are 5 values defined for mode and behavior: On, Blocked, Test, Test / Blocked and Off.

Table. 5.3.1.1 - 351. Behavior descriptions.

LNBeh	On	Blocked	Test	Test / Blocked	Off
Function working	Yes	Yes	Yes	Yes	No
Data quality	Relevant to data	Relevant to data	q.test = True	q.test = True	q.validity = Invalid
Output to process	Yes	No	Yes	No	No
Accept normal control	Yes	Yes	No	No	No
Accept test control	No	No	Yes	Yes	No

The communication services for the data object Mod do not care about the status of the LNBeh. Mod will always accept commands with q.test = False.

Data objects Mod, Beh and Health will always have q.validity = Good. Regardless of the status of LNBeh, the quality test attribute of Mod, Beh and Health shall be q.test = False.

Behavior determination

The values for LDMod and LNMod are settable by the user by using HMI, setting tool, or IEC 61850 client. The value for LNBeh are then determined using following rules.

- If either LDMod or LNMod is Off, LNBeh is Off.
- Otherwise,
    - If either LDMod or LNMod is set to either "Test" or "Test / Blocked" mode, LNBeh is in Test mode.
    - If either LDMod or LNMod is set to either "Blocked" or "Test / Blocked" mode, LNBeh is in Blocked mode.
    - If LNBeh still doesn't have anything, LNBeh is "On".

All the possible combinations are laid out in the following table.

Table. 5.3.1.1 - 352. All possible logical device and logical node combinations.

LDMod	LNMod	LNBeh
Off	Off	Off
	Test / Blocked	Off
	Test	Off
	Blocked	Off
	On	Off
Test / Blocked	Off	Off
	Test / Blocked	Test / Blocked
	Test	Test / Blocked
	Blocked	Test / Blocked
	On	Test / Blocked

LDMod	LNMod	LNBeh
Test	Off	Off
	Test / Blocked	Test / Blocked
	Test	Test
	Blocked	Test / Blocked
	On	Test
Blocked	Off	Off
	Test / Blocked	Test / Blocked
	Test	Test / Blocked
	Blocked	Blocked
	On	Blocked
On	Off	Off
	Test / Blocked	Test / Blocked
	Test	Test
	Blocked	Blocked
	On	On

Processing of incoming data in different behaviors

This part only applies to incoming data with quality information.

The table below gives the functional processing of the data in different behavior states as defined by the standard. Logical nodes should process receiving data according to their quality information:

- Processed as valid - Reacts according to the quality.
- Processed as invalid - Reacts as if the quality of the data had been invalid.
- Processed as questionable - The application decides how to consider the status value.
- Not processed - Do not belong to communication services, no quality bit can be evaluated.

Table. 5.3.1.1 - 353. Processing of incoming data in different behaviors as defined by the standard.

	On	Blocked	Test	Test / Blocked	Off
q.validity = Good q.test = False	Processed as valid	Processed as valid	Processed as valid	Processed as valid	Not processed
q.validity = Questionable q.test = False	Processed as questionable	Processed as questionable	Processed as questionable	Processed as questionable	Not processed
q.validity = Good q.test = True	Processed as invalid	Processed as invalid	Processed as valid	Processed as valid	Not processed

	On	Blocked	Test	Test / Blocked	Off
q.validity = Questionable q.test = True	Processed as invalid	Processed as invalid	Processed as questionable	Processed as questionable	Not processed
q.validity = Invalid q.test = True/ False	Processed as invalid	Processed as invalid	Processed as invalid	Processed as invalid	Not processed

Arcteq's implementation treats “Processed as questionable” and “Processed as invalid” in the same way with “Not processed”. Only "Processed as valid" is passed to the application.

Table. 5.3.1.1 - 354. Arcteq's implementation of processing of incoming data in different behaviors.

	On	Blocked	Test	Test / Blocked	Off
q.validity = Good q.test = False	Processed as valid	Processed as valid	Processed as valid	Processed as valid	
q.validity = Questionable q.test = False					
q.validity = Good q.test = True			Processed as valid	Processed as valid	
q.validity = Questionable q.test = True					
q.validity = Invalid q.test = True/False					

Using mode and behavior

Enabling LDMod and LNMod changing can be done at *General → Device info*.

Table. 5.3.1.1 - 355. Parameters to allow changing of LNMod and LDMod.

Name	Range	Default	Description
Allow setting of device mode	• Prohibited • From HMI/ setting tool only • Allowed	Prohibited	Allows global mode to be modified from setting tool, HMI and IEC61850. Prohibited: Cannot be changed. From HMI/setting tool only: Can only be changed from the setting tool or HMI. Allowed: Can be changed from the setting tool, HMI, and IEC 61850 client.

Name	Range	Default	Description
Allow setting of individual LN mode	• Prohibited • From HMI/ setting tool only • Allowed	Prohibited	Allow local modes to be modified from setting tool, HMI and IEC61850. This parameter is visible only when "Allow setting of device mode" is enabled. Prohibited: Cannot be changed. From HMI/setting tool only: Can only be changed from the setting tool or HMI Allowed: Can be changed from the setting tool, HMI, and IEC 61850 client.

When enabled it is possible to change LDMod at *Communication → Protocols → IEC61850*.

Table. 5.3.1.1 - 356. Parameter for changing logical device mode.

Name	Range	Default	Description
Allow setting of device mode	• On • Blocked • Test • Test/ Blocked • Off	On	Set mode of logical device. This parameter is visible only when *Allow setting of device mode* is enabled in *General* menu.

Each protection, control and monitoring function has its own logical node mode which can be changed individually. This parameter is found in the functions *Info*-menu. Each function also reports its behavior. Behavior of the function is influenced by the status of the device mode setting and the functions mode setting.

Table. 5.3.1.1 - 357. LNMod parameters.

Name	Range	Default	
LN mode	• On • Blocked • Test • Test/ Blocked • Off	On	Set mode of function logical node. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.
LN behavior	• On • Blocked • Test • Test/ Blocked • Off	On	Displays the mode of the function logical node. This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu.

5.3.1.2 GOOSE

Arcteq devices 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 status is "low" (that is, when the quality is marked as "0"). The value of the input quality can switch on 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*.

General GOOSE setting

The table below presents general settings for GOOSE publisher.

Table. 5.3.1.2 - 358. General GOOSE publisher settings.

Name	Range	Description
GOOSE control block 1 simulation bit GOOSE control block 2 simulation bit	• Disabled (Default) • Enabled	The publisher will publish frames with simulation bit active if enabled. For GOOSE simulation testing purposes.

The table below presents general settings for GOOSE subscriber

Table. 5.3.1.2 - 359. General GOOSE subscriber settings.

Name	Range	Description
GOOSE subscriber enable	• Disabled (Default) • Enabled	Enables or disables GOOSE subscribing for the device.
Not used GOOSE input Quality	• Bad quality (1) • Good quality (0)	Defines what state should GOOSE input quality signal to be in the logic if the input has been set as "disabled".
Subscriber checks GoCBRef Subscriber checks SqNum	• No (Default) • Yes	When subscriber sees GOOSE frame it checks APPID and Conf. Rev but can also check if GoCBRef or SqNum match.
Subscriber process simulation messages	• No (Default) • Yes	Subscriber can be set to process frames which are published with simulation bit high if enabled. The subscriber can still subscribe to non-simulated frames from a publisher until that a simulated frame is received from a publisher. From that point on, only simulated frames are accepted from that publisher. For other publishers, non-simulated frames are accepted normally (given no simulated frame is received from that publisher). This behavior ends when the setting is set back to No.

GOOSE input settings

The table below presents the different settings available for all 64 GOOSE inputs.

These settings can be found from *Communication → Protocols → IEC61850/GOOSE → GOOSE Input Settings*.

Table. 5.3.1.2 - 360. GOOSE input settings.

Name	Range	Description
In use	• No (Default) • Yes	Enables and disables the GOOSE input in question.
Application ID ("AppID")	0×0…0×3FFF	Defines the application ID that will be matched with the publisher's GOOSE control block.
Configuration revision ("ConfRev")	1…2^{32}-1	Defines the configuration revision that will be matched with the publisher's GOOSE control block.
Data index ("DataIdx")	0…99	Defines the data index of the value in the matched published frame. It is the status of the GOOSE input.
NextIdx is quality	• No (Default) • Yes	Selects whether or not the next received input is the quality bit of the GOOSE input.
Data type	• Boolean (Default) • Integer • Unsigned • Floating point	Selects the data type of the GOOSE input.
Control block reference	-	GOOSE subscriber can be set to check the GCB reference of the published GOOSE frame. This setting is automatically filled when Ed2 GOOSE configuration is done by importing cid file of the publisher.

GOOSE input descriptions

Each of the GOOSE inputs can be given a description. The user defined description are displayed in most of the menus:

- logic editor
- matrix
- block settings
- event history
- disturbance recordings
- etc.

These settings can be found from *Control → Device IO → Logical Signals → GOOSE IN Description*.

Table. 5.3.1.2 - 361. GOOSE input user description.

Name	Range	Default	Description
User editable description GI x	1...31 characters	GOOSE IN x	Description of the GOOSE input. This description is used in several menu types for easier identification.

GOOSE input values

Each of the GOOSE subscriber inputs (1...64) have indications listed in the following table. These indications can be found from *Communication → Protocols → IEC61850/GOOSE → GOOSE input values*.

Table. 5.3.1.2 - 362. GOOSE input indications

Name	Range	Description
Subscription status	• Not Active • Active	When active correct data received and passed to application.
Processing simulation message	• False • True	When true subscriber is processing simulation frames for this input (and rejecting non-simulated frames).
Needs commissioning	• False • True	When true configuration doesn't match the received frame (goCBRef, confRev).
Last received state number	0...4294967295	Status number (stNum) of the last data passed to application.
GOOSE IN X boolean value	0...1	GOOSE input 1...64 boolean value.
GOOSE IN X analog value	-3.4E+38...3.4E+38	GOOSE input 1...64 analog value.
GOOSE IN X quality	• Old data • Failure • Oscillatory • Bad reference • Out of range • Overflow • Invalid • Reserved/ Questionable • Operator blocked • Test • Substituted • Inaccurate • Inconsistent	GOOSE input quality indication.
GOOSE IN X time	DD/MM/YYYY HH:MM:SS	Time when publisher sent GOOSE frame.
GOOSE IN X time fraction	0...4294967295 µs	Microseconds of the publisher GOOSE frame.

GOOSE events

GOOSE signals generate events from status changes. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp and with process data values. The time stamp resolution is 1 ms.

Table. 5.3.1.2 - 363. GOOSE event

Event block name	Event name	Description
GOOSE1...GOOSE2	GOOSE IN 1...64 ON/OFF	Status change of GOOSE input.
GOOSE3...GOOSE4	GOOSE IN 1...64 quality Bad/ Good	Status change of GOOSE inputs quality.
GOOSE5...GOOSE6	GOOSE Subscription status 1...64 Active/Not active	When active correct data received and passed to application.
GOOSE7...GOOSE8	GOOSE Processing simulated messages 1...64 True/False	When true subscriber is processing simulation frames for this input (and rejecting non-simulated frames).
GOOSE9...GOOSE10	GOOSE Subscription needs commissioning 1...64 True/ False	When true configuration doesn't match the received frame (goCBRef, confRev).

Setting the publisher

The configuration of the GOOSE publisher is done using the IEC 61850 tool in AQtivate (*Tools → Communication → IEC 61850*). Refer to *AQtivate-200 Instruction manual* for more information on how to set up GOOSE publisher.

5.3.2 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 device via the AQtivate software (*Tools → Communication → Modbus Map*). 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 device and the master. Modbus map can be edited with Modbus Configurator (*Tools → Communication → Modbus Configurator*).

Table. 5.3.2 - 364. Modbus/TCP settings.

Parameter	Range	Description
Enable Modbus/TCP	• Disabled • 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.
Ethernet port	• All • COM A • Double Ethernet card	Defines which ethernet ports are available for Modbus connection. Visible if any double ethernet option card is installed in the device.
Event read mode	• Get oldest available • Continue previous connection • New events only	Get oldest event possible (Default) Continue with the event idx from previous connection Get only new events from connection time and forward.

Table. 5.3.2 - 365. Modbus/RTU settings.

Parameter	Range	Description
Slave address	1…247	Defines the Modbus/RTU slave address for the unit.

Reading events

Modbus protocol does not support time-stamped events by standard definition. This means that every vendor must come up with their own definition how to transfer events from the device to the client. In AQ-200 series devices events can be read from HR17...HR22 holding registers. HR17 contains the event-code, HR18...20 contains the time-stamp in UTC, HR21 contains a sequential index and HR22 is reserved for future expansion. See the Modbus Map for more information. The event-codes and their meaning can be found from Event list (*Tools → Events ang Logs → Event list* in setting tool). The event-code in HR17 is 0 if no new events can be found in the device event-buffer. Every time HR17 is read from client the event in event-buffer is consumed and on following read operation the next un-read event information can be found from event registers. HR11…HR16 registers contains a back-up of last read event. This is because some users want to double-check that no events were lost

5.3.3 IEC 103

IEC 103 is the 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 AQ-200 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 device 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.

5.3.4 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. 5.3.4 - 366. 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. 5.3.4 - 367. IEC 104 settings.

Name	Range	Step	Default	Description
IEC 104 enable	• Disabled • Enabled	-	Disabled	Enables and disables the IEC 104 communication protocol.
IP port	0…65 535	1	2404	Defines the IP port used by the protocol.

Name	Range	Step	Default	Description
Ethernet port	• All • COM A • Double Ethernet card	-	All	Defines which ethernet ports are available for Modbus connection. Visible if any double ethernet option card is installed in the device.
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.
APDU timeout (t1)	0...3600 s	1 s	0 s	The maximum amount of time the slave waits for a transmitted Application Protocol Data Unit (APDU) to be confirmed as received by the master.
Idle timeout (t3)	0...3600 s	1 s	0 s	The slave outstation can use a test fram to determine if the channel is still available after a prolonged period of communications inactivity. Test frame is sent at an interval specified here.

Measurement scaling coefficients

The measurement scaling coefficients are available for the following measurements, in addition to the general measurement scaling coefficient:

Table. 5.3.4 - 368. Measurements with scaling coefficient settings.

Name	Range
Active energy	• 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
Reactive energy	
Active power	
Reactive power	
Apparent power	
Power factor	
Frequency	
Current	
Residual current	
Voltage	
Residual voltage	
Angle	

Deadband settings.

Table. 5.3.4 - 369. 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…1000.0kWh	0.1kWh	2kWh	Determines the data reporting deadband settings for this measurement.
Reactive energy deadband	0.1…1000.0kVar	0.1kVar	2kVar	
Active power deadband	0.1…1000.0kW	0.1kW	2kW	
Reactive power deadband	0.1…1000.0kVar	0.1kVar	2kVar	
Apparent power deadband	0.1…1000.0kVA	0.1kVA	2kVA	
Power factor deadband	0.01…0.99	0.01	0.05	
Frequency deadband	0.01…1.00Hz	0.01Hz	0.1Hz	
Current deadband	0.01…50.00A	0.01A	5A	
Residual current deadband	0.01…50.00A	0.01A	0.2A	
Voltage deadband	0.01…5000.00V	0.01V	200V	
Residual voltage deadband	0.01…5000.00V	0.01V	200V	
Angle measurement deadband	0.1…5.0deg	0.1deg	1deg	
Integration time	0…10 000ms	1ms	-	Determines the integration time of the protocol. If this parameter is set to "0 ms", no integration time is in use.

5.3.5 SPA

The device can act as a SPA slave. SPA can be selected as the communication protocol for the RS-485 port (Serial COM1). When the device has a serial option card, the SPA protocol can also be selected as the communication protocol for the serial fiber (Serial COM2) ports or RS-232 (Serial COM3) port. 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*.

Table. 5.3.5 - 370. SPA setting parameters.

Name	Range	Description
SPA address	1...899	SPA slave address.
UTC time sync	• Disabled • Enabled	Determines if UTC time is used when synchronizing time. When disabled it is assumed time synchronization uses local time. If enabled it is assumed that UTC time is used. When UTC time is used the timezone must be set at *Commands → Set time zone*.

NOTICE!
To access SPA map and event list, an .aqs configuration file should be downloaded from the device.

5.3.6 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. 5.3.6 - 371. Settings.

Name	Range	Step	Default	Description
Enable DNP3 TCP	• Disabled • Enabled	-	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.
Ethernet port	• All • COM A • Double Ethernet card	-	All	Defines which ethernet ports are available for Modbus connection. Visible if any double ethernet option card is installed in the device.
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 000ms	1ms	0ms	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.

Name	Range	Step	Default	Description
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. 5.3.6 - 372. Default variations.

Name	Range	Default	Description
Group 1 variation (BI)	• Var 1 • Var 2	Var 1	Selects the variation of the binary signal.
Group 2 variation (BI change)	• Var 1 • Var 2	Var 2	Selects the variation of the binary signal change.
Group 3 variation (DBI)	• Var 1 • Var 2	Var 1	Selects the variation of the double point signal.
Group 4 variation (DBI change)	• Var 1 • Var 2	Var 2	Selects the variation of the double point signal.
Group 20 variation (CNTR)	• Var 1 • Var 2 • Var 5 • Var 6	Var 1	Selects the variation of the control signal.
Group 22 variation (CNTR change)	• Var 1 • Var 2 • Var 5 • Var 6	Var 5	Selects the variation of the control signal change.
Group 30 variation (AI)	• Var 1 • Var 2 • Var 3 • Var 4 • Var 5	Var 5	Selects the variation of the analog signal.
Group 32 variation (AI change)	• Var 1 • Var 2 • Var 3 • Var 4 • Var 5 • Var 7	Var 5	Selects the variation of the analog signal change.

Setting the analog change deadbands

Table. 5.3.6 - 373. 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…1000.0kWh	0.1kWh	2kWh	Determines the data reporting deadband settings for this measurement.
Reactive energy deadband	0.1…1000.0kVar	0.1kVar	2kVar	
Active power deadband	0.1…1000.0kW	0.1kW	2kW	
Reactive power deadband	0.1…1000.0kVar	0.1kVar	2kVar	
Apparent power deadband	0.1…1000.0kVA	0.1kVA	2kVA	
Power factor deadband	0.01…0.99	0.01	0.05	
Frequency deadband	0.01…1.00Hz	0.01Hz	0.1Hz	
Current deadband	0.01…50.00A	0.01A	5A	
Residual current deadband	0.01…50.00A	0.01A	0.2A	
Voltage deadband	0.01…5000.00V	0.01V	200V	
Residual voltage deadband	0.01…5000.00V	0.01V	200V	
Angle measurement deadband	0.1…5.0deg	0.1deg	1deg	
Integration time	0…10 000ms	1ms	0ms	Determines the integration time of the protocol. If this parameter is set to "0 ms", no integration time is in use.

5.3.7 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. 5.3.7 - 374. 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.

Name	Range	Description
Module x type	• ADAM-4018+ • 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. 5.3.7 - 375. Channel settings.

Name	Range	Step	Default	Description
Thermocouple type	• +/- 20mA • 4…20mA • Type J • Type K • Type T • Type E • Type R • Type S	-	4…20mA	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…2 000.0	0.1	-	Displays the input value of the selected channel.
Input status	• Invalid • OK	-	-	Displays the input status of the selected channel.

5.4 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.

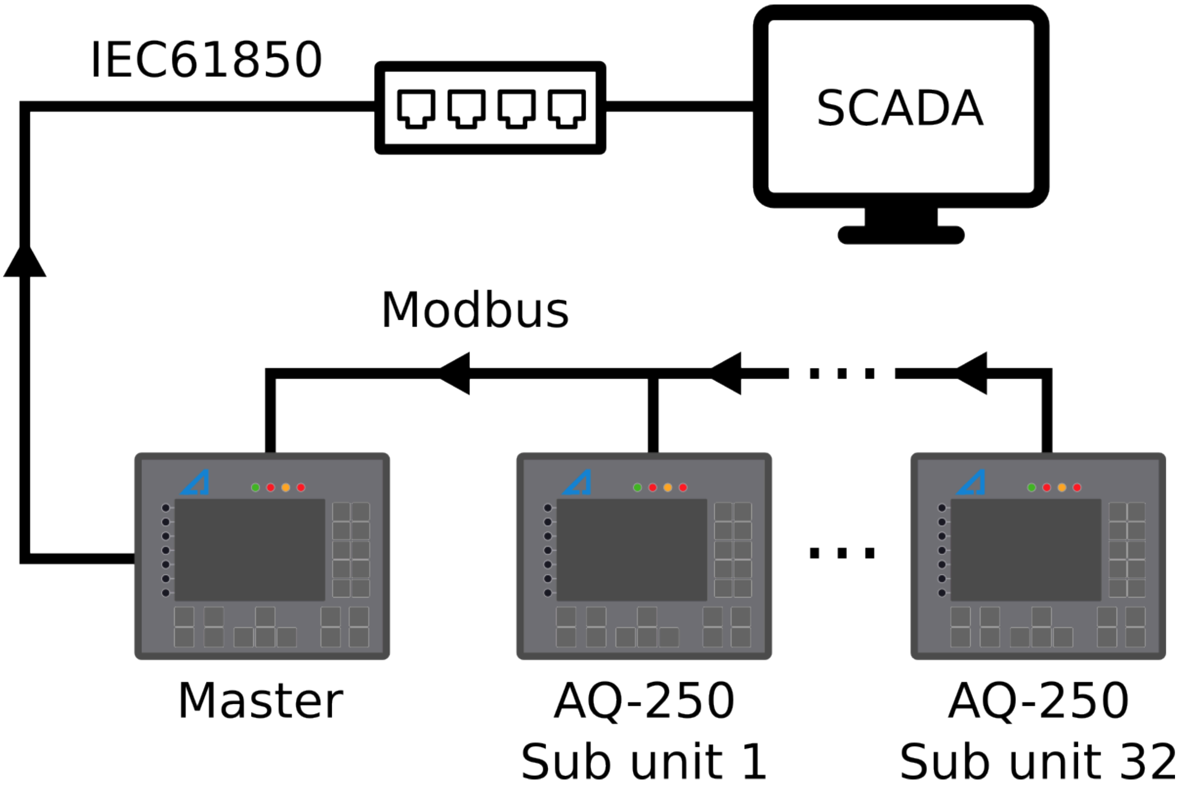
Table. 5.4 - 376. Fault register settings.

Name	Range	Step	Default	Description
Select record source	Not in use I>, I>>, I>>>, I>>>> (IL1, IL2, IL3) Id>, Id>>, Id>>>, Id>>>> (IL1, IL2, IL3) I0>, I0>>, I0>>>, I0>>>> (I0) I0d>, I0d>>, I0d>>>, I0d>>>> (I0) FLX (Fault locator)	-	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	• TRIP signal • START signal • START and TRIP signals	-	TRIP signal	Selects what triggers the fault register recording: the selected function's TRIP signal, its START signal, or either one.

Name	Range	Step	Default	Description
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.

5.5 Modbus Gateway

Figure. 5.5 - 203. Example setup of Modbus Gateway application.



Any AQ-250 device can be setup as a Modbus Gateway (i.e. master). Modbus Gateway device can import messages (measurements, status signals etc.) from external Arcteq and third-party devices. RS-485 serial communication port. Up to 32 sub units can be connected to an AQ-200 master unit. These messages can then be used for controlling logic in the master device, display the status in user created mimic. Binary signals can be reported forward to SCADA with IEC61850, IEC101, IEC103, IEC104, Modbus, DNP3 or SPA.

Arc protection relays AQ-103 and AQ-103 LV Modbus variant is designed to work as a sub unit with Modbus Gateway master. More details about AQ-103 and AQ-103 LV capabilities and how to set them up can be found in *AQ-103 Instruction manual* (arcteq.fi./downloads/). Also see application example at the end of this chapter.

Modbus Gateway and its basic settings can be found from *Communication → Modbus Gateway*. General settings-menu displays the health of connection to each sub unit.

Table. 5.5 - 377. General settings

Name	Range	Description
Modbus Gateway mode	• Disabled (Default) • Enabled	Enables or disables Modbus Gateway.
Modbus Gateway reconfigure	- Reconfigure	Setting this parameter to "Reconfigure" takes new settings into use. Parameter returns back to "-" automatically.
Quality of Modbus Sub unit 1...32	• OK • Old data • Data questionable • Modbus error • Send fail • Receive fail	Quality of each connected sub unit.

Imported signals

Modbus Gateway supports importing of measurements, bits, double bits, counters and integer signals. Up to 128 signals can be imported of each signal type with the exception of double bits (32).

Table. 5.5 - 378. Imported signals

Name	Range
Imported measurement 1-128	-3.4E+38...3.4E+38
Imported bit signal 1-128	0...1
Imported double bit data 1-32	0...3
Imported counter data 1-128	0...4294967295
Imported integer signal 1-128	-2147483648...2147483647

To assign the signals use Modbus Gateway editor (*Tools → Communication → Modbus Gateway*). Detailed description of this tool can be found in *AQtivate 200 Instruction manual* (arcteq.fi./downloads/).

All imported signals can be given a description. The description will be displayed in most of menus with the signal (logic editor, matrix, block settings etc.).

Table. 5.5 - 379. Imported signal user description.

Name	Range	Default	Description
Describe measurement x	1...31 characters	Acq. Meas x	User settable description for the signal. This description is used in several menu types for easier identification.
Describe bit signal x		Acq. Bit x	
Describe doube bit signal x		Acq. Binary x	

Name	Range	Default	Description
Describe counter signal x		Acq. Counter x	
Describe integer signal x		Acq. Integer x	

Events

The Modbus Gateway generates events the status changes in imported bits and double bits. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

Table. 5.5 - 380. Event messages

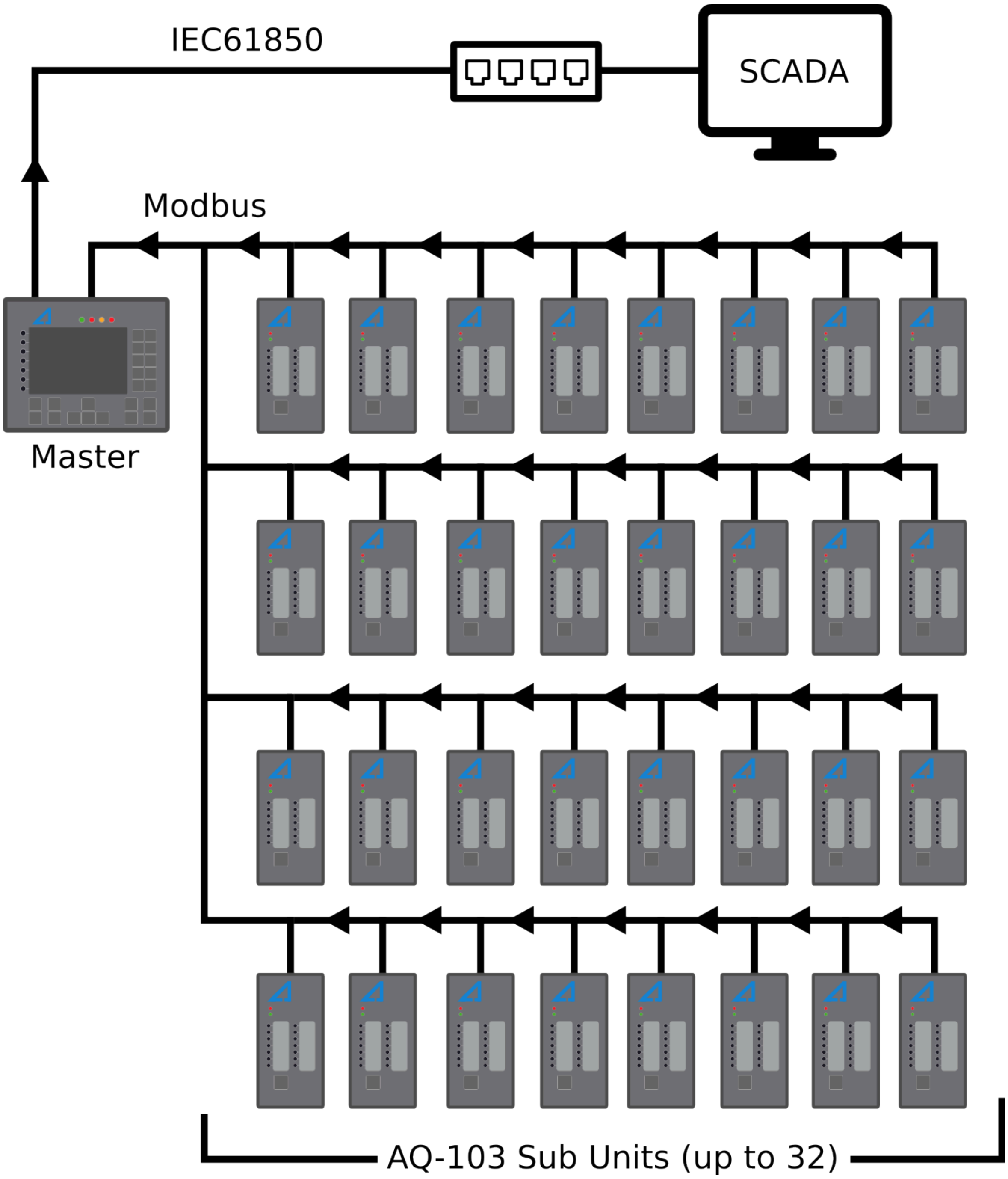
Event block name	Event names
MGWB1	Bit 1...Bit 32 (ON, OFF)
MGWB2	Bit 33...Bit 64 (ON, OFF)
MGWB3	Bit 65...Bit 96 (ON, OFF)
MGWB4	Bit 97...Bit 128 (ON, OFF)
MGWD1	Double Bit 1... Double bit 16 (ON/ON, OFF/OFF, ON/OFF, OFF/ON)
MGWD2	Double Bit 17... Double bit 32 (ON/ON, OFF/OFF, ON/OFF, OFF/ON)

Connect AQ-103 devices to Modbus Gateway device

AQ-103 is a sophisticated microprocessor-based arc flash protection unit for arc light detection. AQ-103 acts as a sub-unit to AQ-110P (or, AQ-110F) in an AQ-100 arc protection system. It can also function as a stand-alone unit in light-only systems. AQ-103 provides communication through RS-485 and Modbus protocol as ordering options. Through the Modbus communication AQ-103 connects to an AQ-250 device for indication of exact fault location and to a SCADA system either trough a AQ-250 device or RTU.

AQ-103 Modbus variant is able to report various signals like number of installed sensors, sensor activations, I/O activations etc. Holding registers of each signal can be found in the AQ-103 instruction manual.

Figure. 5.5 - 204. AQ-250 device can receive signals through modbus and use them to control logic of the device, create mimics and report the values to IEC 61850.



The signals received from AQ-103 device can be used for fault indications on AQ-200 device and for reporting the signals forward with IEC 61850 or other communication protocol. Fault indication can be done by setting up an alarm display for each incoming signal or by building a mimic.

Figure. 5.5 - 205. To report imported bit signals to SCADA the signals must be connected to a logical output.

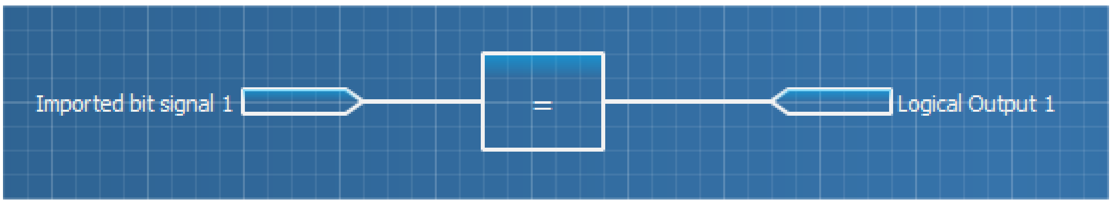
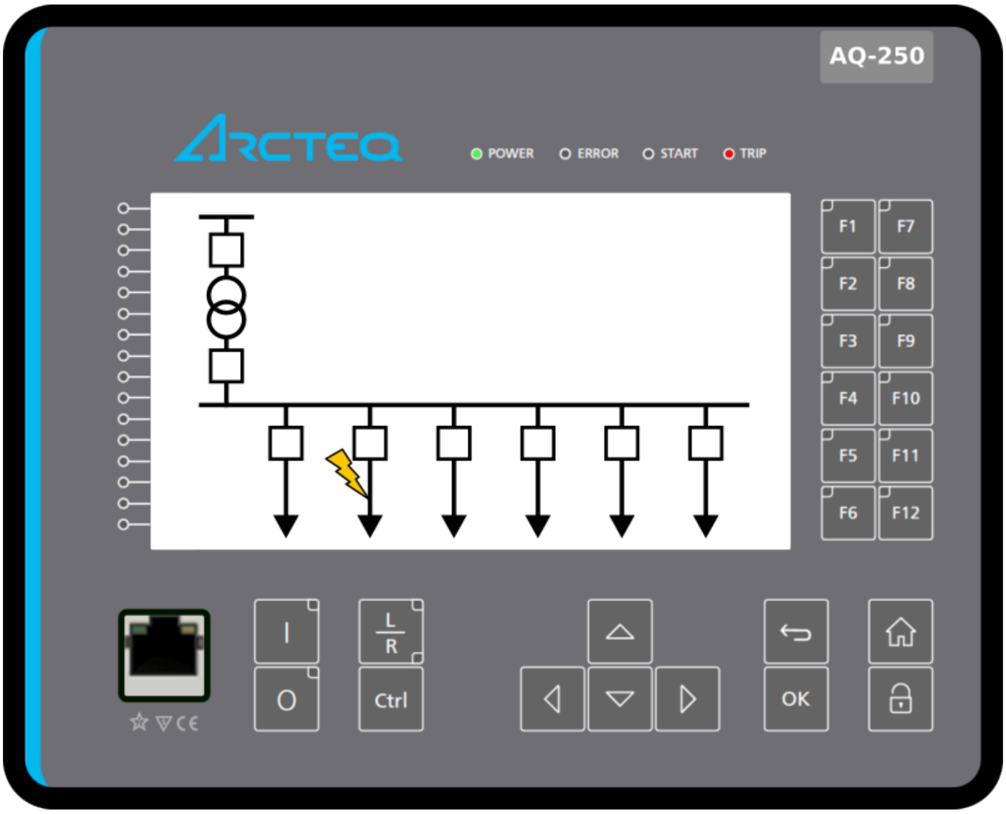


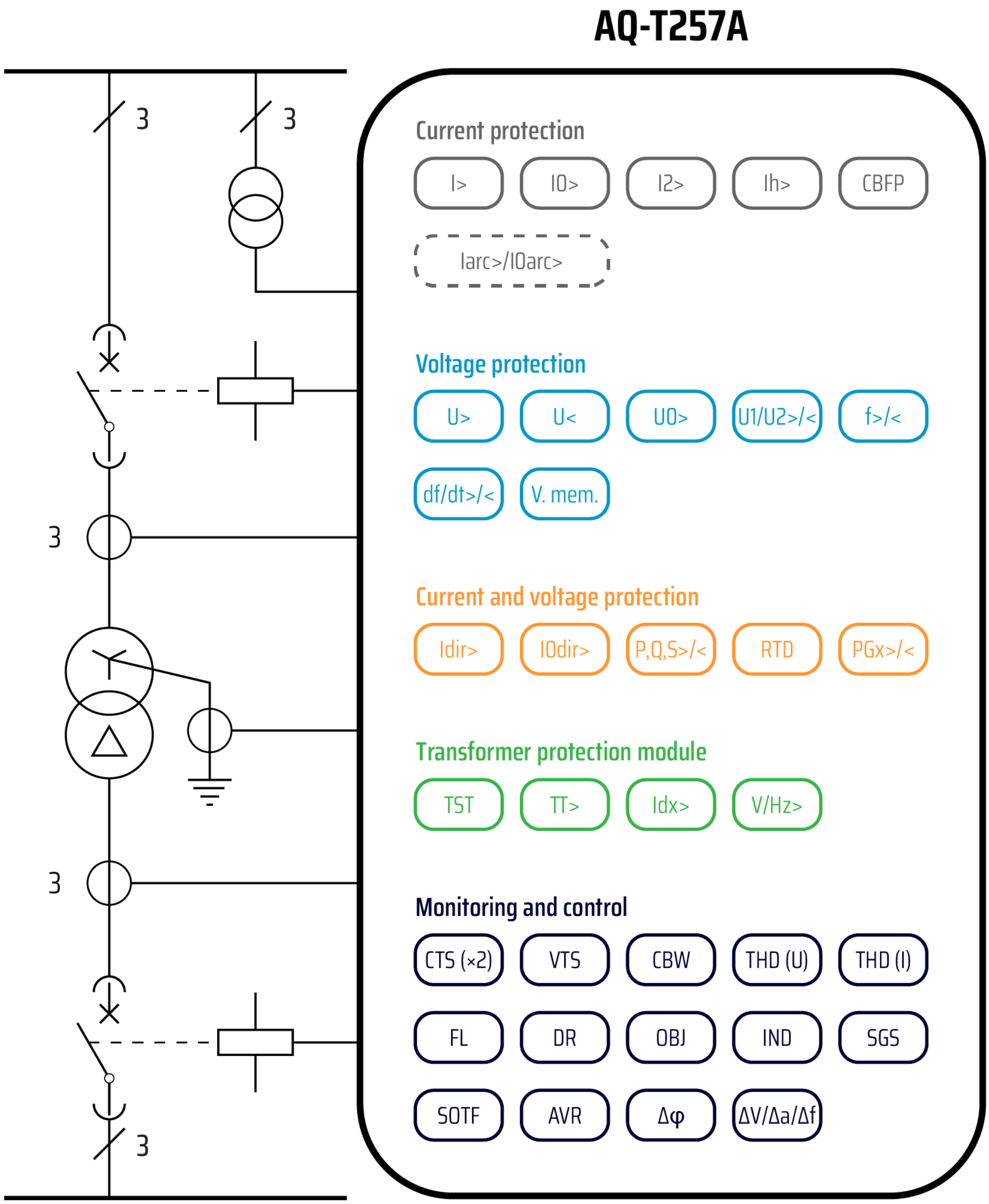
Figure. 5.5 - 206. Example mimic where sensor activation location is indicated with a symbol.



6 Connections and application examples

6.1 Connections of AQ-T257

Figure. 6.1 - 207. AQ-T257 application example with function block diagram.

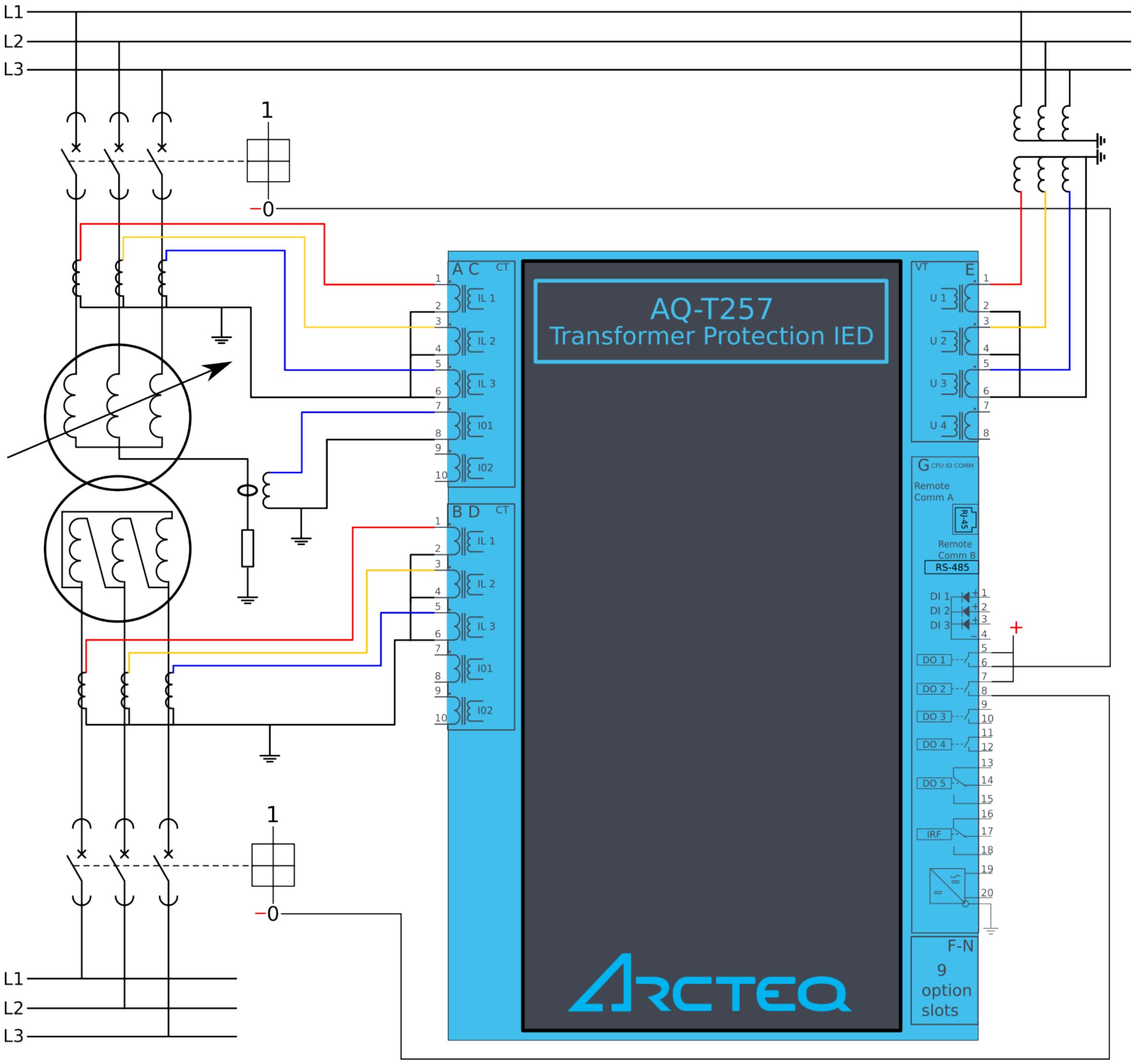


6.2 Application example and its connections

This chapter presents an application example for the two-winding transformer differential relay. 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, since three line-to-neutral voltages are connected, this application's voltage transformer uses the voltage measurement mode "3LN".

Figure. 6.2 - 208. Application example and its connections.



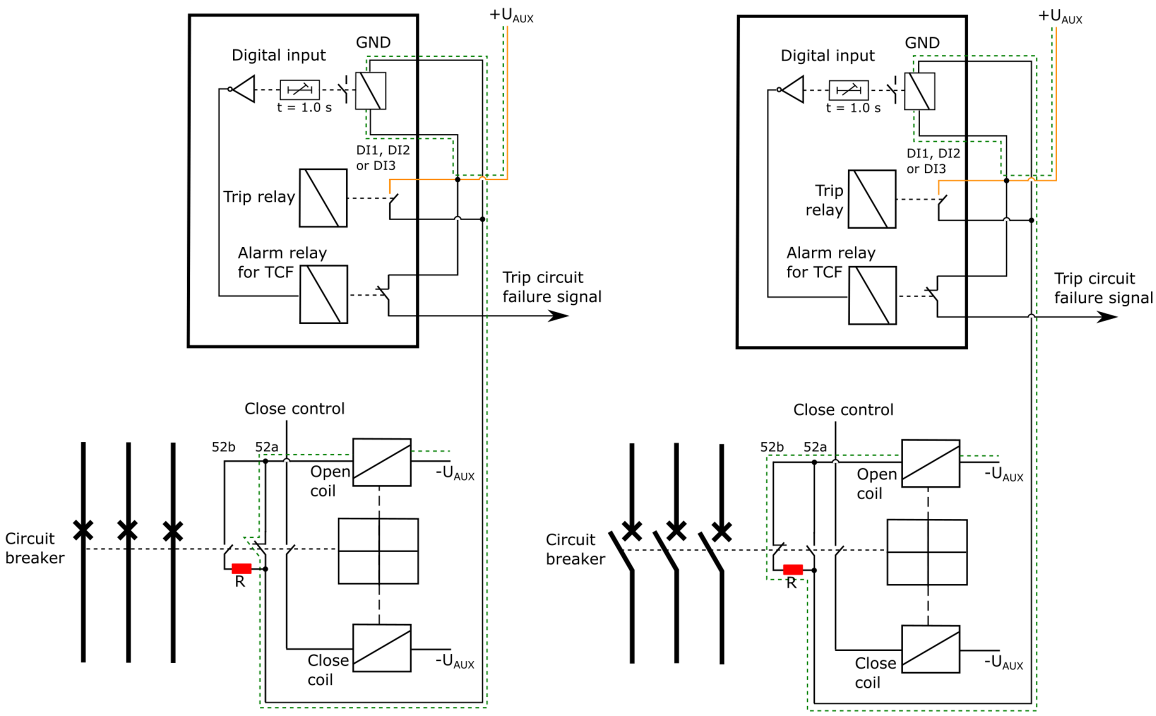
6.3 Trip circuit supervision (95)

Trip circuit supervision is used to monitor the wiring from auxiliary power supply, through the device's digital output, and all the way to the open coil of the breaker. It is recommended to supervise the health of the trip circuit when 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. 6.3 - 209. Trip circuit supervision with one DI and one non-latched trip output.

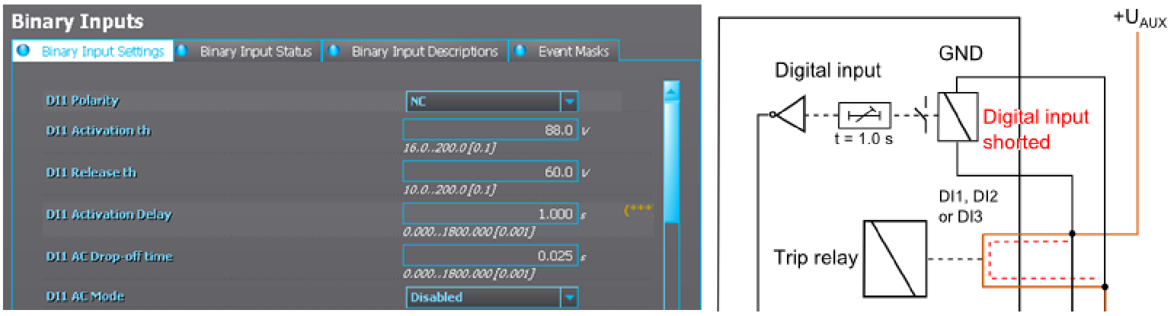


Note that the digital input that monitors the circuit is normally closed, and the same applies to the alarm relay if one is used. For monitoring and especially trip circuit supervision purposes it is recommended to use a normally closed contact to confirm the wiring's condition. An active digital input generates a less than 2 mA current to the circuit, which is usually small enough not to make the breaker's open coil operate.

When the trip relay is controlled and the circuit breaker is opening, the digital input is shorted 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, $t_{DI} = t_{CB} + t_{IEDrelease} + t_{CBFP}$.

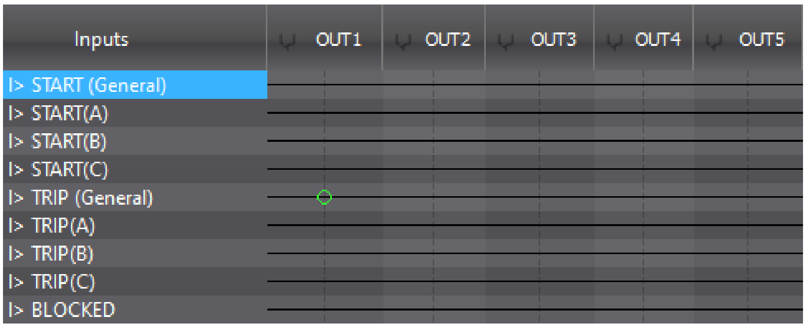
The image below presents the necessary settings when using a digital input for trip circuit supervision. The input's polarity must be NC (normally closed) and a one second delay is needed to avoid nuisance alarm while the circuit breaker is controlled open.

Figure. 6.3 - 210. 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. 6.3 - 211. Non-latched trip contact.



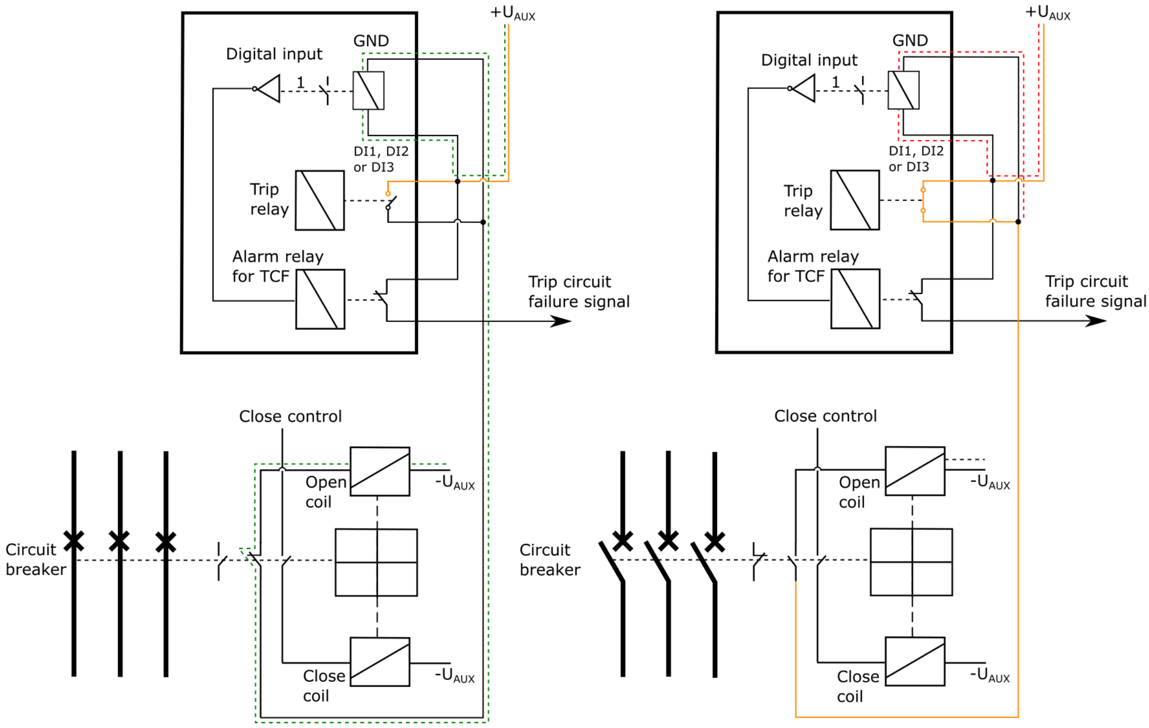
When the auto-reclosing function is used in feeder applications, the trip output contacts must be non-latched. Trip circuit supervision is generally easier and more reliable to build with non-latched outputs.

The open coil remains energized only as long as the circuit breaker is opened and the 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 device'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 device's trip output.

Figure. 6.3 - 212. Trip circuit supervision with one DI and one latched output contact.

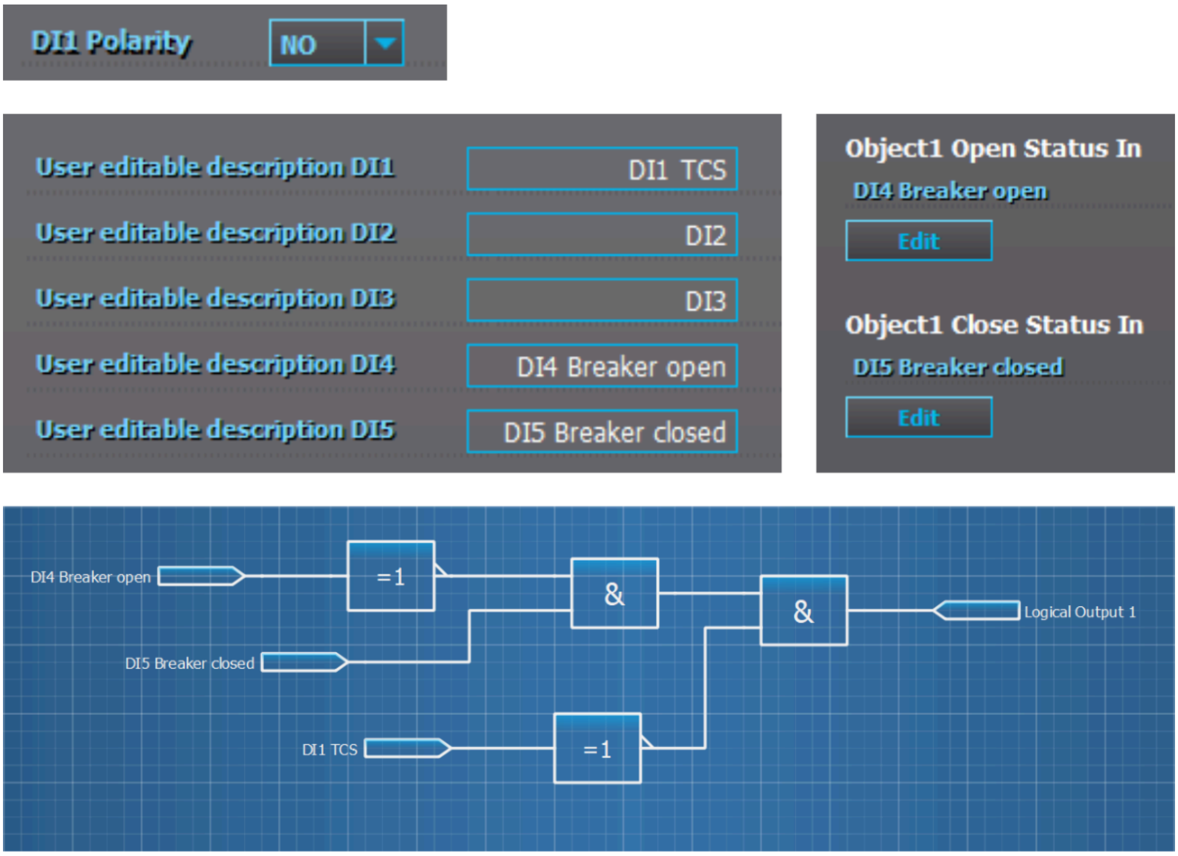


The trip circuit with a latched output contact can be monitored, but only when the circuit breaker's status is "Closed". Whenever the breaker is open, the supervision is blocked by an internal logic scheme. Its disadvantage is that the user does not know whether or not the trip circuit is intact when the breaker is closed again.

The following logic scheme (or similar) blocks 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. 6.3 - 213. Example block scheme.



7 Construction and installation

7.1 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) and the fully optioned model (AQ-X257-XXXXXXX-BBBCCCCCJ).

Figure. 7.1 - 214. Modular construction of AQ-X257-XXXXXXX-AAAAAAAAA

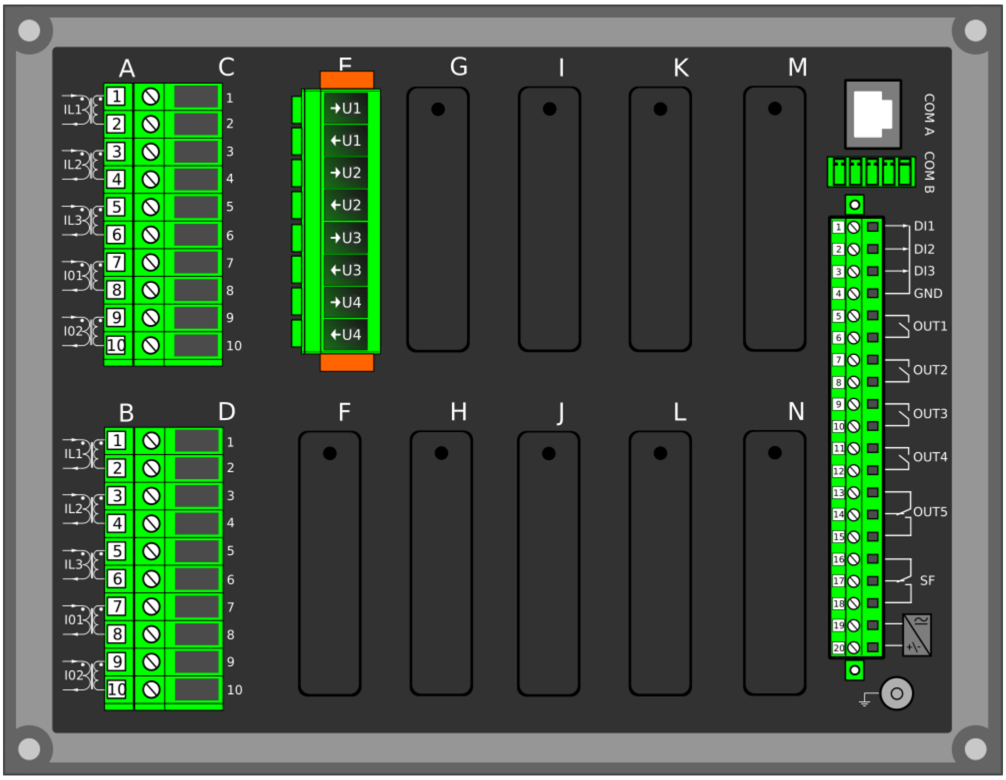
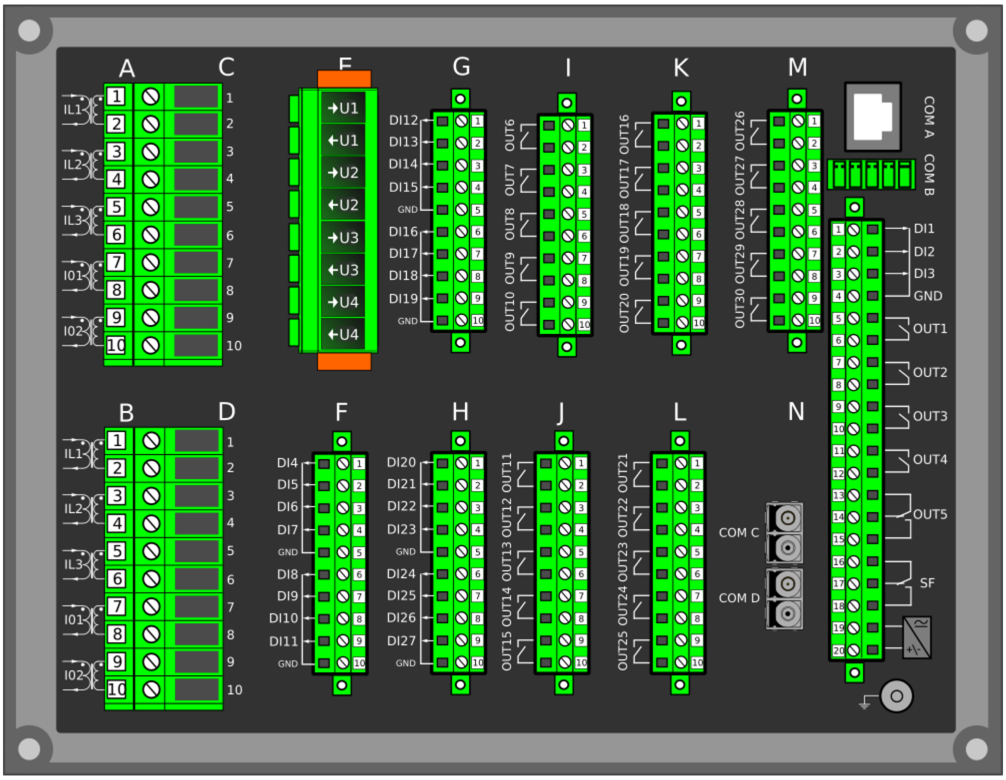


Figure. 7.1 - 215. Modular construction of AQ-X257-XXXXXXX-BBBCCCCCJ



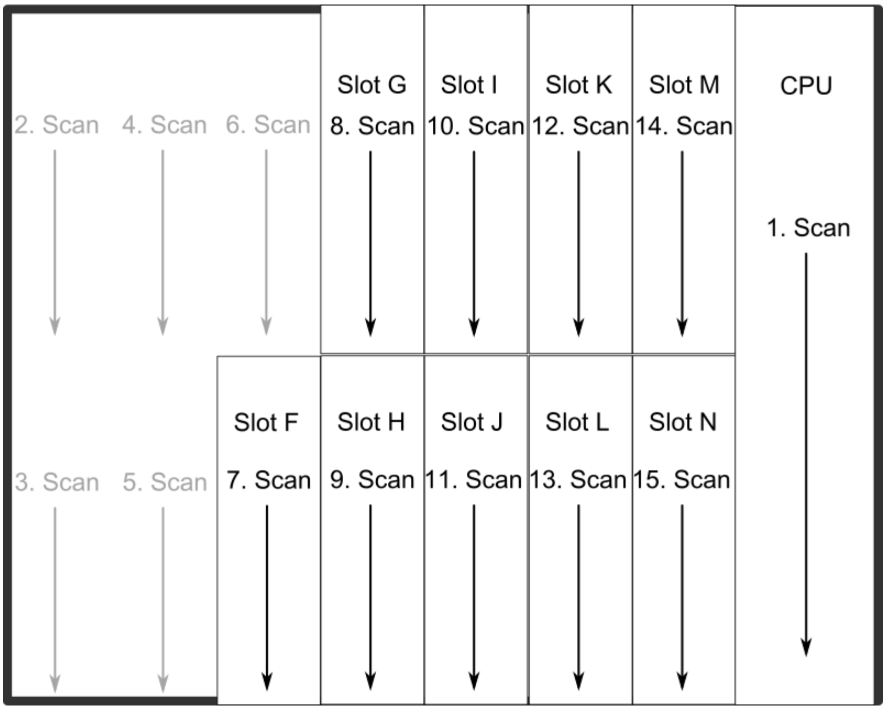
The modular structure of AQ-X257 allows for scalable solutions for different application requirements. In non-standard configurations Slots from F to N accept all available add-on modules, such as digital I/O modules, integrated arc protection and other special modules. The only difference between the slots affecting device scalability is that Slots M and N both also support communication options.

Start-up scan searches for modules according to their type designation code. If the module content is not what the device expects, the device issues a hardware configuration error message. In field upgrades, therefore, add-on modules 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.

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. 7.1 - 216. 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.

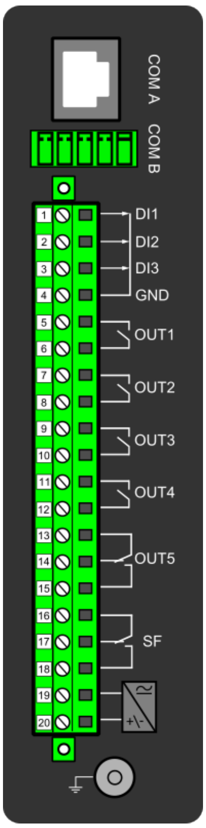
8. Scan
   Scans Slot G, and moves to the next slot if Slot G is empty. If the scan finds an 8DI module, it reserves the designations "DI4", "DI5", "DI6", "DI7", "DI8", "DI9", "DI10" and "DI11" to this slot. If Slot F also has an 8DI module (and therefore has already reserved these designations), the 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 chapter 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 devices.

7.2 CPU module

Figure. 7.2 - 217. CPU module.



Connector	Description
COM A	Communication port A, or the RJ-45 port. Used for the 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	Signaling relay 5, with a changeover contact. Not to be used in trip coil control.
X1-16:17:18	System fault's signaling 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 80…265 VAC/DC (model A; order code "H") or 18…75 DC (model B; order code "L"). Positive side (+) to Pin 20.
GND	The device'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 device's basic digital I/O.

The digital output controls are also set by the user with software. 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 (80…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 inputs

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 scannced in 5 ms program cycles. Their pick-up and release thresholds depend on the selection of the order code. Their delays and NO/NC selection, however, can be set with software.

The settings described in the table below can be found at *Control → Device I/O → Digital input settings* in the device settings.

Table. 7.2 - 381. Digital input settings.

Name	Range	Step	Default	Description
DIx Polarity	• NO (Normally open) • NC (Normally closed)	-	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 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	• Disabled • Enabled	-	Disabled	Selects whether or not a 30-ms deactivation delay is added to account for alternating current.

Digital input and output descriptions

CPU card digital inputs and outputs can be given a description. The user defined description are displayed in most of the menus:

- logic editor
- matrix
- block settings
- event history
- disturbance recordings
- etc.

Table. 7.2 - 382. Digital input and output user description.

Name	Range	Default	Description
User editable description DIx	1...31 characters	DIx	Description of the digital input. This description is used in several menu types for easier identification.
User editable description OUTx		OUTx	Description of the digital output. This description is used in several menu types for easier identification.

NOTICE!
After editing user descriptions the event history will start to use the new description only after resetting the HMI. HMI can be reset from *General → Device info → HMI restart*.

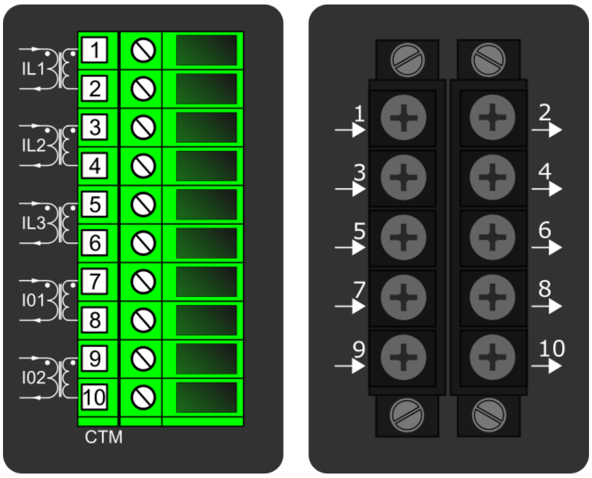
Scanning cycle

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.

NOTICE!
The mechanical delay of the relay is not included in these approximations!

7.3 Current measurement module

Figure. 7.3 - 218. Module connections with standard and ring lug terminals.



{{Default-Series}}. 7.3 - 1.

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 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:

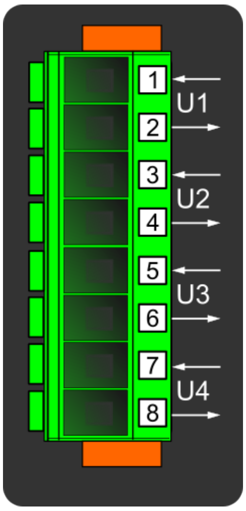
- The angle measurement inaccuracy is less than ± 0.2 degrees with nominal current.
- The frequency measurement range of the phase current inputs is 6…1800 Hz with standard hardware.

- 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.

7.4 Voltage measurement module

Figure. 7.4 - 219. 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 voltage can be set between 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:

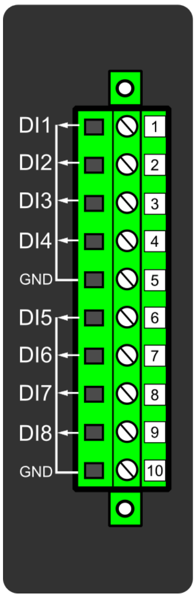
- The measurement range is 0.5…480.0 V per channel.
- The angle measurement inaccuracy is less than ± 0.5 degrees within the nominal range.
- The frequency measurement range of the voltage inputs is 6…1800 Hz with standard hardware.
- The quantization of the measurement signal is applied with 18-bit 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.

7.5 Option cards

7.5.1 Digital input module (optional)

Figure. 7.5.1 - 220. 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 device settings.

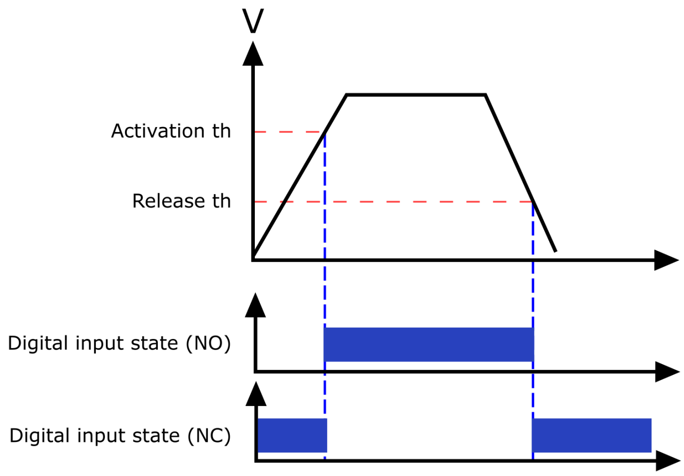
Table. 7.5.1 - 383. Digital input settings of DI8 module.

Name	Range	Step	Default	Description
DIx Polarity	• NO (Normally open) • NC (Normally closed)	-	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 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	• Disabled • Enabled	-	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	$0 \ldots 2^{32}-1$	1	0	Displays the number of times the digital input has changed its status from 0 to 1.
DIx Clear counter	• - • Clear	-	-	Resets the DIx counter value to zero.

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. 7.5.1 - 221. Digital input state when energizing and de-energizing the digital input channels.



Digital input descriptions

Option card inputs can be given a description. The user defined description are displayed in most of the menus:

- logic editor
- matrix
- block settings
- event history
- disturbance recordings
- etc.

Table. 7.5.1 - 384. Digital input user description.

Name	Range	Default	Description
User editable description DIx	1...31 characters	DIx	Description of the digital input. This description is used in several menu types for easier identification.

NOTICE!
After editing user descriptions the event history will start to use the new description only after resetting the HMI. HMI can be reset from *General → Device info → HMI restart*.

Digital input voltage measurements

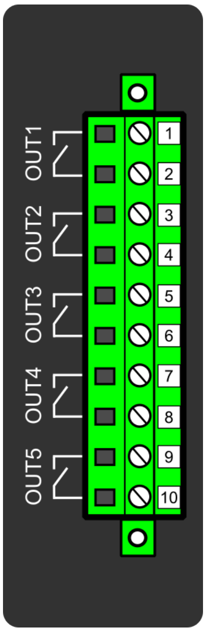
Digital input option card channels measure voltage on each channel. The measured voltage can be seen at *Control → Device IO → Digital inputs → Digital input voltages*.

Table. 7.5.1 - 385. Digital input channel voltage measurement.

Name	Range	Step	Description
DIx Voltage now	0.000...275.000 V	0.001 V	Voltage measurement of a digital input channel.

7.5.2 Digital output module (optional)

Figure. 7.5.2 - 222. 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.

Digital output descriptions

Option card outputs can be given a description. The user defined description are displayed in most of the menus:

- logic editor
- matrix

- block settings
- event history
- disturbance recordings
- etc.

Table. 7.5.2 - 386. Digital output user description.

Name	Range	Default	Description
User editable description OUTx	1...31 characters	OUTx	Description of the digital output. This description is used in several menu types for easier identification.

NOTICE!
After editing user descriptions the event history will start to use the new description only after resetting the HMI. HMI can be reset from *General → Device info → HMI restart*.

7.5.3 Point sensor arc protection module (optional)

Figure. 7.5.3 - 223. Arc protection module.

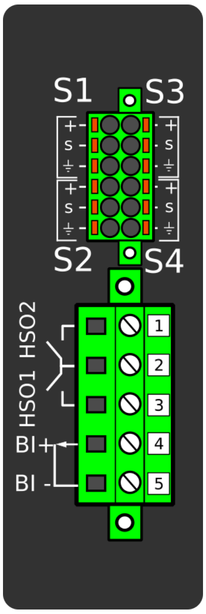


Table. 7.5.3 - 387. Module connections.

Connector	Description
S1	Light sensor channels 1…4 with positive ("+"), sensor ("S") and earth connectors.
S2	
S3	
S4	
X 1	HSO2 (+, NO)
X 2	Common battery positive terminal (+) for the HSOs.

Connector	Description
X 3	HSO1 (+, 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.

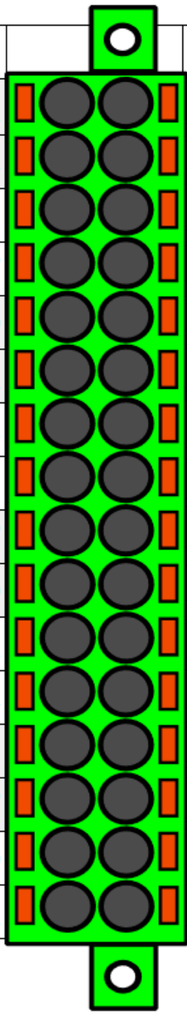
The rated voltage of the binary input is 24 VDC. The threshold picks up at ≥16 VDC. The binary input can be used for external light information or for similar applications. It can also be used as a part of various ARC schemes. Please note that the binary input's delay is 5…10ms.

NOTICE!
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*).

7.5.4 RTD input module (optional)

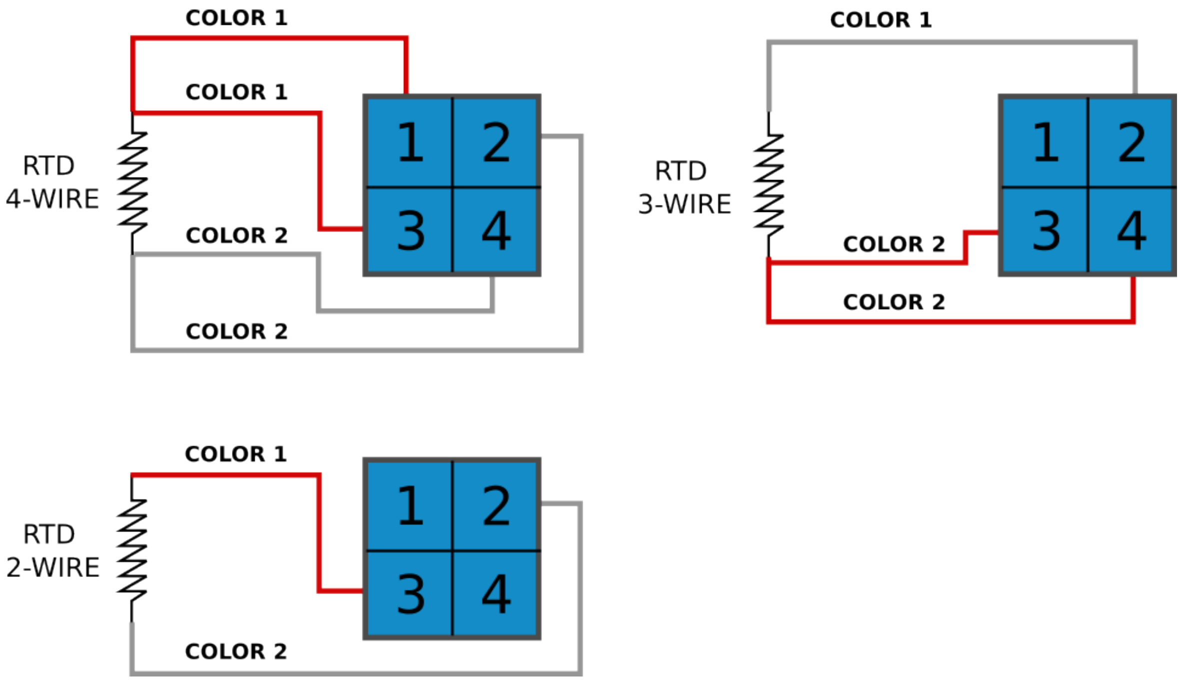
Figure. 7.5.4 - 224. RTD input module connectors.

Channel	Connector		Connector	
1	RTD1-1	1	2	RTD1-2
	RTD1-3	3	4	RTD1-4
2	RTD2-1	5	6	RTD2-2
	RTD2-3	7	8	RTD2-4
3	RTD3-1	9	10	RTD3-2
	RTD3-3	11	12	RTD3-4
4	RTD4-1	13	14	RTD4-2
	RTD4-3	15	16	RTD4-4
5	RTD5-1	17	18	RTD5-2
	RTD5-3	19	20	RTD5-4
6	RTD6-1	21	22	RTD6-2
	RTD6-3	23	24	RTD6-4
7	RTD7-1	25	26	RTD7-2
	RTD7-3	27	28	RTD7-4
8	RTD8-1	29	30	RTD8-2
	RTD8-3	31	32	RTD8-4



The RTD input module is an add-on module with eight (8) RTD input channels. Each input supports 2-wire, 3-wire and 4-wire RTD sensors. The sensor type can be selected with software for two groups, four channels each. The card supports Pt100 and Pt1000 sensors

Figure. 7.5.4 - 225. RTD sensor connection types.



7.5.5 Serial RS-232 communication module (optional)

Figure. 7.5.5 - 226. Serial RS-232 module connectors.

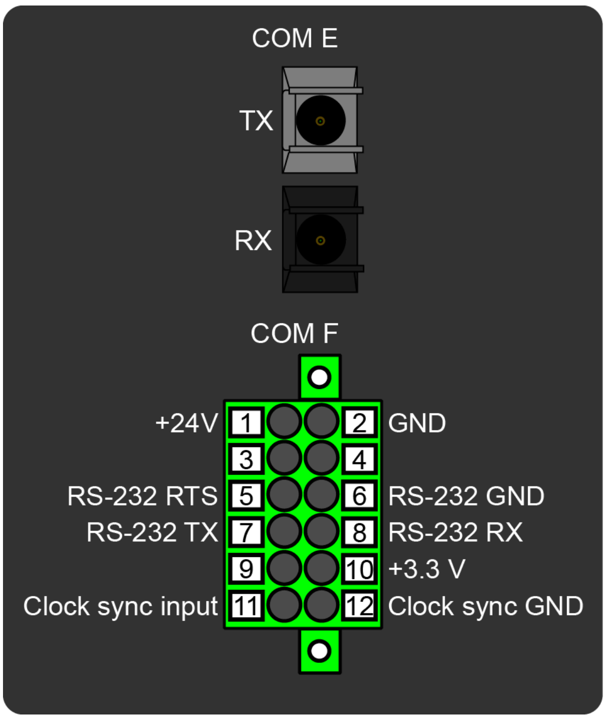


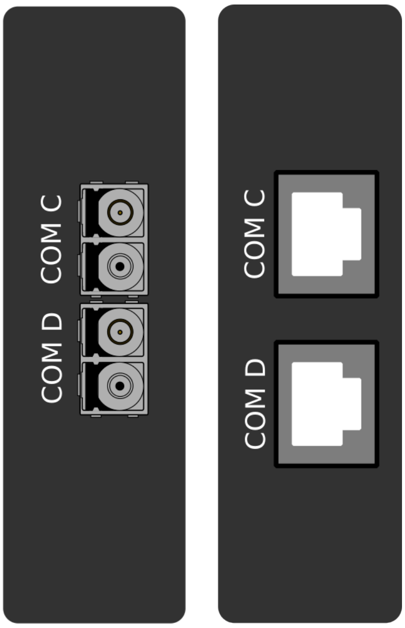
Table. 7.5.5 - 388. Module connections.

Connector	Pin	Name	Description
COM E	-	Serial fiber	• Serial-based communications • Port options: ◦ Glass/glass ◦ Plastic/plastic ◦ Glass/plastic ◦ Plastic/glass • 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	1	+24 V input	Optional external auxiliary voltage for serial fiber.
	2	GND	
	3	-	Not in use.
	4		
	5	RS-232 RTS	Serial based communications.
	6	RS-232 GND	
	7	RS-232 TX	
	8	RS-232 RX	
	9	-	Not in use.
	10	+3.3 V output (spare)	Spare power source for external equipment (45 mA).
	11	Clock sync input	Clock synchronization input (supports IRIG-B).
	12	Clock sync GND	

The option card includes two serial communication interfaces: COM E is a serial fiber interface with glass/glass, plastic/plastic, glass/plastic and plastic/glass options, COM F is an RS-232 interface.

7.5.6 LC or RJ45 100 Mbps Ethernet communication module (optional)

Figure. 7.5.6 - 227. LC and RJ45 100 Mbps Ethernet module connectors.

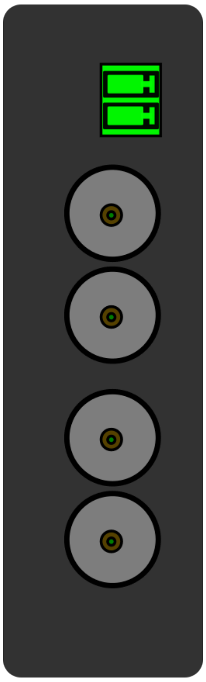


Connector	Description (LC ports)	Description (RJ45)
COM C:	• Communication port C, 100 MbpsLC fiber connector. • 62.5/125 µm or 50/125 µm multimode (glass). • Wavelength 1300 nm.	• RJ-45 connectors • 10BASE-T and 100BASE-TX
COM D:	• Communication port D, 100 Mbps LC fiber connector. • 62.5/125 µm or 50/125 µm multimode (glass). • Wavelength 1300 nm.	• RJ-45 connectors • 10BASE-T and 100BASE-TX

Both cards support both HSR and PRP protocols.

7.5.7 Double ST 100 Mbps Ethernet communication module (optional)

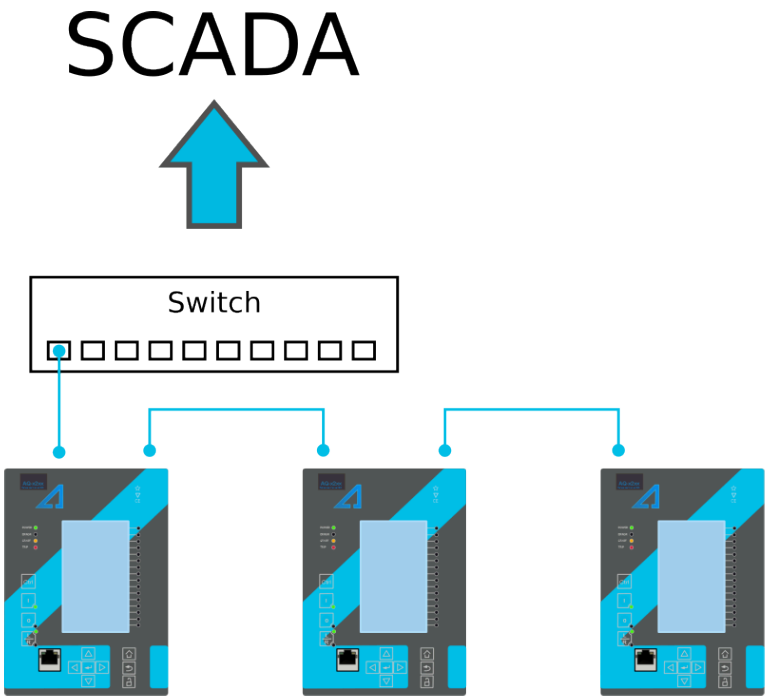
Figure. 7.5.7 - 228. Double ST 100 Mbps Ethernet communication module connectors.



Connector	Description
Two-pin connector	• IRIG-B input
ST connectors	• Duplex ST connectors • 62.5/125 µm or 50/125 µm multimode fiber • Transmitter wavelength: 1260…1360 nm (nominal: 1310 nm) • Receiver wavelength: 1100…1600 nm • 100BASE-FX • Up to 2 km

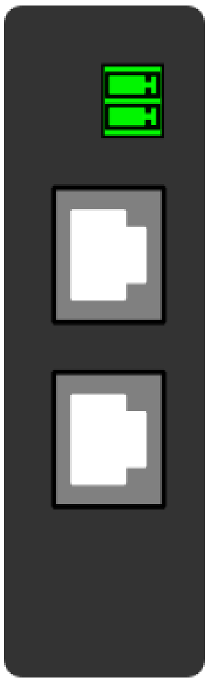
This option cards supports redundant ring configuration and multidrop configurations. Please note that each ring can only contain AQ-200 series devices, and any third party devices must be connected to a separate ring.

Figure. 7.5.7 - 229. Example of a multidrop configuration.



7.5.8 Double RJ45 10/100 Mbps Ethernet communication module (optional)

Figure. 7.5.8 - 230. Double RJ-45 10/100 Mbps Ethernet communication module.

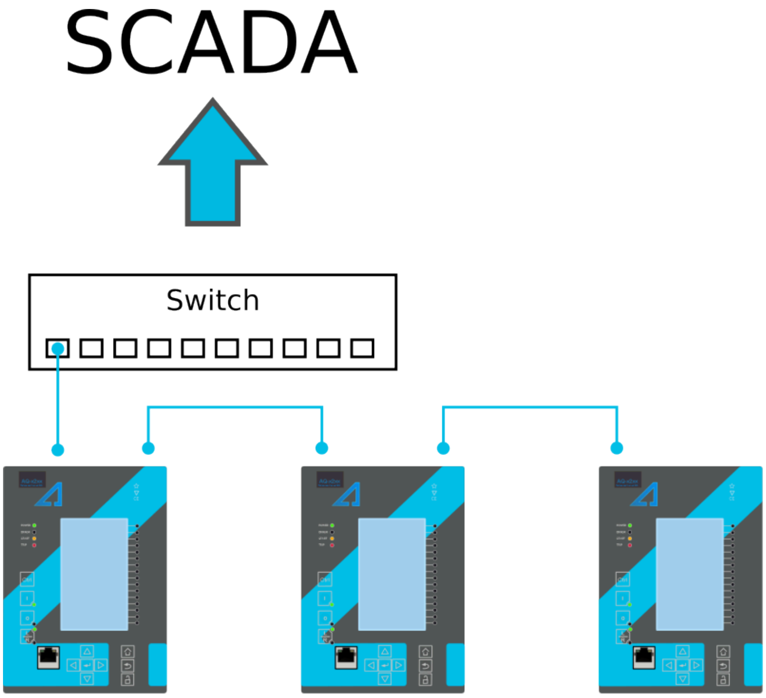


Connector	Description
Two-pin connector	• IRIG-B input

Connector	Description
RJ-45 connectors	• Two Ethernet ports • RJ-45 connectors • 10BASE-T and 100BASE-TX

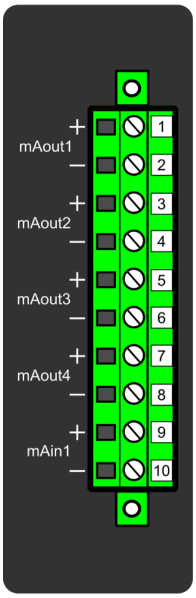
This option card supports multidrop configurations.

Figure. 7.5.8 - 231. Example of a multidrop configuration.



7.5.9 Milliampere output (mA) I/O module (optional)

Figure. 7.5.9 - 232. Milliampere output (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 device configuration settings.

7.6 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. 7.6 - 233. Device dimensions.

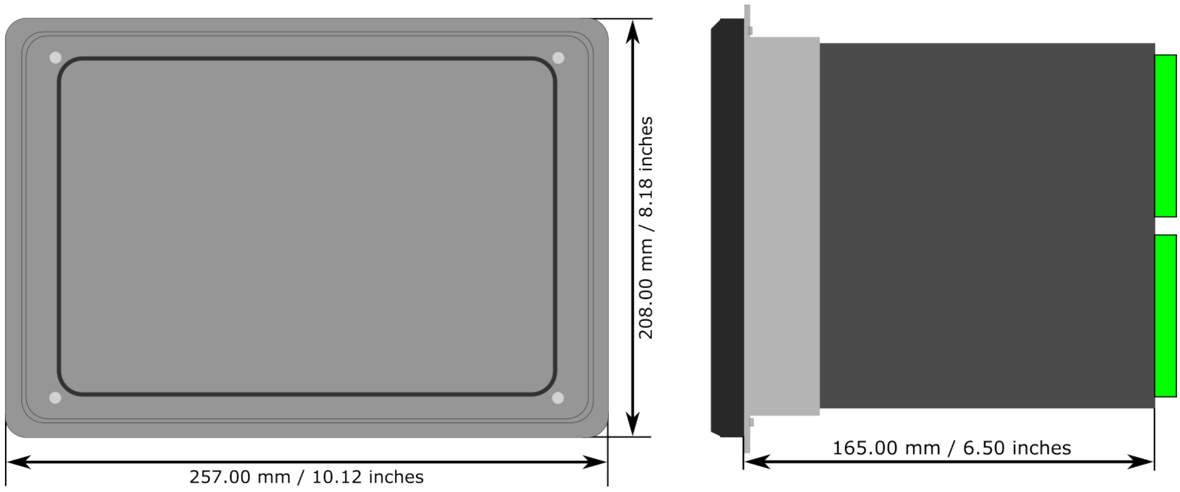


Figure. 7.6 - 234. Device installation.

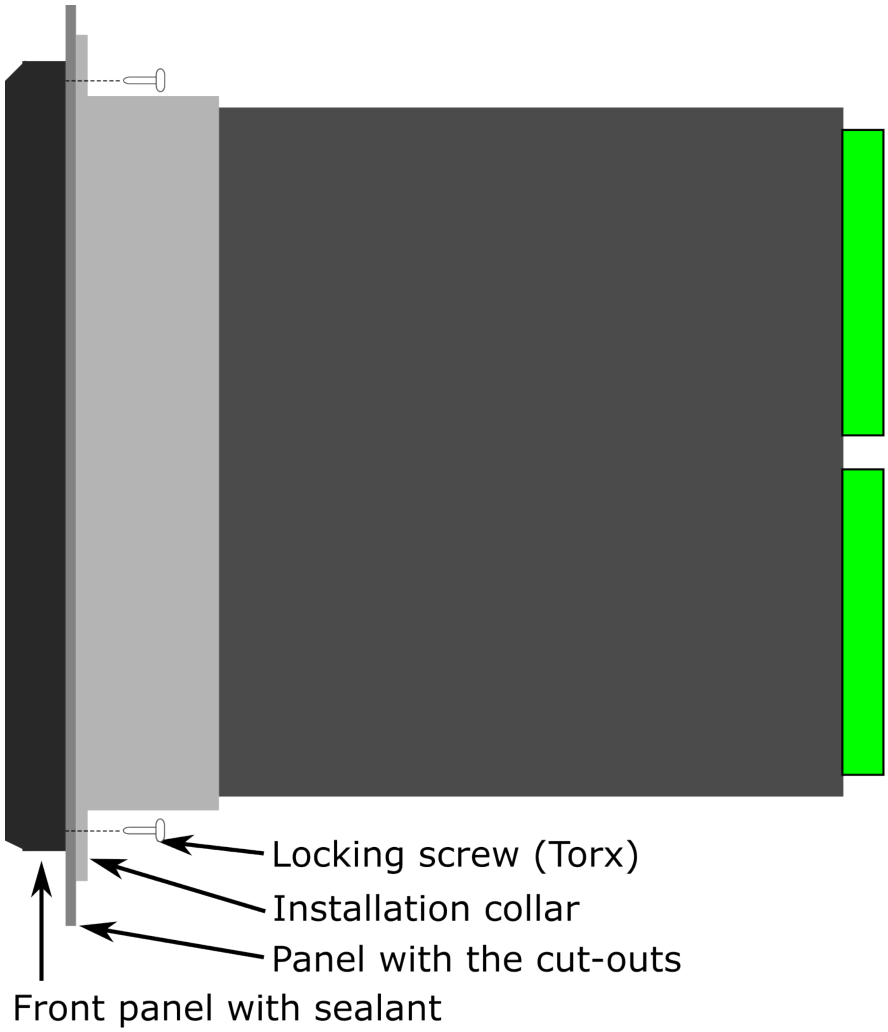
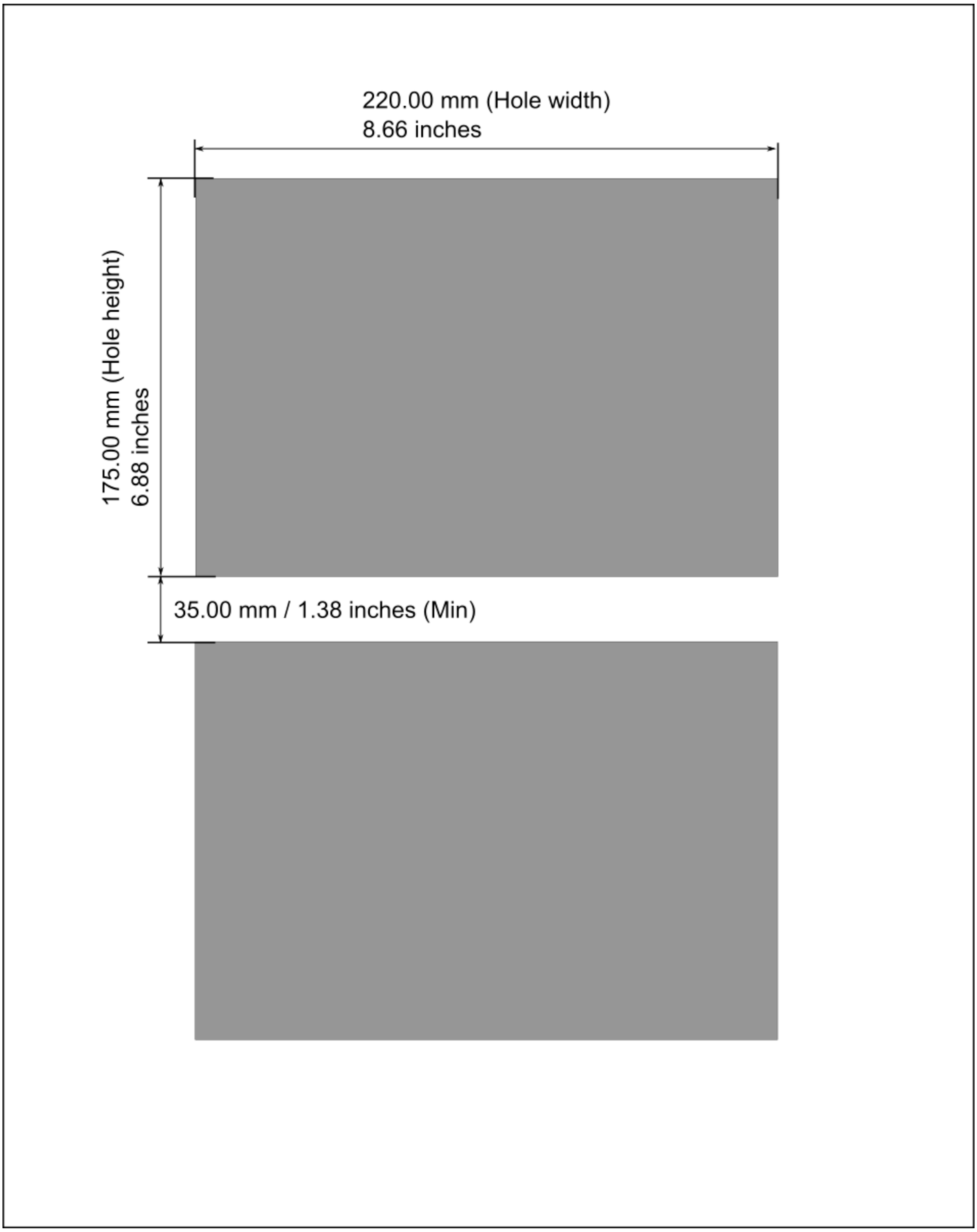


Figure. 7.6 - 235. Panel cut-out and spacing of the devices.



8 Technical data

8.1 Hardware

8.1.1 Measurements

8.1.1.1 Current measurement

Table. 8.1.1.1 - 389. Technical data for the current measurement module.

General information	
Spare part code	#SP-2XX-CM
Compatibility	AQ-210 and AQ-250 series models
Connections	
Measurement channels/CT inputs	Three phase current inputs: IL1 (A), IL2 (B), IL3 (C) Two residual current inputs: Coarse residual current input I01, Fine residual current input I02
Phase current inputs (A, B, C)	
Sample rate	64 samples per cycle in frequency range 6...75Hz
Rated current I_N	5 A (configurable 0.2…10 A)
Thermal withstand	20 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 31st 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 0.1…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 0.001…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	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 %
Screw connection terminal block (standard)	
Terminal block	Phoenix Contact FRONT 4-H-6,35
Solid or stranded wire Nominal cross section	4 mm^2
Ring lug terminal block connection (option)	
Ring terminal dimensions	Max 8mm diameter, with minimum 3,5mm screw hole

NOTICE!
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.

8.1.1.2 Voltage measurement

Table. 8.1.1.2 - 390. Technical data for the voltage measurement module.

General information	
Spare part code	#SP-2XX-VT
Compatibility	AQ 200 series and AQ 250 series models
Connection	
Measurement channels/VT inputs	4 independent VT inputs (U1, U2, U3 and U4)
Measurement	
Sample rate	64 samples per cycle in frequency range 6...75Hz
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 31^{st} harmonic voltage
Terminal block connection	
Screw connection terminal block (standard)	Phoenix Contact PC 5/ 8-STCL1-7,62
Spring cage terminal block (optional)	Phoenix Contact SPC 5/ 8-STCL-7,82
Solid or stranded wire Nominal cross section	6 mm^2
Input impedance	~24.5 MΩ
Burden (50/60 Hz)	<0.02 VA
Thermal withstand	630 V_{RMS} (continuous)

NOTICE!
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.

8.1.1.3 Voltage memory

Table. 8.1.1.3 - 391. Technical data for the voltage memory function.

Measurement inputs

Voltage inputs	U_{L1}, U_{L2}, U_{L3} U_{L12}, U_{L23}, U_{L31} + U_0
Current inputs (back-up frequency)	Phase current inputs: I_{L1} (A), I_{L2} (B), I_{L3} (C)
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

NOTICE!
Voltage memory is activated only when all line voltages fall below set pick-up value.

NOTICE!
Voltage memory activation captures healthy situation voltage angles, one cycle before actual activation (50Hz/20ms before "bolted" fault)

8.1.1.4 Power and energy measurement

Table. 8.1.1.4 - 392. 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	0.5% down to 1A RMS (50/60Hz) as standard 0.2% down to 1A RMS (50/60Hz) option available (see the order code for details)

8.1.1.5 Frequency measurement

Table. 8.1.1.5 - 393. 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

8.1.2 CPU & Power supply

Table. 8.1.2 - 394. General information for the CPU module.

General information	
Spare part code	#SP-250-CPU
Compatibility	AQ-250 series models
Terminal block connection	
Screw connection terminal block (standard)	Phoenix Contact MSTB 2,5/5-ST-5,08
Spring cage terminal block (option)	Phoenix Contact FKC 2,5/20-STF-5,08
Solid or stranded wire Nominal cross section	2.5 mm^2
RS-485 serial terminal block connection	
Screw connection terminal block (standard)	Phoenix Contact MC 1,5/ 5-ST-3,81
Spring cage terminal block (option)	Phoenix Contact FK-MCP 1,5/ 5-ST-3,81
Solid or stranded wire Nominal cross section	1.5 mm^2

8.1.2.1 Auxiliary voltage

Table. 8.1.2.1 - 395. Power supply model A

Rated values	
Rated auxiliary voltage	80…265 V (AC/DC)
Power consumption	< 20 W (no option cards) < 40 W (maximum number of option cards)
Maximum permitted interrupt time	< 40 ms with 110 VDC
DC ripple	< 15 %
Other	
Minimum recommended fuse rating	MCB C2

Table. 8.1.2.1 - 396. Power supply model B

Rated values	
Rated auxiliary voltage	18…72 VDC
Power consumption	< 20 W (no option cards) < 40 W (maximum number of option cards)
Maximum permitted interrupt time	< 40 ms with 24 VDC
DC ripple	< 15 %
Other	
Minimum recommended fuse rating	MCB C2

8.1.2.2 CPU communication ports

Table. 8.1.2.2 - 397. 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/s
System integration	Cannot be used for system protocols, only for local programming

Table. 8.1.2.2 - 398. 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/s
System integration	Can be used for system protocols and for local programming

Table. 8.1.2.2 - 399. 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

8.1.2.3 CPU digital inputs

Table. 8.1.2.3 - 400. CPU model-isolated digital inputs, with thresholds defined by order code.

Rated values	
Rated auxiliary voltage	265 V (AC/DC)
Nominal voltage	Order code defined: 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

8.1.2.4 CPU digital outputs

Table. 8.1.2.4 - 401. Digital outputs (Normally 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 Open / Normally Closed

Table. 8.1.2.4 - 402. Digital outputs (Change-Over)

Rated values	
Rated auxiliary voltage	265 V (AC/DC)
Continuous carry	2.5 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 0.3 A 0.15 A
Control rate	5 ms
Settings	
Polarity	Software settable: Normally Open / Normally Closed

CAUTION!
Please note, that signaling relay 5 and system fault's signaling relay are designed only for signaling purposes, and are not to be used in trip coil control.

8.1.3 Option cards

8.1.3.1 Digital input module

Table. 8.1.3.1 - 403. Technical data for the digital input module.

General information	
Spare part code	#SP-250-DI8
Compatibility	AQ-250 series models
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	
Screw connection terminal block (standard)	Phoenix Contact MSTB 2,5/10-ST-5,08
Spring cage terminals block (option)	Phoenix Contact FKC 2,5/10-STF-5,08
Solid or stranded wire Nominal cross section	2.5 mm^2

8.1.3.2 Digital output module

Table. 8.1.3.2 - 404. Technical data for the digital output module.

General information	
Spare part code	#SP-250-DO5
Compatibility	AQ-250 series models
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	
Screw connection terminal block (standard)	Phoenix Contact MSTB 2,5/10-ST-5,08
Spring cage terminals block (option)	Phoenix Contact FKC 2,5/10-STF-5,08

Solid or stranded wire Nominal cross section	2.5 mm^2

8.1.3.3 Point sensor arc protection module

Table. 8.1.3.3 - 405. Technical data for the point sensor arc protection module.

General information	
Spare part code	#SP-2XX-ARC
Compatibility	AQ-200 series & AQ-250 series models
Connections	
Input arc point sensor channels	S1, S2, S3, S4 (pressure and light, or light only)
Sensors per channel	3
Maximum cable length	200 m
Performance	
Pick-up light intensity	8, 25 or 50 kLx (the sensor is selectable in the order code)
Point sensor detection radius	180 degrees
Start and instant operating time (light only)	Typically <5 ms with dedicated semiconductor outputs (HSO) Typically <10 ms regular output relays

Table. 8.1.3.3 - 406. 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

Table. 8.1.3.3 - 407. Binary input channel

Rated values	
Voltage withstand	265 VDC

Nominal voltage Pick-up threshold Release threshold	24 VDC ≥16 VDC ≤15 VDC
Scanning rate	5 ms
Polarity	Normally Off
Current drain	3 mA

Table. 8.1.3.3 - 408. Terminal block connections

Arc point sensor terminal block connections	
Spring cage terminal block	Phoenix Contact DFMC 1,5/ 6-STF-3,5
Solid or stranded wire Nominal cross section	1.5 mm^2
Binary input and HSO terminal block connections	
Screw connection terminal block (standard)	Phoenix Contact MSTB 2,5/5-ST-5,08
Spring cage terminals block (option)	Phoenix Contact FKC 2,5/10-STF-5,08
Solid or stranded wire Nominal cross section	2.5 mm^2

NOTICE!
The polarity must be correct!

8.1.3.4 Milliampere output module (mA out & mA in)

Table. 8.1.3.4 - 409. Technical data for the milliampere output module.

General information	
Spare part code	#SP-2XX-MA
Compatibility	AQ-200 series & AQ-250 series models
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
Terminal block connection	
Screw connection terminal block (standard)	Phoenix Contact MSTB 2,5/10-ST-5,08
Spring cage terminals block (option)	Phoenix Contact FKC 2,5/10-STF-5,08
Solid or stranded wire Nominal cross section	2.5 mm^2

8.1.3.5 RTD input module

Table. 8.1.3.5 - 410. Technical data for the RTD input module.

General information	
Spare part code	#SP-2xx-RTD
Compatibility	AQ-200 series & AQ-250 series models
Channels 1-8	
2/3/4-wire RTD	
Pt100 or Pt1000	
Terminal block connection	
Spring cage terminals block	Phoenix Contact DFMC 1,5/ 16-STF-3,5
Solid or stranded wire Nominal cross section	1.5 mm^2

8.1.3.6 RS-232 & serial fiber communication module

Table. 8.1.3.6 - 411. Technical data for the RS-232 & serial fiber communication module.

General information	
PP Spare part code	#SP-2XX-232PP
PG Spare part code	#SP-2XX-232PG
GP Spare part code	#SP-2XX-232GP
GG Spare part code	#SP-2XX-232GG

Compatibility	AQ-200 series & AQ-250 series models
Ports	
RS-232	
Serial fiber (GG/PP/GP/PG)	
Serial port wavelength	
660 nm	
Cable type	
1 mm plastic fiber	
Terminal block connections	
Spring cage terminals block	Phoenix Contact DFMC 1,5/ 6-STF-3,5
Solid or stranded wire Nominal cross section	1.5 mm^2

8.1.3.7 Double LC 100 Mbps Ethernet communication module

Table. 8.1.3.7 - 412. Technical data for the double LC 100 Mbps Ethernet communication module.

General information	
Spare part code	#SP-2XX-2XLC
Compatibility	AQ-200 series & AQ-250 series models
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)

8.1.3.8 Double ST 100 Mbps Ethernet communication module

Table. 8.1.3.8 - 413. Technical data for the double ST 100 Mbps Ethernet communication module.

General information	
Spare part code	#SP-2XX-2XST
Compatibility	AQ-200 series & AQ-250 series models
Dimensions	74 mm X 179 mm

Ports	ST connectors (2) and IRIG-B connector (1)
Protocols	
Protocols	IEC61850, DNP/TCP, Modbus/TCP, IEC104 & FTP
ST connectors	
Connector type	Duplex ST connectors 62.5/125 µm or 50/125 µm multimode fiber 100BASE-FX
Transmitter wavelength	1260…1360 nm (nominal: 1310 nm)
Receiver wavelength	1100…1600 nm
Maximum distance	2 km
IRIG-B Connector	
Screw connection terminal block	Phoenix Contact MC 1,5/ 2-ST-3,5 BD:1-2
Solid or stranded wire Nominal cross section	1.5 mm^2

8.1.4 Display

Table. 8.1.4 - 414. Technical data for the HMI TFT display.

General information	
Spare part code	#SP-200-DISP
Compatibility	AQ-250 series models
Dimensions and resolution	
Number of dots/resolution	800 x 480
Size	154.08 × 85.92 mm (6.06 × 3.38 in)
Display	
Type of display	TFT
Color	RGB color

8.2 Functions

8.2.1 Protection functions

8.2.1.1 Non-directional overcurrent protection (I>; 50/51)

Table. 8.2.1.1 - 415. Technical data for the non-directional overcurrent function.

Measurement inputs	
Current inputs	Phase current inputs: I_{L1} (A), I_{L2} (B), I_{L3} (C)
Current input magnitudes	RMS phase currents TRMS phase currents Peak-to-peak phase currents
Pick-up	
Pick-up current setting	0.10…50.00 × I_n, setting step 0.01 × I_n
Inrush 2nd harmonic blocking	0.10…50.00 %I_{fund}, setting step 0.01 %I_{fund}
Inaccuracy: - Current - 2nd harmonic blocking	 ±0.5 %I_{set} or ±15 mA (0.10…4.0 × I_{set}) ±1.0 %-unit of the 2nd 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 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)	<30 ms
Instant operation time	
Start time and instant operation time (trip): - I_m/I_{set} ratio = 2 - I_m/I_{set} ratio = 5 - I_m/I_{set} ratio = 10	 Typically 25 ms Typically 16 ms Typically 12 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

NOTICE!
The release delay does not apply to phase-specific tripping!

8.2.1.2 Non-directional earth fault protection (I0>; 50N/51N)

Table. 8.2.1.2 - 416. Technical data for the non-directional earth fault function.

Measurement inputs	
Current input (selectable)	Residual current channel I_{01} (Coarse) Residual current channel I_{02} (Fine) Calculated residual current: I_{L1} (A), I_{L2} (B), I_{L3} (C)
Current input magnitudes	RMS residual current (I_{01}, I_{02} or calculated I_0) TRMS residual current (I_{01} or I_{02}) Peak-to-peak residual current (I_{01} or I_{02})
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 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)	<30 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 (typically 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

NOTICE!
The operation and reset time accuracy does not apply when the measured secondary current in I02 is 1…20 mA. The pick-up is tuned to be more sensitive and the operation times vary because of this.

8.2.1.3 Directional overcurrent protection (Idir>; 67)

Table. 8.2.1.3 - 417. Technical data for the directional overcurrent function.

Input signals	
Current inputs	Phase current inputs: I_{L1} (A), I_{L2} (B), I_{L3} (C)
Current input magnitudes	RMS phase currents TRMS phase currents Peak-to-peak phase currents
Current input calculations	Positive sequence current angle
Voltage inputs	U_{L1}, U_{L2}, U_{L3} U_{L12}, U_{L23}, U_{L31} + U0
Voltage input calculations	Positive sequence voltage angle
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 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 (typically 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

NOTICE!
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.

8.2.1.4 Directional earth fault protection (I0dir>; 67N/32N)

Table. 8.2.1.4 - 418. Technical data for the directional earth fault function.

Measurement inputs	
Current input (selectable)	Residual current channel I_{01} (Coarse) Residual current channel I_{02} (Fine) Calculated residual current: I_{L1} (A), I_{L2} (B), I_{L3} (C)
Current input magnitudes	RMS residual current (I_{01}, I_{02} or calculated I_0) TRMS residual current (I_{01} or I_{02}) Peak-to-peak residual current (I_{01} or I_{02})
Voltage input (selectable)	Residual voltage from U3 or U4 voltage channel Residual voltage calculated from U_{L1}, U_{L2}, U_{L3}
Voltage input magnitudes	RMS residual voltage U_0 Calculated RMS residual voltage U_0
Pick-up	
Characteristic direction	Unearthed (Varmetric 90°) Petersen coil GND (Wattmetric 180°) *Earthed* (Adjustable sector)

When the *earthed* mode is active: - Tripping area center - Tripping 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…75.00 %$U0_n$, 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}) ±1.0 %$U0_{set}$ or ±30 mV ±0.2° (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 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 ±25 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	<55 ms (typically 45 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

8.2.1.5 Negative sequence overcurrent/ phase current reversal/ current unbalance protection (I2>; 46/46R/46L)

Table. 8.2.1.5 - 419. Technical data for the current unbalance function.

Measurement inputs	
Current inputs	Phase current inputs: I_{L1} (A), I_{L2} (B), I_{L3} (C)
Current input calculations	Positive sequence current (I1) Negative sequence current (I2)

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 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	 ±2.0 % or ±30 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

8.2.1.6 Harmonic overcurrent protection (Ih>; 50H/51H/68H)

Table. 8.2.1.6 - 420. Technical data for the harmonic overcurrent function.

Measurement inputs	
Current inputs	Phase current inputs: I_{L1} (A), I_{L2} (B), I_{L3} (C) Residual current channel I_{01} (Coarse) Residual current channel I_{02} (Fine)
Pick-up	
Harmonic selection	2^{nd}, 3^{rd}, 4^{th}, 5^{th}, 6^{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 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

NOTICE!
Harmonics generally: The amplitude of the harmonic content must 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.

8.2.1.7 Circuit breaker failure protection (CBFP; 50BF/52BF)

Table. 8.2.1.7 - 421. Technical data for the circuit breaker failure protection function.

Measurement inputs	
Current inputs	Phase current inputs: I_{L1} (A), I_{L2} (B), I_{L3} (C) Residual current channel I_{01} (Coarse) Residual current channel I_{02} (Fine)
Current input magnitudes	RMS phase currents RMS residual current (I_{01}, I_{02} or calculated I_0)
Pick-up	
Monitored signals	Digital input status, digital output status, logical signals
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

8.2.1.8 Overvoltage protection (U>; 59)

Table. 8.2.1.8 - 422. Technical data for the overvoltage function.

Measurement inputs	
Voltage inputs	U_{L1}, U_{L2}, U_{L3} U_{L12}, U_{L23}, U_{L31} (+ U_0)
Voltage input magnitudes	RMS line-to-line or line-to-neutral voltages
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 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

8.2.1.9 Undervoltage protection (U<; 27)

Table. 8.2.1.9 - 423. Technical data for the undervoltage function.

Measurement inputs	
Voltage inputs	U_{L1}, U_{L2}, U_{L3} U_{L12}, U_{L23}, U_{L31} (+ U_0)
Voltage input magnitudes	RMS line-to-line or line-to-neutral voltages
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 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

NOTICE!
The low-voltage block is not in use when its pick-up setting is set to 0 %. The undervoltage function trip signal is active when the LV block is disabled and the device has no voltage injection.

NOTICE!
After the low voltage blocking condition, the undervoltage stage does not trip unless the voltage exceeds the pick-up setting first.

8.2.1.10 Neutral overvoltage protection (U0>; 59N)

Table. 8.2.1.10 - 424. Technical data for the neutral overvoltage function.

Measurement inputs	
Voltage input (selectable)	Residual voltage from U3 or U4 voltage channel Residual voltage calculated from U_{L1}, U_{L2}, U_{L3}

Voltage input magnitudes	RMS residual voltage U_0 Calculated RMS residual voltage U_0
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 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

8.2.1.11 Sequence voltage protection (U1/U2>/<; 47/27P/59NP)

Table. 8.2.1.11 - 425. Technical data for the sequence voltage function.

Measurement inputs	
Voltage inputs	U_{L1}, U_{L2}, U_{L3} U_{L12}, U_{L23}, U_{L31} (+ U_0)
Voltage input calculations	Positive sequence voltage (I1) Negative sequence voltage (I2)
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 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

8.2.1.12 Overfrequency and underfrequency protection (f>/<; 81O/81U)

Table. 8.2.1.12 - 426. 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	±20 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)

NOTICE!
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.

NOTICE!
The frequency is measured two seconds after a signal is received.

8.2.1.13 Rate-of-change of frequency protection (df/dt>/<; 81R)

Table. 8.2.1.13 - 427. 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	0.15…1.00 Hz/s, setting step 0.01 Hz
f> limit	10.00…70.00 Hz, setting step 0.01 Hz
f< limit	7.00…65.00 Hz, setting step 0.01 Hz
Pick-up inaccuracy	
- df/dt	±5.0 %I_{SET} or ±20 mHz/s
- frequency	±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)
Start time and instant operation time (trip):	
- f_M/f_{SET} ratio +/- 20 mHz (overreach)	<200 ms
- f_M/f_{SET} ratio +/- 200 mHz (overreach)	<90 ms
Reset	
f< and f> frequency limit	±0.020 Hz
df/dt	±10.0 % of pick-up or 50 mHz/s
Instant reset time and start-up reset: - f_M/f_{SET} ratio +/- 50 mHz	<325 ms (max. step size: 100 mHz)

NOTICE!
Frequency is measured two seconds after a signal is received.

8.2.1.14 Transformer thermal overload protection (TT>; 49T)

Table. 8.2.1.14 - 428. Technical data for the transformer thermal overload protection function.

Measurement inputs	
Current inputs	Phase current inputs: I_{L1} (A), I_{L2} (B), I_{L3} (C)
Current input magnitudes	TRMS phase currents (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

8.2.1.15 Power protection (P, Q, S>/<; 32)

Table. 8.2.1.15 - 429. Technical data for the power protection function.

Measurement inputs	
Current inputs	Phase current inputs: I_{L1} (A), I_{L2} (B), I_{L3} (C)
Voltage inputs	U_{L1}, U_{L2}, U_{L3} U_{L12}, U_{L23}, U_{L31} (+ U_0)
Calculated measurements	Three-phase active, reactive or apparent power (P, Q or S) value based on the chosen or set nominal amplitude.
Pick-up	
Comparator selection	> or <
> 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

8.2.1.16 Underimpedance protection (Z<; 21U)

Table. 8.2.1.16 - 430. Technical data for the underimpedance function.

Measurement inputs	
Current inputs	Phase current inputs: I_{L1} (A), I_{L2} (B), I_{L3} (C)
Voltage inputs	U_{L1}, U_{L2}, U_{L3} U_{L12}, U_{L23}, U_{L31} + U_0

Calculated impedances	Phase-to-phase impedances Phase-to-ground impedances Positive sequence impedance
Pick-up	
Pick-up setting	0.1…150.0 Ω, setting step 0.1 Ω
Inaccuracy: - Impedance calculation	Typically <1.0 %Z_{SET}
Operation time	
Definite time function operating time setting	0.00…1800.00 s, setting step 0.005 s
Inaccuracy: - Definite time (Z_M/Z_{SET} ratio <0.95)	±1.0 % or ±25 ms
Instant operation time	
Start time and instant operation time (trip): - Z_M/Z_{SET} ratio <0.95	<45 ms
Reset	
Reset ratio	103 %Z_{SET}
Reset time setting Inaccuracy: Reset time	0.010…150.000 s, step 0.005 s ±1.0 % or ±25 ms
Instant reset time and start-up reset	<45 ms

8.2.1.17 Volts-per-hertz overexcitation protection (V/Hz>; 24)

Table. 8.2.1.17 - 431. Technical data for the volts-per-hertz overexcitation protection function.

Measurement inputs	
Voltage input	U_{L1}, U_{L2}, U_{L3} U_{L12}, U_{L23}, U_{L31}
Voltage input magnitude	Maximum line-to-line voltage
Frequency reference 1 Frequency reference 2 Frequency reference 3	CT1IL1, CT2IL1, VT1U1, VT2U1 CT1IL2, CT2IL2, VT1U2, VT2U2 CT1IL3, CT2IL3, VT1U3, VT2U3
Pick-up	
Pick-up setting	0.01…75.00 %, setting step 0.01 %
Inaccuracy: - V/Hz	±1.0 %
Operation time	
Definite time function operating time setting	0.00…1800.00 s, setting step 0.005 s
Inaccuracy: - Definite time (VHZ_M/VHZ_{SET} ratio 1.05)	±1.0 % or ±25 ms

Instant operation time	
Start time and instant operation time (trip): - VHZ_M/VHZ_{SET} ratio 1.05)	<40 ms
Reset	
Reset ratio	97 % of the pick-up setting
Reset time setting Inaccuracy: Reset time	0.000…150.000 s, step 0.005 s ±1.0 % or ±25 ms
Instant reset time and start-up reset	<40 ms

8.2.1.18 Transformer status monitoring

Table. 8.2.1.18 - 432. 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

8.2.1.19 Resistance temperature detectors (RTD)

Table. 8.2.1.19 - 433. Technical data of the resistance temperature detectors.

Inputs

Resistance input magnitudes	Measured temperatures measured by RTD sensors
RTD channels	12 individual RTD channels
Settable alarms	24 alarms available (two per each RTD 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

8.2.1.20 Generator/transformer differential protection (Idb>/Idi>/I0dHV>/I0dLV>; 87T/87N/87G)

Table. 8.2.1.20 - 434. Technical data for the transformer differential protection function.

Measurement inputs	
Current inputs (CT1 and CT2 current measurement module)	Phase current inputs: I_{L1} (A), I_{L2} (B), I_{L3} (C) Residual current channel I_{01} (Coarse) Residual current channel I_{02} (Fine) Calculated residual current: I_{L1} (A), I_{L2} (B), I_{L3} (C)
Current input magnitudes	The phase currents of the high-voltage and the low-voltage sides. 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 - 2nd harmonic	±3.0 %ISET or ±75 mA (0.10…4.0 x ISET) ±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	<50 ms

NOTICE!
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.

8.2.1.21 Arc fault protection (IArc>/I0Arc>; 50Arc/50NArc) (optional)

Table. 8.2.1.21 - 435. Technical data for the arc fault protection function.

Measurement inputs	
Current inputs	Phase current inputs: I_{L1} (A), I_{L2} (B), I_{L3} (C) Residual current channel I_{01} (Coarse) Residual current channel I_{02} (Fine)
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>)	±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)

8.2.2 Control functions

8.2.2.1 Automatic voltage regulator (90)

Table. 8.2.2.1 - 436. Technical data for the automatic voltage regulator function.

Measurement inputs	
Voltage inputs	U_{L1}, U_{L2}, U_{L3} U_{L12}, U_{L23}, U_{L31} + U_0 U4 channel voltage
Voltage input magnitudes	RMS line-to-line voltages U4 channel RMS voltage
Current inputs	Phase current inputs: I_{L1} (A), I_{L2} (B), I_{L3} (C)
Current input magnitudes (I> blocking)	RMS phase currents
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

8.2.2.2 Setting group selection

Table. 8.2.2.2 - 437. 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 binary 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

8.2.2.3 Object control and monitoring

Table. 8.2.2.3 - 438. Technical data for the object control and monitoring function.

General	
Number of objects	10
Supported object types	Circuit breaker Circuit breaker with withdrawable cart Disconnector (MC) Disconnector (GND) Custom object image
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.

Table. 8.2.2.3 - 439. Technical data for the circuit breaker wear monitoring 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

8.2.2.4 Indicator object monitoring

Table. 8.2.2.4 - 440. Technical data for the indicator object monitoring function.

General	
Number of objects	10
Supported object types	Disconnector (GND) Custom object image
Signals	
Input signals	Digital inputs Software signals

8.2.2.5 Cold load pick-up (CLPU)

Table. 8.2.2.5 - 441. Technical data for the cold load pick-up function.

Measurement inputs	
Current inputs	Phase current inputs: I_{L1} (A), I_{L2} (B), I_{L3} (C)
Current input magnitudes	RMS phase currents

Pick-up	
Pick-up current setting - $I_{LOW}/I_{HIGH}/I_{OVER}$	0.01…40.00 × I_N, setting step 0.01 × I_N
Reset ratio	97 % of the pick-up current setting
Inaccuracy: - Current	±0.5 %I_{SET} or ±15 mA (0.10…4.0 × I_{SET})
Operation time	
Definite time function operating time settings: - t_{SET} - t_{MAX} - t_{MIN}	0.000…1800.000 s, setting step 0.005 s 0.000…1800.000 s, setting step 0.005 s 0.000…1800.000 s, setting step 0.005 s
Inaccuracy: - Definite time (I_M/I_{SET} ratio = 1.05/0.95)	±1.0 % or ±45 ms
Instant operation time	
CLPU activation and release	<45 ms (measured from the trip contact)

NOTICE!
A single-phase current (IL1, IL2 or IL3) is enough to prolong or release the blocking during an overcurrent condition.

8.2.2.6 Switch-on-to-fault (SOTF)

Table. 8.2.2.6 - 442. Technical data for the switch-on-to-fault function.

Initialization signals	
SOTF activate input	Any blocking input signal (Object closed signal, etc.)
Pick-up	
SOTF function input	Any blocking input signal (I> or similar)
SOTF activation time	
Activation time	<40 ms (measured from the trip contact)
SOTF release time	
Release time setting	0.000…1800.000 s, setting step 0.005 s
Inaccuracy: - Definite time	±1.0 % or ±30 ms
SOTF instant release time	<40 ms (measured from the trip contact)

8.2.2.7 Vector jump (Δφ; 78)

Table. 8.2.2.7 - 443. Technical data for the vector jump protection function.

Measurement inputs	
Voltage inputs	U_{L1}, U_{L2}, U_{L3} U_{L12}, U_{L23}, U_{L31} + U_0
Monitored voltages	Any or all system line-to-line voltage(s) Any or all system line-to-neutral voltage(s) Specifically chosen line-to-line or line-to-neutral voltage U4 channel voltage
Pick-up	
Pick-up setting	0.05…30.00°, setting step 0.01°
Inaccuracy: - Voltage angle	±30% overreach or 1.00 °
Low-voltage blocking	
Pick-up setting	0.01…100.00 %U_N, setting step 0.01 %U_N
Inaccuracy: - Voltage	±1.5 %U_{SET} or ±30 mV
Instant operation time	
Alarm and trip operation time: - (Im/Iset ratio > ±30% overreach or 1.00 °)	<40 ms (typically 30 ms) 50/60 Hz <50 ms (typically 40 ms) 16.67 Hz
Reset	
Trip pulse	~5-10ms

8.2.2.8 Synchrocheck (ΔV/Δa/Δf; 25)

Table. 8.2.2.8 - 444. Technical data for the synchrocheck function.

Input signals	
Voltage inputs	U1, U2, U3 or U4 voltage channel
Voltage input magnitudes	RMS line-to-line or line-to-neutral voltages U3 or U4 voltage channel 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

NOTICE!
The minimum voltage for direction and frequency solving is 20.0 %U_N.

8.2.3 Monitoring functions

8.2.3.1 Current transformer supervision

Table. 8.2.3.1 - 445. Technical data for the current transformer supervision function.

Measurement inputs	
Current inputs	Phase current inputs: I_{L1} (A), I_{L2} (B), I_{L3} (C) Residual current channel I_{01} (Coarse) (optional) Residual current channel I_{02} (Fine) (optional)
Current input magnitudes	RMS phase currents RMS residual current (I_{01}, I_{02}) (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)

8.2.3.2 Voltage transformer supervision (60)

Table. 8.2.3.2 - 446. Technical data for the voltage transformer supervision function.

Measurement inputs	
Voltage inputs	U_{L1}, U_{L2}, U_{L3} U_{L12}, U_{L23}, U_{L31}
Voltage input magnitudes	RMS line-to-line or line-to-neutral voltages
Pick-up	
Pick-up 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

NOTICE!
When turning on the auxiliary power of a device, the normal condition of a stage has to be fulfilled before tripping.

8.2.3.3 Current total harmonic distortion

Table. 8.2.3.3 - 447. Technical data for the total harmonic distortion function.

Input signals	
Current inputs	Phase current inputs: I_{L1} (A), I_{L2} (B), I_{L3} (C) Residual current channel I_{01} (Coarse) Residual current channel I_{02} (Fine)
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 × I_N setting; 5 mA < 0.5 × 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 %

8.2.3.4 Fault locator (21FL)

Table. 8.2.3.4 - 448. Technical data for the fault locator function.

Input signals	
Current inputs	Phase current inputs: I_{L1} (A), I_{L2} (B), I_{L3} (C)
Voltage inputs	U_{L1}, U_{L2}, U_{L3} U_{L12}, U_{L23}, U_{L31} + U_0
Calculated reactance magnitudes when line-to-neutral voltages available	XL12, XL23, XL31, XL1, XL2, XL3
Calculated reactance magnitudes when line-to-line voltages available	XL12, XL23, XL31
Pick-up	
Trigger current >	0.00…40.00 × I_N, setting step 0.01 × I_N
Inaccuracy: - Triggering	±0.5 %I_{SET} or ±15 mA (0.10…4.0 × I_{SET})
Reactance	
Reactance per kilometer	0.000…5.000 s, setting step 0.001 Ω/km
Inaccuracy: - Reactance	±5.0 % (typically)
Operation (Triggering)	
Activation	From the trip signal of any protection stage
Minimum operation time	At least 0.040 s of stage operation time required

8.2.3.5 Disturbance recorder

Table. 8.2.3.5 - 449. Technical data for the disturbance recorder function.

Recorded values	
Recorder analog channels	0…20 channels Freely selectable
Recorder digital channels	0…95 channels Freely selectable analog 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

8.2.3.6 Event logger

Table. 8.2.3.6 - 450. Technical data for the event logger function.

General information	
Event history capacity	15 000 events
Event timestamp resolution	1 ms

8.3 Tests and environmental

Electrical environment compatibility

Table. 8.3 - 451. 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. 8.3 - 452. 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. 8.3 - 453. 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. 8.3 - 454. 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. 8.3 - 455. 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. 8.3 - 456. 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

9 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 0.5%
- 2 Power/Energy measurement accuracy 0.2%

Terminals
- A Standard
- B Ring lug terminals
- C Standard current terminals, spring cage voltage and I/O terminals
- D Ring-lug current terminals, spring cage voltage and I/O terminals

Reserved for future use
- A N/A

Digital inputs on power supply module
- A 3 Digital inputs, 24 V nominal threshold
- B 3 Digital inputs, 110 V nominal threshold
- C 3 Digital 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 Digital inputs
- C 5 Output relays (max. 6 pcs)
- D Arc protection with 4 point sensor channels, 2 x HSO, 1 x BI (max. 1 pcs)
- F 8 x RTD input (max. 2 pcs)
- G 2 x RJ-45 100Mb Ethernet & IRIG-B (max. 1 pcs) *
- H 2 x ST 100Mb Ethernet & IRIG-B (max. 1 pcs) *
- I 4 x mA outputs - 1 x mA input (max. 2 pcs)
- J Double LC 100Mb Ethernet (HSR, PRP redundant protocols) (max. 1 pcs) *
- K Double RJ45 100Mb Ethernet (HSR, PRP redundant protocols) (max. 1 pcs) *
- L RS-232 - Serial fiber (Plastic-Plastic) (max. 1 pcs) *
- M RS-232 - Serial fiber (Plastic-Glass) (max. 1 pcs) *
- N RS-232 - Serial fiber (Glass-Plastic) (max. 1 pcs) *
- O RS-232 - Serial fiber (Glass-Glass) (max. 1 pcs) *

* Can only be applied to the two last slots

Accessories

Order code	Description	Note
AX007	External 6-channel 2 or 3 wires RTD Input module, pre-configured	Requires an external 24 VDC supply.
AX008	External 8-ch Thermocouple mA Input module, pre-configured	Requires an external 24 VDC supply.
AX013	AQ-250 series raising frame 120mm	
AQX014	AQ-250 series raising frame 40mm	

AQX015	AQ-250 series wall mounting bracket	
AQ-01A	Light point sensor unit (8,000 lux threshold)	Max. cable length 200 m
AQ-01B	Light point sensor unit (25,000 lux threshold)	Max. cable length 200 m
AQ-01C	Light point sensor unit (50,000 lux threshold)	Max. cable length 200 m
AQ-02A	Pressure and light point sensor unit (8,000 lux threshold)	Max. cable length 200 m
AQ-02B	Pressure and light point sensor unit (25,000 lux threshold)	Max. cable length 200 m
AQ-02C	Pressure and light point sensor unit (50,000 lux threshold)	Max. cable length 200 m

10 Contact and reference information

Manufacturer

Arcteq Relays Ltd.

Visiting and postal address

Kvartsikatu 2 A 1
65300 Vaasa, Finland

Contacts

Phone:	+358 10 3221 370
Website:	arcteq.com
Technical support:	arcteq.com/support-login +358 10 3221 388 (EET 9:00 – 17.00)
E-mail (sales):	sales@arcteq.fi