AQ-L3x9

Line differential protection device

Instruction manual

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Disclaimer

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

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.

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1 Document information

Table. 1 - 1. History of Revision 1.

Revision	1.00
Date	November 2010
Changes	• The first revision of the manual.
Revision	1.01
Date	January 2011
Changes	• HW construction and application drawing revised.
Revision	1.02
Date	February 2011
Changes	• Directional earth fault function revised. • Synchrocheck function revised. • Voltage measurement module revised. • CPU module description added. • Binary input module description revised. • IRIG-B information added. • Voltage variation (sag and swell) function added. • Ordering information and type designation updated. • Technical data revised.
Revision	1.03
Date	March 2012
Changes	• The "Line differential communication applications" chapter added.
Revision	1.04
Date	July 2012
Changes	• Line differential with transformer in protected zone added. • MHO characteristics added. • Synchrocheck parameters updated. • Technical data updated. • Order code updated.
Revision	1.05
Date	February 2015
Changes	• Current and voltage measurement descriptions revised.
Revision	1.06
Date	March 2015

Changes	• Description for trip logic revised. • Description for the common function added. • Description for the line measurements function added.
Revision	1.07
Date	May 2018
Changes	• The separated parameters for phase-to-phase and phase-to-earth fault detection (distance) added.
Revision	1.09
Date	December 2019
Changes	• The "Construction and installation" chapter updated.

Table. 1 - 2. History of Revision 2.

Revision	2.00
Date	February 2023
Changes	• Updated the Arcteq logo on the cover. • An overall visual update for the manual's layout and design. • Added the "Safety information" chapter. • Added the "Abbreviations" chapter. • Added the previously separate documents "AQ 300 Operator's manual" and "AQ 300 Web server description" into the "IED user interface" chapter. • Various images updated. • Updated contact and reference information.

2 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.

3 Abbreviations

AC
: alternating current

AVR
: automatic voltage regulator

CB
: circuit breaker

CBFP
: circuit breaker failure protection

CPU
: central processing unit

CT
: current transformer

CTS
: current transformer supervision

CVT
: capacitive voltage transformer

DC
: direct current

DI
: digital input(s)

DLD
: dead line detection

DO
: digital output(s)

EFT
: electronic fast transients

EMC
: electromagnetic compatibility

EOB
: Ethernet Overboard

ESD
: electrostatic discharge

HMI
: human—machine interface

IDMT
: inverse definite minimum time

IED
: intelligent electronic device

IO
: inputs and outputs

LCD
: liquid-crystal display

LED
: light-emitting diode

NC
: normally closed

NO
: normally open

NTP
: Network Time Protocol

RF
: radio frequency

RCA
: relay characteristic angle

RMS
: root mean square

SCADA
: supervisory control and data acquisition

SDRAM
: synchronous dynamic random access memory

SLD
: single-line diagram

SOTF
: switch-on-to-fault

TMS
: time multiplier setting

VT
: voltage transformer

VTS
: voltage transformer supervision

4 General

The AQ-L3x9 line protection IED is a member of the AQ-300 product line. The AQ-300 protection product line in respect of hardware and software is a modular device. The hardware modules are assembled and configured according to the application IO requirements and the software determines the available functions. This manual describes the specific application of the AQ-L3x9 line protection IED.

Arcteq protection IED can be ordered in two mechanical sizes. The AQ-L359 comes in half of 19 inch rack arrangement and the AQ-L399 comes in full 19 inch rack arrangement allowing for larger quantity of IO cards. The functionality is the same in both units.

5 IED user interface

5.1 Front panel

The figure below presents the front panel structure for AQ-300 series units, while the table below the image describes the functions of the front panel's various elements.

Figure. 5.1 - 1. AQ-300 front panel structure.

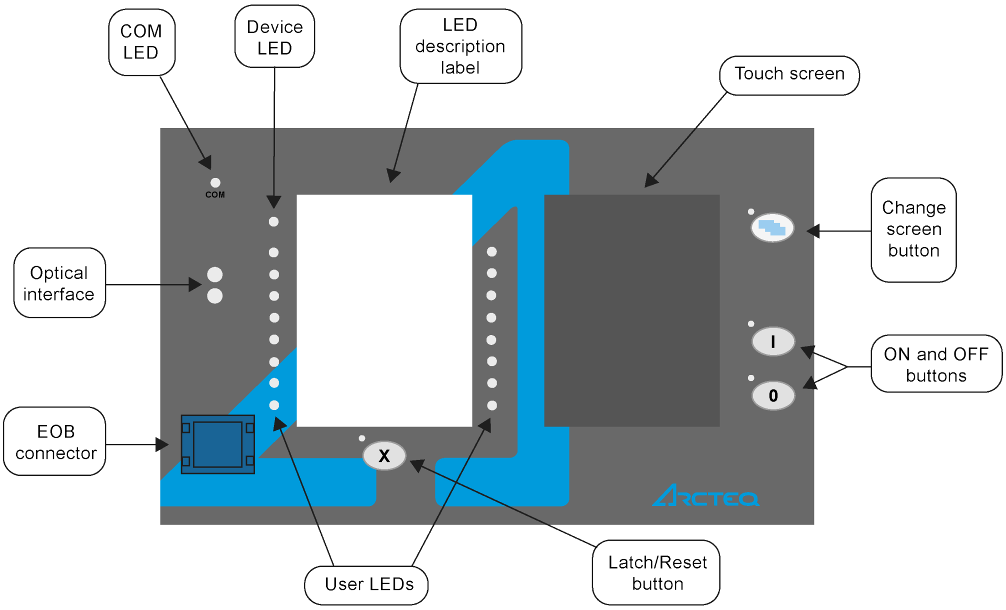


Table. 5.1 - 3. Elements of the front panel.

Function	Description
Device LED	One (1) three-colored circular LED. • Green = normal operation • Yellow = warning state • Red = alarm state
COM LED	One (1) yellow circular LED, which indicates the EOB communication link and activity.
User LEDs	Three-colored circular LEDs. Their number depends on the relay model.
LED description label	A changable label with LED functionality descriptions.
Optical interface	(for factory usage)
EOB connector	Ethernet Overboard communication interface. It attains an isolated and non-galvanic Ethernet connection with the help of a magnetic EOB device. The EOB device has an RJ-45 type connector which supports 10Base-T Ethernet connection to the user's computer.
Touch screen	The main screen, a 3.5" (320 x 240 pixels) portrait-oriented TFT display with a resistive touch screen interface. Optionally, the touch screen can be 5.7" and landscape-oriented.

Function	Description
Operation buttons	The device has four (4) capacitive operational buttons: • "X" (below the LED label) latches and resets the LEDs. • The button with a blue icon (top right) changes the touch screen menus. • "ON" and "OFF" (bottom right). Pushing a button causes an audible buzzer pressure feedback. All four buttons also have an LED off their top-left corner to indicate their status.

5.2 LED assignment

On the front panel of the device there is user LEDs with the "Changeable LED description label". Some LEDs are factory assigned, some are free to be defined by the user. Table below shows the LED assignment of the AQ-L3x9 factory configuration.

Table. 5.2 - 4. The LED assignment of AQ-L3x9.

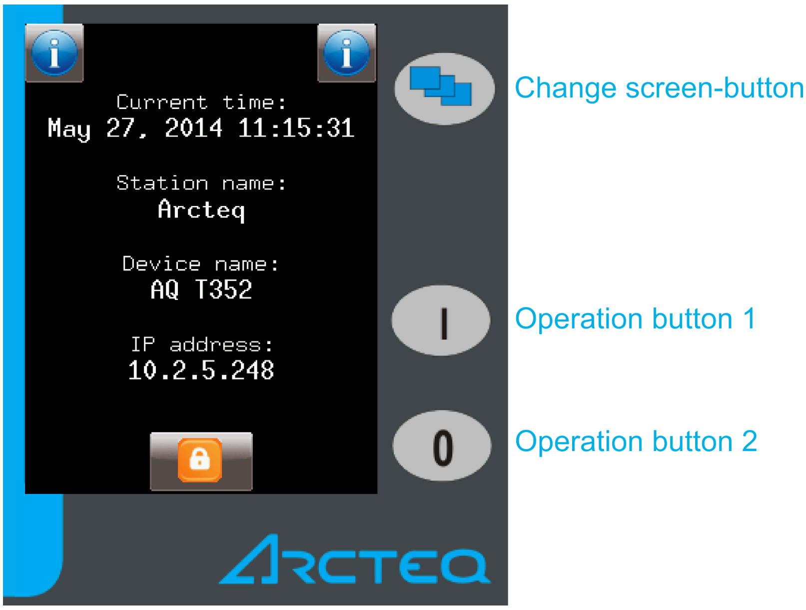
LED	Explanation
Gen. Trip	Trip command generated by the TRC94 function
OC trip	Trip command generated by the phase overcurrent function
OCN trip	Trip command generated by the residual overcurrent protection function
Therm. Trip	Trip command of the line thermal protection function
Unbal. Trip	Trip command of the current unbalance protection function
Inrush	Inrush current detected
Voltage trip	Trip command generated by the voltage-related functions
Frequ trip	Trip command generated by the frequency-related functions
REC blocked	Blocked state of the automatic reclosing function
Reclose	Reclose command of the automatic reclosing function
Final trip	Final trip command at the end of the automatic reclosing cycles
LED 312	Free LED
LED 313	Free LED
LED 314	Free LED
LED 315	Free LED
LED 316	Free LED

5.3 Touch screen

The touch screen comes with a variety of powerful features, including the ability to make customized menus. It also supports single-line diagrams (SLD). The touch screen can be accessed and controlled remotely via the device's web interface. For more information on the remote user interface, please refer to "The embedded web server" chapter below.

The image below depicts the main screen of the front panel as well as the "ON", "OFF" and "Change screen" buttons.

Figure. 5.3 - 2. The main menu and three operation buttons.



The touch screen is the main control where you can enable functions and input values.

The "Change screen" button changes the menu shown on the main display. The menus are in the following order by default: the main menu, the parameter menu, the online measurement menu, the events menu, and the system settings menu. You can also add a number of customized menus which can be created with EuroCAP software. Pushing the button moves the displayed menu by one, in a cycle.

The operation buttons can be used to define certain functions on customer-defined menus. For example, you can set up these buttons to turn a circuit breaker on or off, or to increment and decrement the position of a transformer's tap changer. For more information, please refer to the "Custom user-defined menus" chapter.

Main menu

The main menu is the first one shown when the device is turned on. It displays general information such as the device and station names, the current time, and language options (when available).

Figure. 5.3 - 3. Lock status indicator, as displayed in the main menu.

The lock status indicator shows whether a password is required to unlock the device before parameters or settings can be changed. By default, the device is not password-protected. However, is such a functionality is needed, you can set the password application via the web interface.

NOTICE!
The password cannot be set with the touch screen.

When a device is protected by a password, push the lock icon. This brings up a password input screen (see the image below) where you can enter the password. When the password is entered correctly, the lock status indicator on the main menu becomes unlocked, as does the menu in question. The device can be unlocked from any of the menus.

Figure. 5.3 - 4. The password input screen.

NOTICE!
The lock icon is displayed even when the device has no password!

Parameter menu

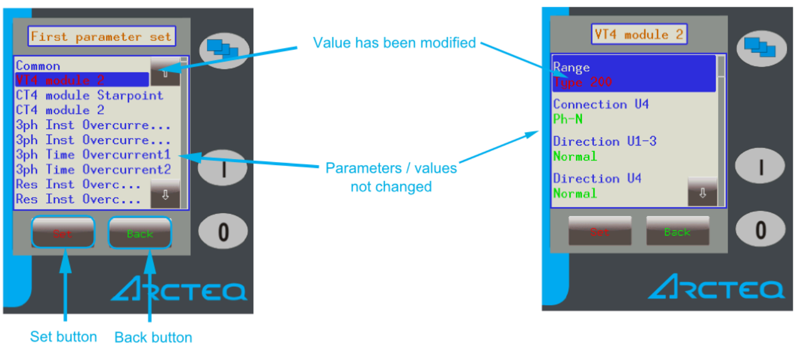
In the parameters menu (below) you can view, set and edit certain parameters within the device. You can also choose which of the parameter sets the device uses.

The parameter set that is currently active has a red box around it (see the figure below). When you want to edit or activate a parameter set, touching its name to select and highlight it and then press the "Edit" or "Activate" button.

Figure. 5.3 - 5. The parameter set menu.

The Activate button activated the selected parameter set, which the device will now use. Depending on the device's configuration, the "Activate" button may not be available. The Edit button takes you to another screen where you can choose which function blocks the parameter set uses. Please note that when there is only one parameter set, the device takes you immediately to the parameter set edit screen (below).

Figure. 5.3 - 6. The parameter set edit screen (left) and the function block screen (right).



Normally, the various function blocks appear blue. However, if any value has been changed within a function block, its listing appears red to notify the user. This also happens in the function block screen, where unmodified parameter values appear green but modified values appear red.

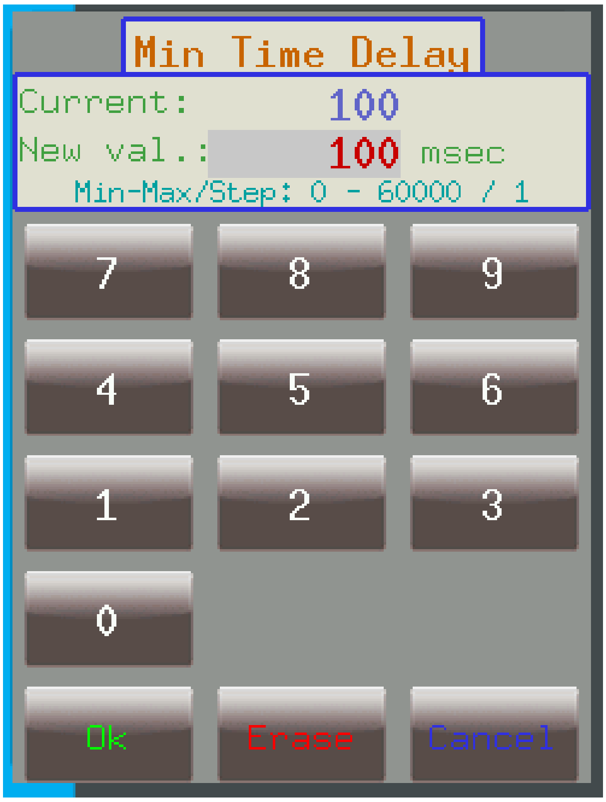
The Set button brings up a screen where you can modify a value. If there is a lock icon instead of the "Set" button, the device must first be unlocked. The Back button returns you to the previous screen.

Within all function blocks, the parameter values can have one of the following four types of input:

- Integer
  A whole number, entered with the number pad.

- Floating-point number
  A number with a decimal point, entered with the number pad. Please note that the pad has the decimal point available only when the value can be entered as a floating-point number!
- List item
  The parameter lists thr available options as a list, and the user selects the desired option from them.
- Checkbox
  The user can enable and disable the parameter as a whole.

Figure. 5.3 - 7. Editing the parameter values.



The new parameter value is put in the "New value" field. The "Current value" field shows the parameter value that is currently in use. The "Min–Max/Step" field shows the range within which the parameter's value can be modified, as well as the step with which the value can be incremented or decremented. For example, in the image above, the range is between 1 000 and 10 000 with a step value of 1. This means that the value can be 1 001, 1 002, 1 003,...,9 999, 10 0000. If the step value were 5, the field would only accept values such as 1 005, 1 010, 1 015, and so on.

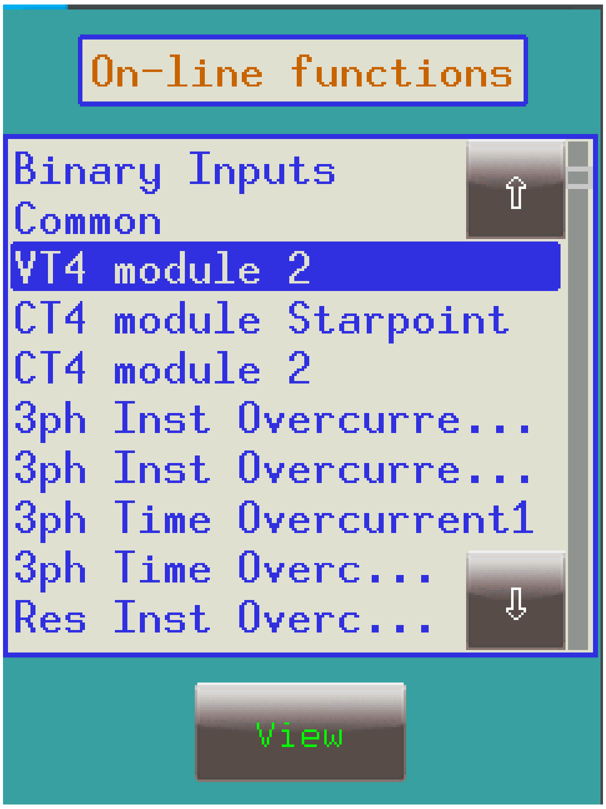
The OK button confirms the value in the "New value" field and returns the user to the previous screen. The Cancel button deletes a single digit from the "New value" field. The Erase button discards any changes to the current parameter and returns the user to the previous menu item.

CAUTION!
Make sure that only one person edits the parameters at any one time, either in the touch screen or in the web interface! Simultaneous editing leads to confusion as to what the values of a parameter set actually are.

Online measurement menu

The online measurement menu displays real-time data depending on what is connected to the device. When you have selected a specific function block from the online functions list, clicking the View button takes you to a new window that displays the parameters and their current values. The image below shows the values of VT4 module 2: the voltages and angles for channels U1 and U2.

Figure. 5.3 - 8. Online measurement menu.

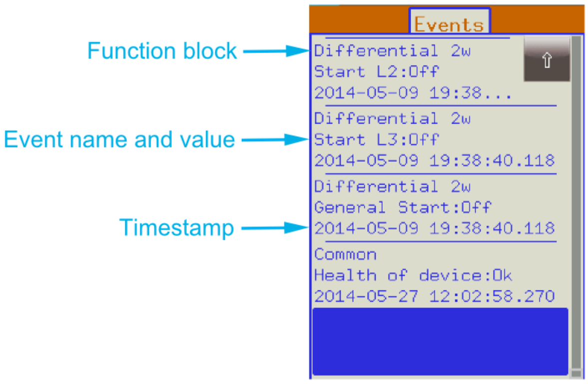


Events menu

The events menu displays a list of events that have occurred within and in relation to the device. This menu screen is continuously updated. If the scrollbar on the right is at the bottom, the screen shifts as a new event occurs. However, if the scrollbar is not on the bottom, the screen stays in place even when a new event occurs. This allows you to take a closer look at the events.

The first row of an event displays the function block's name, the second row displays the event's name and value, and the third row displays the event's time stamp (see the image below).

Figure. 5.3 - 9. Event structure.



NOTICE!
The events menu does not display the whole event log, only the first few hundred items in the log!

System settings menu

Figure. 5.3 - 10. System settings menu.

In the system settings menu you can set certain parameter values that are related to the device itself (as opposed to its protection functions and operations). The menu works similarly to the parameters menu and the same properties apply.

Table. 5.3 - 5. The system settings.

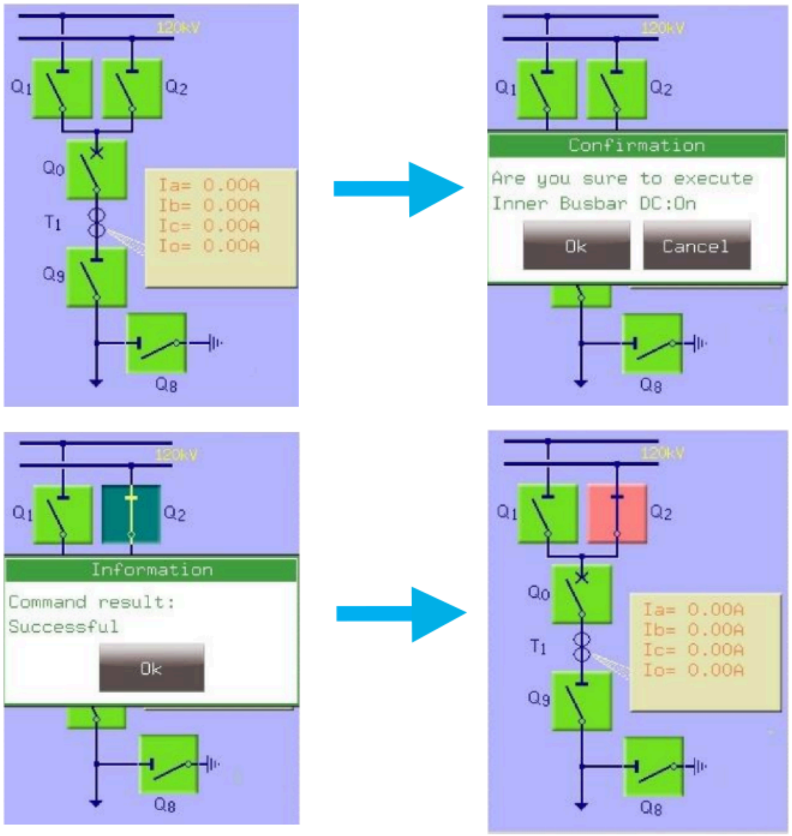
Setting	Description
System parameters and station bus settings (IP address, netmask, default gateway, DNS servers)	Please contact your local network administrator for further information about these settings.
Ethernet communication (IEC 61850 enabled, IEC 104 enabled)	Enables or disables the IEC 61850 and IEC 104 communication protocols.
Serial communication	Selects which serial protocol the device uses. The "Serial baudrate" field sets the baudrate to a specific amount. Please note that this and link address only apply to legacy protocols!
Time synchronization	When time synchronization via NTP server addresses is enabled, the device uses Network Time Protocol to synchronize time with one of the servers. The device also supports other, non-NTP time synchronization methods, such as pin and serial.
Time zone settings	"GMT offset" defines the positive or negative offset for Greenwich Mean Time. "Use DST" and "DST start/stop" define the daylight savings time setting. As DST is different in each country, set these as appropriate.
LCD backlight	Changes the brightness of the touch screen's back illumination.

Custom user-defined menus

You can add menus based on your application needs with the help of the AQtivate 300 software. You can also set up the operation buttons "I" and "0" to perform specific functions.

For example, let us say we have the following network depicted in the top-left image in the figure below as a single-line drawing. We have set the operation buttons to function as "ON" and "OFF", and now we would like to switch the line disconnecter Q2 on.

Figure. 5.3 - 11. Turning on Q2.



(1) First, we press Q2 on the touch screen to highlight the object. This causes Q2 to start blinking for a short while; if an action is not performed within this time, the object deselects on its own. So, while Q2 is highlighted and blinking, we press the "I" button (configured to function as an "ON" button) to turn it on. (2) A window pops up to confirm we want to do this action; again, we have a shirt time to give an answer (in this case, to press "Yes") before the requested operation is automatically cancelled. (3) Another window pops up to state that the operation was successful. (4) After acknowledging this window, the display is updated as appropriate, with the Q2 line disconnector in the "ON" position.

Just as the online measurement and events menus, this menu is also updated continuously. Therefore, any kind of change in the states or in the measured parameters are shown and updated accordingly. If there is an error with an operation, the device signals the user of this with an error pop-up window that includes the error code and the reason for the error.

5.4 The embedded web server

Introduction

This product offers the ability to remotely monitor and modify various parameters and settings within the device. You can access the front panel and choose other options with the help of a web browser. With the user-friendly interface, you can easily manage the device. Password protection is available to grant certain priviledges and access to special functions.

You can perform the following actions with the embedded web server:

- modify user parameters
- check the event list and disturbance records
- manage the password
- display the measured data and the generated binary information
- perform commands

- provide remote or local firmware updgrades
- perform administrative tasks.

System requirements

In order to access the device interface you need a compatible web browser as well as an Ethernet connection. It is recommended that the screen resolution is at least 1024 x 768 so that the screen can display data properly.

You can use any of the following web browsers:

- Microsoft Internet Explorer, version 7.0 or higher
- Mozilla Firefox, version 1.5 or higher (version 3.0 or higher recommended!)
- Apple Safari, version 2.0.4 or higher
- Google Chrome, version 1.0 or higher
- Opera, version 9.25 or higher

You must also enable JavaScript within your browser. For security reasons the device is only allowed a limited number of connections over the network.

To access the device via a web browser write the correct IP address on the browser's address bar. You can find the device's IP address on the main menu of the device's touch screen.

5.4.1 Ethernet connections

Properties of the Ethernet connection

An AQ-300 unit has five (5) Ethernet ports built into the device, allowing it to be connected to IP/Ethernet-based networks. The unit has the following Ethernet ports available (the first is located in the front panel, the others on the rear side of the CPU unit):

- Ethernet over board (EOB) 10Base-T user interface
- Station Bus (100Base-FX Ethernet)
- Redundant Station Bus (100Base-FX Ethernet)
- Process Bus (100Base-FX Ethernet, in preparation)
- 10/100Base-Tx port via the RJ45 connector

There are three different types of interfaces for the communication ports:

- The EOB interface is attachable to the device's front panel by a proprietary magnetic connector. The connector box ends in a RJ45 8/8 plug, and the interface is a 10Base-T full duplex interface.
- The 100Base-FX Ethernet interface is of type ST, which offers 1 300 nm/MM for a 50 μm/125 μm (or, 62.5 μm/125 μm) fiber.
- The 10/100Base-Tx Ethernet interface is an RJ45 8/8 plug.

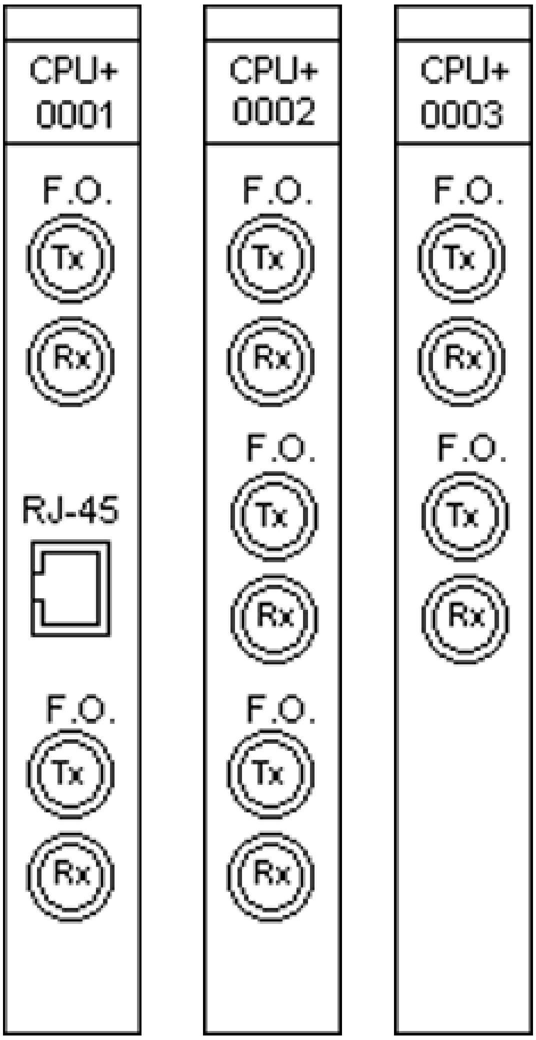
The following table catalogues the different Ethernet communication versions available for the different AQ-300 CPU versions.

Table. 5.4.1 - 6. The available Ethernet communication in different CPU versions.

CPU version	EOB	Station Bus	Redundant Station Bus	Process Bus	RJ45	Legacy port/protocol
CPU+0001	Yes	Yes	No	Prep	Yes	No
CPU+0002	Yes	Yes	Yes	Prep	No	No
CPU+0003	Yes	Yes	Yes	No	No	No

The diagram below depicts the three (3) different CPU versions and their structures:

Figure. 5.4.1 - 12. The three CPU versions.



Settings needed for Ethernet connection

The AQ-300 devices can only be accessed over Ethernet-based communication protocols. This is why it is very important for the network to be set up correctly before accessing the device.

IP settings

The device operates with fixed IPv4 addressing. At the moment dynamically assigned IP addresses are not supported. We recommend using the private address range as defined in RFC 1918. All addresses must be in the same network range. Additionally, the computer should be set to use fixed IP settings.

You can connect to a stand-alone device by plugging the EOB cable into your computer or by using the RJ45 connector at the back of the device (this requires a crossover UTP cable). When you want to connect the device to a station or corporate network, contact the system administrator for all the required information: an available IP address, the gateway address, the netmask, the DNS and NTP server addresses.

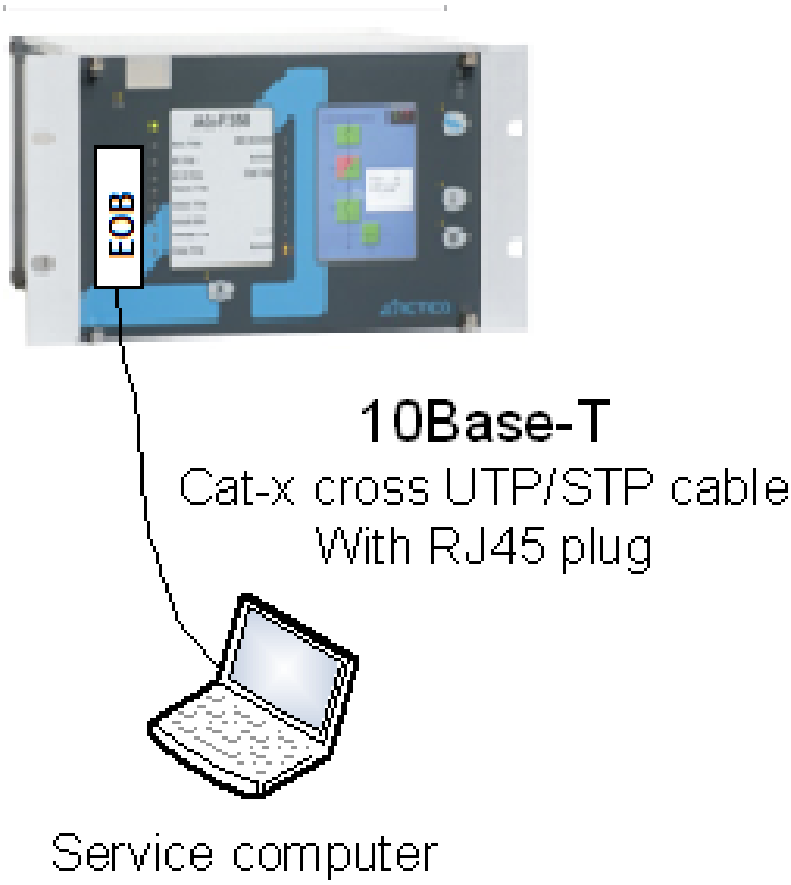
Web browser settings

Make sure that your browser does NOT use a proxy server while accessing an AQ-300 device. However, if there is a proxy server in your network, contact the system administrator and have them add an exception.

EOB connection

Attach the magnetic EOB connector to the front panel of the device; the magnets assure that the adapter is in the correct position. Next, connect the other end of the cable to a computer's RJ45 port (see the figure below).

Figure. 5.4.1 - 13. Using the EOB connection.

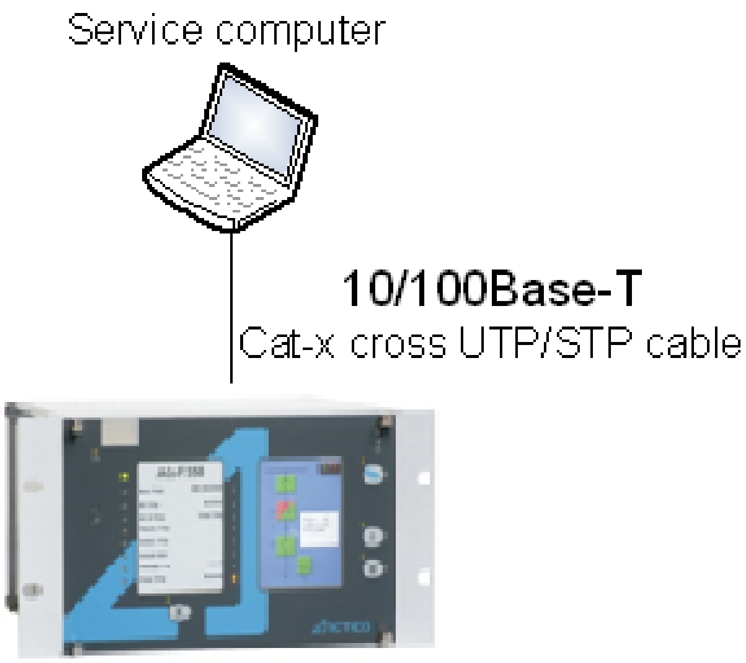


Please note that the RJ45 connector can also be connected to an Ethernet switch. When this is the case, all the network's IEDs with client functionalities (e.g. a computer) have access to the device.

RJ45 connection

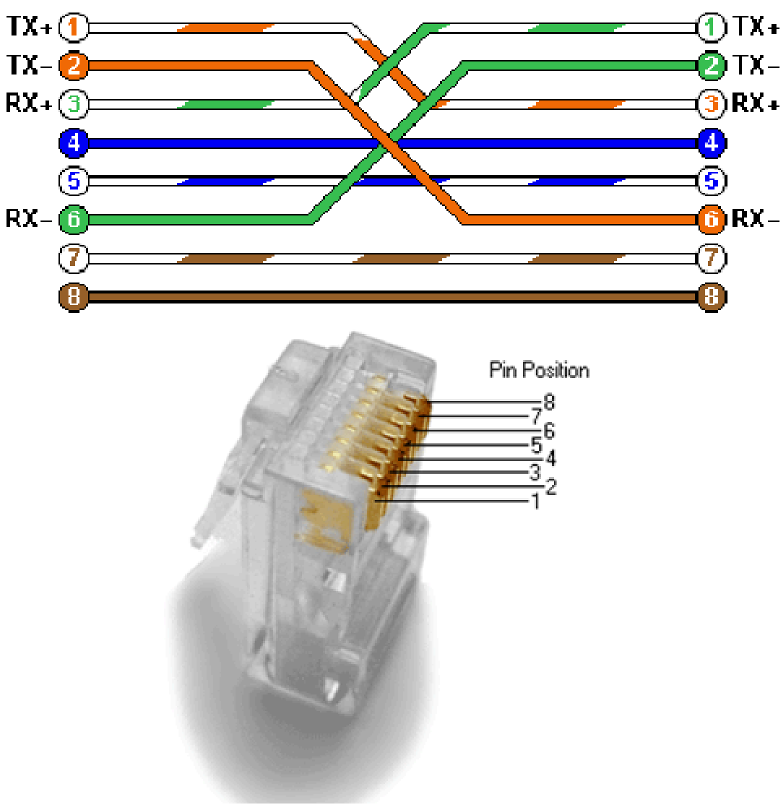
As seen in the beginning of this chapter, the CPU version "+0001" also has an integrated RJ4 port. When using a UTP crossover cable with RJ45 connectors at both ends, you can connect the device directly to a computer (see the figure below).

Figure. 5.4.1 - 14. Using the RJ45 connection.



The crossover cable's pinout has been depicted in the diagram below:

Figure. 5.4.1 - 15. The pinout of the crossover cable.

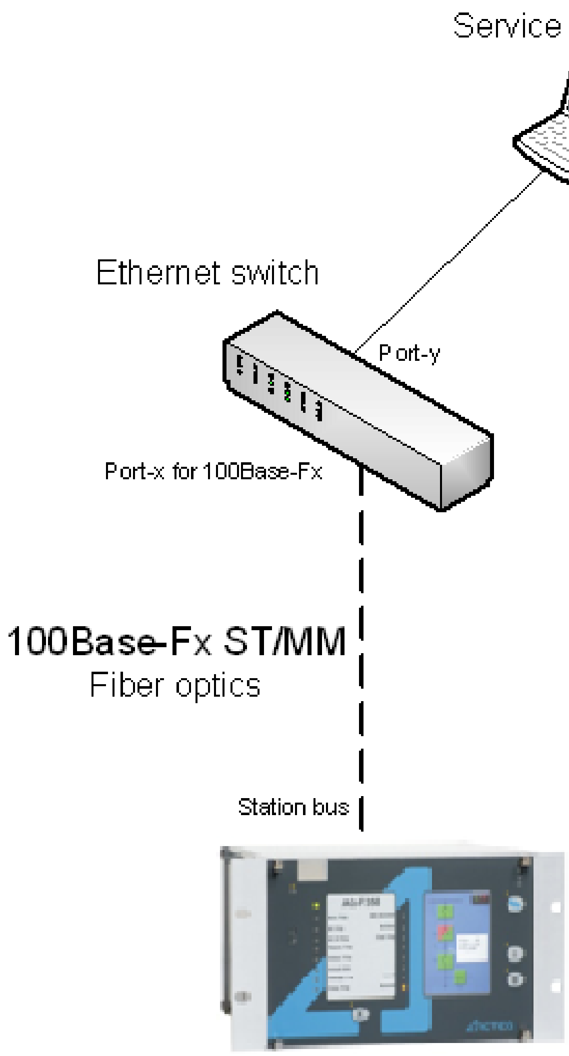


Please note that the cable's RJ45 connector can also be connected to an Ethernet switch. When this is the case, all the network's IEDs with client functionalities (e.g. a computer) have access to the device.

ST-type fiber optic connection

The ST-type fiber optic connector of the 100Base-FX Ethernet provides a connection to an Ethernet switch with an identical fiber optic input. When using this connection, all the network's IEDs with client functionalities (e.g. a computer) have access to the device (see the figure below).

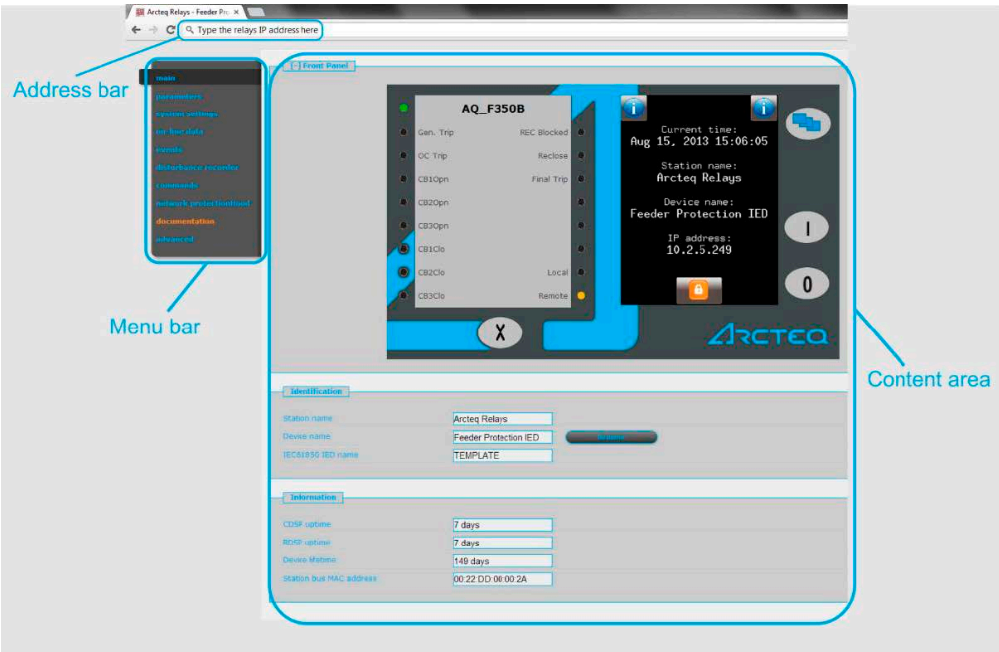
Figure. 5.4.1 - 16. Using the ST-type fiber optic connection to connect computers via an optical Ethernet switch.



5.4.2 Getting started

Make sure you are connected to your AQ-300 device and that you have JavaScript enabled within your web browser. Type the IP address of the device into your browser's address bar to access its embedded web server (see the image below).

Figure. 5.4.2 - 17. Web server elements.



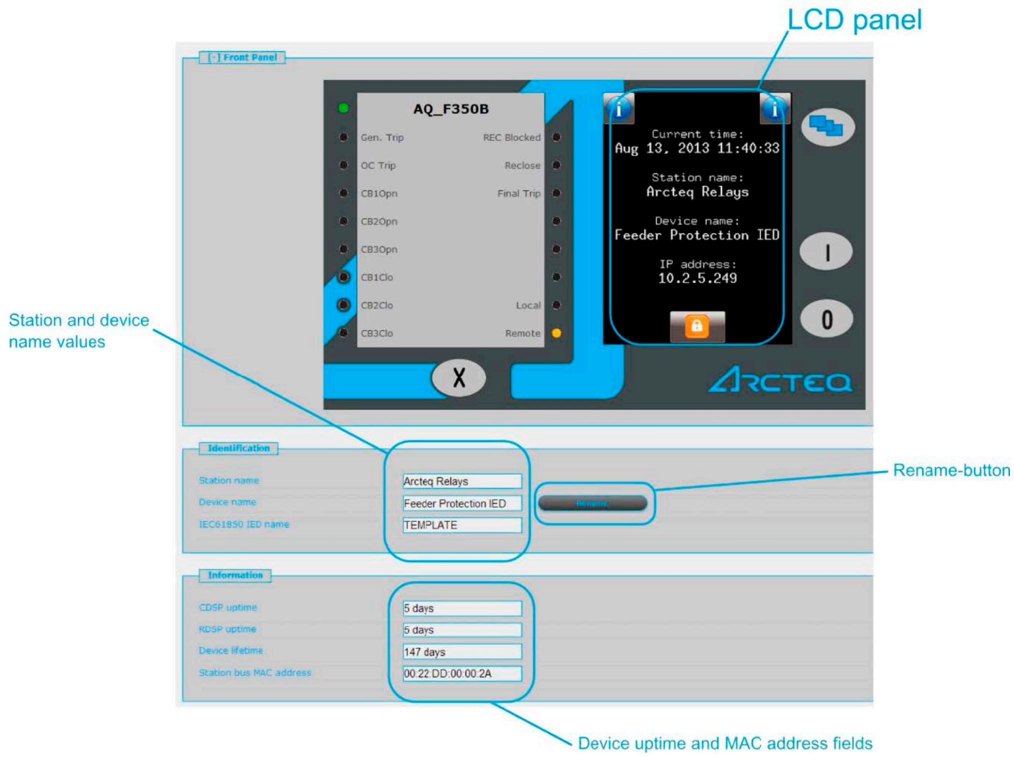
The menu that is currently selected is highlighted in black (in the image above, the main menu is selected). If the content area is too long to fit the browser window, you can scroll down; the menu bar will always be visible as it follows the user.

In some configurations the language that is currently displayed can be changed; to do this, click one of the other available languages represented by flags, located at the top of the touch screen. The page automatically refreshes in the chosen language. Please note that changing the display language only affects the local browser, NOT other browser or the language of the touch screen.

5.4.3 Menu items

Main menu

Figure. 5.4.3 - 18. The main menu and its elements.



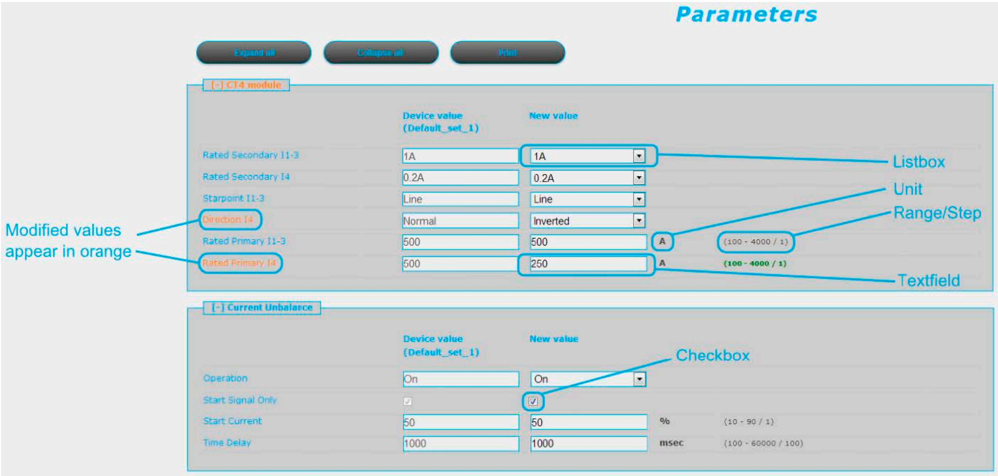
In the main menu you can control the device's front panel. The image of a touch screen (located on the right) behaves the same way as the actual touch screen. For more information on the touch screen, please refer to the "Touch screen" subchapter in the "IED user interface" main chapter.

In the "Identification" section of the view, you can change the station name and the device name. Type the desired name in the relevant field and click the Rename button.

The "Information" section shows additional information about the device. The uptime fields show how much time has passed since the device was last powered on. The "Station bus MAC address" displays the network card's MAC address, which is a uniwue identification number assigned by Arcteq (the address range assigned by the IEEE authority). Please note that these fields are read-only and cannot be modified!

Parameters menu

Figure. 5.4.3 - 19. The parameters menu and its elements.



You can view and change various parameters and variables in this menu. You can manage the different parameter sets by resetting, renaming, exporting and importing them. You can also apply a password for importing, exporting and setting.

All parameters are part of specific function blocks. You can expand and collapse the individual function block information boxes by clicking the [+] and [–] signs in front of its name. You can also use the button at the top to expand all function blocks, collapse them all, or print out a printer-friendly layout of the function blocks (opens in a new browser window).

The parameter sheet has the following general layout

- The first column contains the name of the parameter. In multilingual devices changing the language also changes this name.
- The second column displays the current values of the selected parameter set stored in the device. Changing the parameter does NOT activate it, it only loads to the fields.
- The third column is used to give parameters user-desired values. When changed, the color changes to blue to draw attention to the change. The expected value range and step are located to the right of the parameter line.

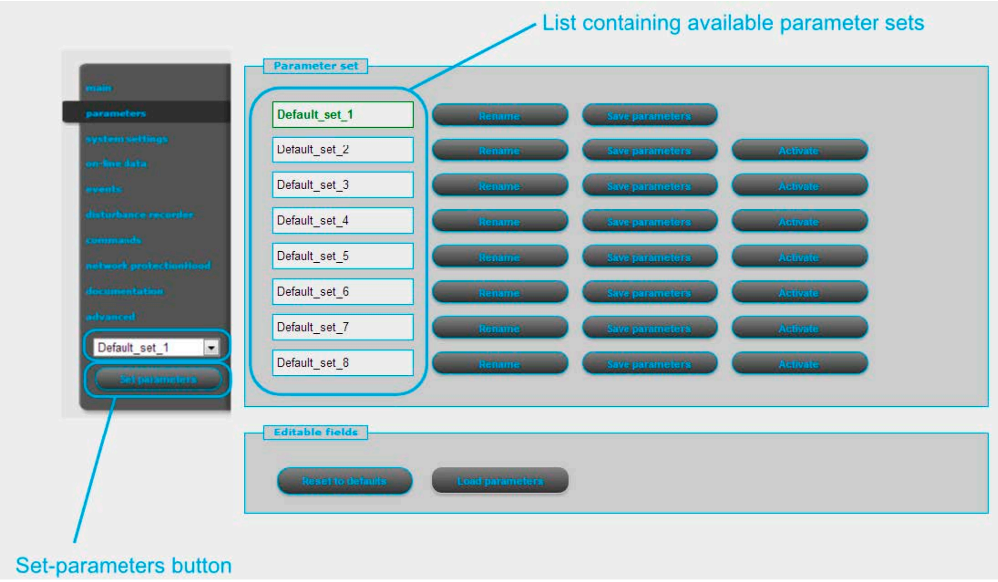
The parameter values are displayed in text fields, checkboxes, or listboxes. All of these can be modified; the name of the parameter whose value has been modifed appears in orange, as does the name of the function block (see the image above). When modifying *text fields*, please be mindful of the parameter range and step, although the device does alert the user when an improper value is entered. The new value is displayed in red. *Checkboxes* (Boolean parameter type) enable and disable certain functions and properties; a ticked checkbox means that the parameter is enabled. *Listboxes* (enumerated parameter type)open a drop-down menu with a number of predetermined values. When a value that is not the default is selected, both the letters and the box outline become red.

> NOTICE!
> A parameter line has the unit between the new value textfield and the range/step information when applicable. Some parameters do not have units!

The parameter values are checked for changes when you navigate away from the parameter page or when you try to load another parameter set. A pop-up window notifies you if you have made changes and try to leave the page without saving them. Clicking Cancel returns you to the parameter page, whereas clicking OK ignores the changes.

In the "Parameter set" section of the page there are options for managing the parameter sets. The section lists all the available parameter sets, and each can be manipulated with the buttons located on the right of the line.

Figure. 5.4.3 - 20. Managing multiple parameter sets.



With the **Activate** button, you can enable the selected parameter set. The device will now use the values from this set. The **Rename** button, unsurprisingly, renames the selected parameter set. The names can include alphanumeric characters, spaces, dashes and underscores. Please note that two or more parameter sets CANNOT share the same name! The **Save parameters** button saves the selected parameter set in a separate file, which can be loaded into the device at any time.

The **Set parameters** button (located below the menu bar on the left) overwrites the selected parameter set with the values that are on the screen. Note that this only modifies the values of the selected set; to have the device use these values you must also activate the set! You can also set a password that is required before overwriting can be done.

The "Editable fields" section has two buttons. The **Reset to defaults** button replaces the values on the screen with the factory default settings. With the **Load parameters** button you can import values from a parameter set file. These values must be saved after loading by pressing the **Set parameters** button.

> NOTICE!
> These buttons and functions only appear if the device is configured to have more than one parameter set. The available buttons and functions depend on the configuration.

System settings menu

In the system settings menu you can adjust the miscellaneous device settings. This menu can also be password protected. The text fields, checkboxes and listboxes function the same as in the parameter menu. The column structure is also the same.

The **Set settings** button (located below the menu bar on the left) enabled the device to use the values displayed on the screen at the time the button was clicked. Please note that if the device's IP address has changed, the device must first be accessed through the new IP address.

Figure. 5.4.3 - 21. The system settings menu.

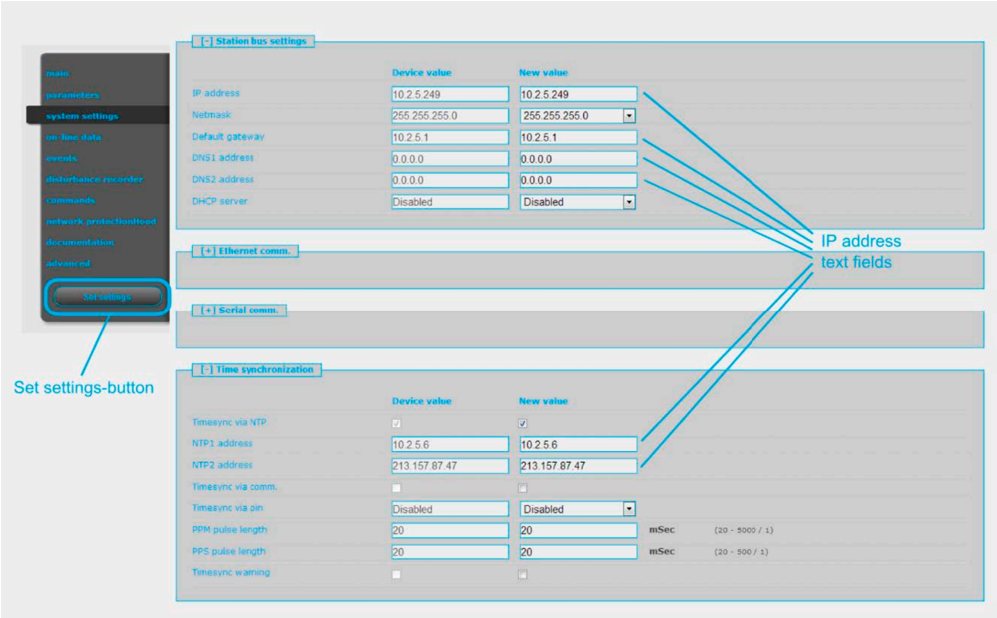


Table. 5.4.3 - 7. The system setting sections and their content.

Section name	Description
Safe settings	If enabled, the device asks you to confirm the saving of new settings by pressing the "I" (ON) button on the device's front panel. Pressing "0" (OFF) discards the changes. This selection must be made within 300 seconds.
Power system frequency	Sets the power system frequency. By default it is 50 Hz, can be changed to 60 Hz. **CAUTION!** Changing this parameter initiates a system restart!
Station bus settings	Contains the settings for IPv4-based communication (IP address, mask, gateway, DNS address). The DHCP server function can be switched on with a combo-box. **CAUTION!** Uncontrolled use of the DHCP server function can cause serious communication failures!
Ethernet communication	The device can communicate using several Ethernet-based protocols at the same time. Only IEC 61850 is licensed, other protocols are available by default. You can adjust the T0 time of GOOSE messaging with the GOOSE repeat rate combo-box.
Serial communication	Contains the physical parameters for serial communication (only one protocol can be selected!). Note that serial communication requires a proper CPU card!
Time synchronization	Contains the settings for a broad range of time synchronzation protocols (NTP, serial communication, pulse inputs). If the "Time sync warning" parameter is enabled and the device is not synchronized, an alarm is raised (that is, the "Status" LED becomes yellow).
Time zone settings	Contains the settings to offset GMT and to define daylight savings time.

Section name	Description
LCD backlight	Contain the parameters to control the LCD panel's behaviour. The light switches off after its set timeout. The "Backlight group" parameter is useful when you have two or more devices close to each other: touching one switches on all devices that have been configured to belong to the same group.

Online data menu

Figure. 5.4.3 - 22. The online data menu.

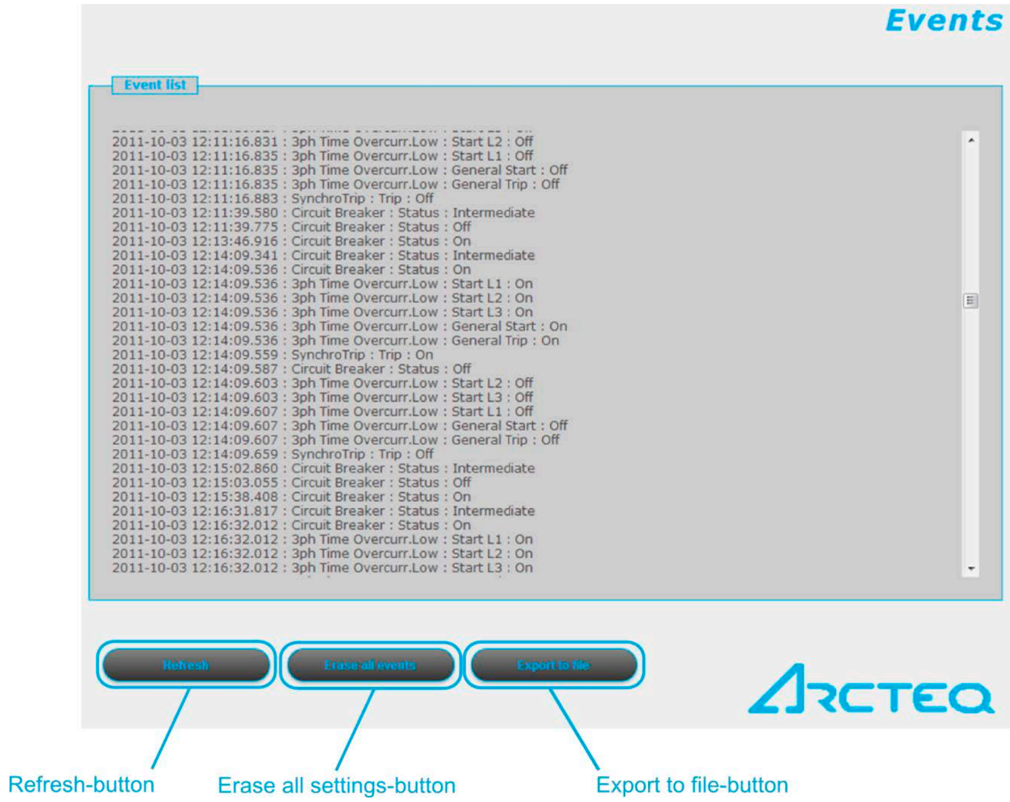
This menu displays the data measured by the device. Each block has their own section, and these sections can be expanded and collapsed individually as needed with the [+] and [–] signs in front of their names. The values on screen are updated every second, which may cause older systems to slow down or halt the browser altogether. All data is strictly read-only, and cannot be modified. If there is a counter on the page, next to it will be a button that resets it.

Binary data is displayed as a checkbox (for example, the "SystemWarning" parameter in the first section in the image above), whereas enumerated data is presented as text information. If you are using a browser compatible with HTML5, analogue measurements are drawn as vectors.

Events menu

This page displays the events that have occured in the device. The events are listed in the following format: [local time] : [function block] : [channel] : [new value].

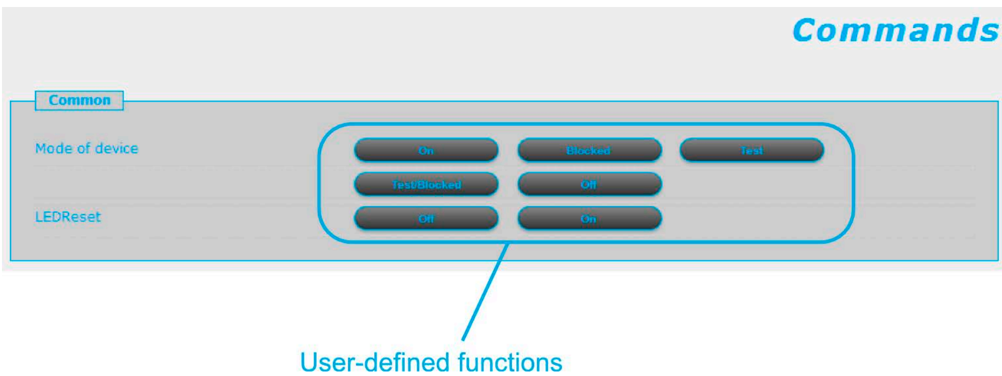
Figure. 5.4.3 - 23. Elements of the events menu.



With the **Refresh** button you can refresh the list displaying the events, the **Erase all events** button clears the list on the screen, and the **Export to file** button downloads the events and saves them as a .txt file.

Commands menu

Figure. 5.4.3 - 24. The commands menu.

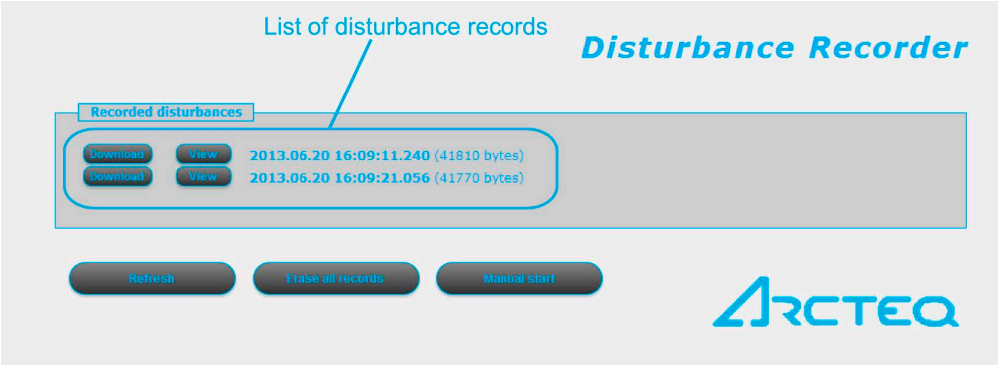


In the commands menu you can instruct the processor to carry out customized, user-defined commands. You can use the various mode buttons (**On**, **Blocked**, **Test**, **Test/Blocked**, **Off**) and LED buttons (**On**, **Off**) to define functions. A status update is always generated with a command, regardless of whether the command was successful or not. If the command was unsuccessful, the device gives the reason for the error.

Disturbance recorder

This page displays a list of the disturbance records that the device has recorded.

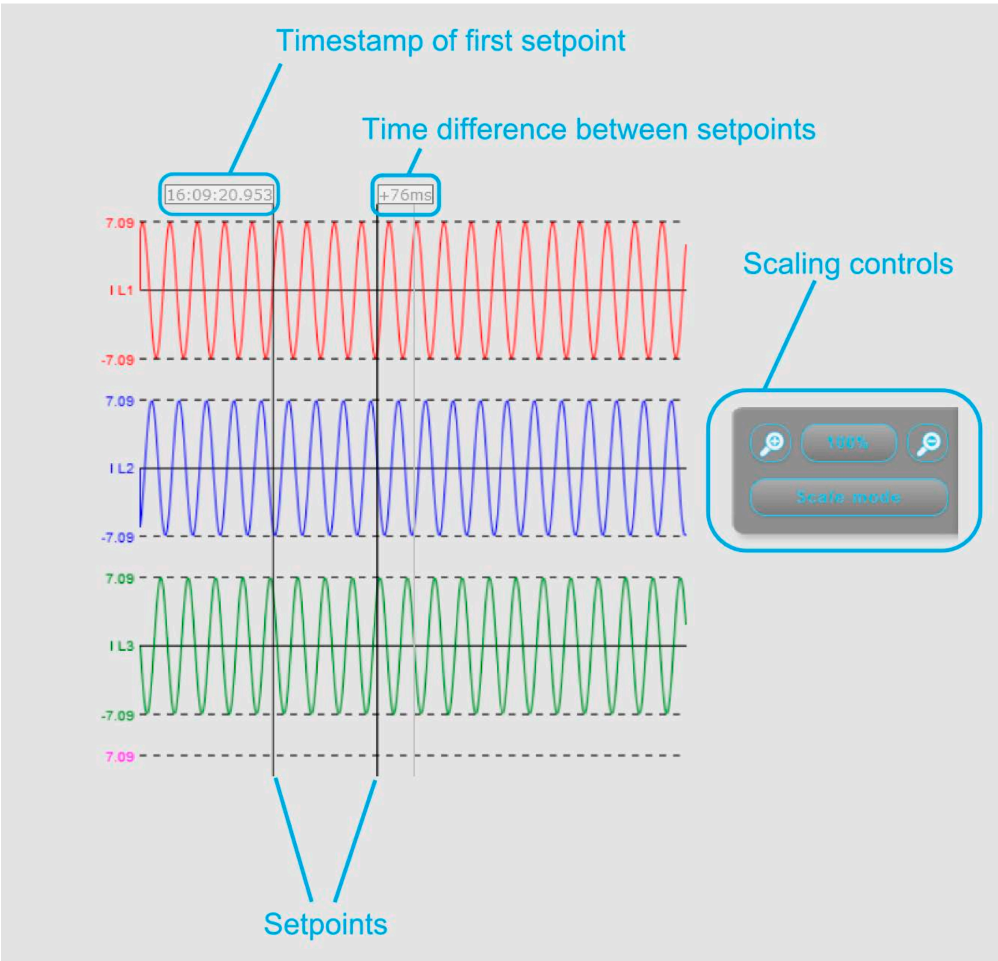
Figure. 5.4.3 - 25. Disturbance recorder.



The "Recorded disturbances" section lists all disturbance records. You can refresh the list with the Refresh button to display any new disturbance records that have occurred after the page was opened or refreshed last. You can also clear the list with the Erase all records button. Additionally, you can create a disturbance record manually by clicking the Manual start button.

There is one one record per line. You can download the chosen record by clicking the Download button on its line; the device downloads you a COMTRADE file which you can then open with any supporting software for further evaluation. You can also click the View button to open a new browser window which then displays a simple preview of the disturbance record (see the image below).

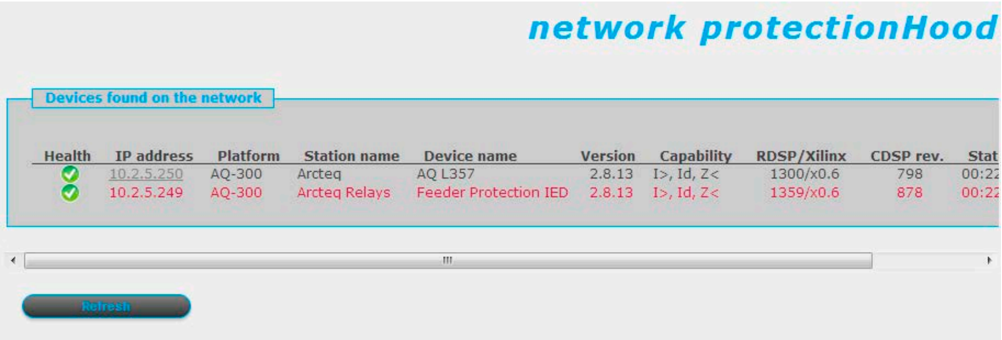
Figure. 5.4.3 - 26. Example of a disturbance record preview.



You can set a setpoint by clicking anywhere on the graph, and the positioning the cursor to a desired second point. The preview then displays the timestamp of the first setpoint, and the time difference between the two setpoints. You can also scale the time axis with the scaling controls (the plus and minus magnifying glasses), or by clicking the Scale mode button to switch between standard and scaled modes. The scaled mode stretches the Y axis of all recorded values.

Network protectionHood

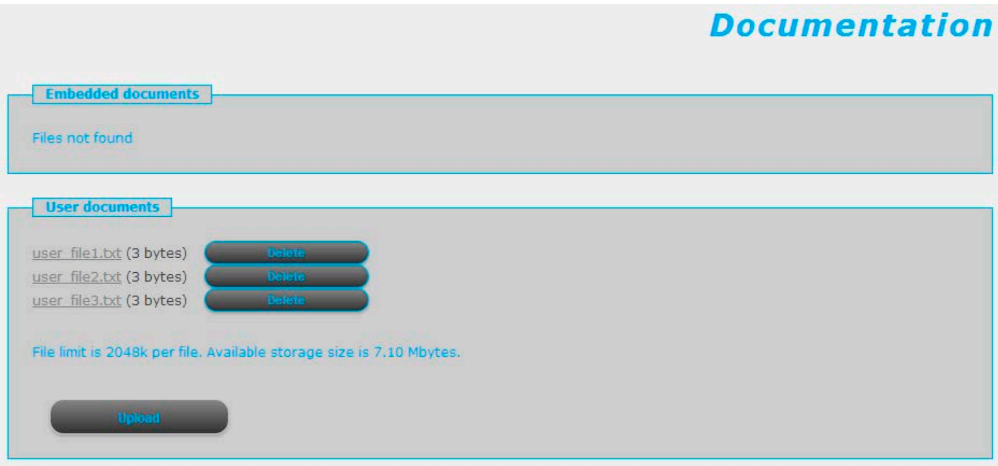
Figure. 5.4.3 - 27. The network protectionHood menu.



This page shows all other devices that are located in the same network with the AQ-300 unit. The page identifies compatible devices and displays information about them, such as their IP address and version. The device that is currently accessed is highlighted in red in the list. You are redirected to other devices by clicking their corresponding links. The Refresh button scans the network for connected devices.

Documentation

Figure. 5.4.3 - 28. The documentation menu.

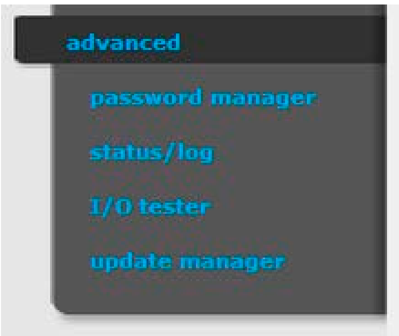


This page displays the documentation files on the device. You can upload other documents and files on the device, which are then saved and can be accessed later. One file can be up to 2048K , and there is storage for up to 8 MB of documentation.

The "Embedded documentation" section displays all the documents that have been preloaded into the device. You cannot delete these. The "User documents" section lists all the files the user has uploaded into the device, and you can delete them with the Delete button. You can upload a selected file with the Upload button. Please ensure that the file size is below the limit and that you have enough storage left before commencing the upload.

Advanced

Figure. 5.4.3 - 29. The Advanced menu.

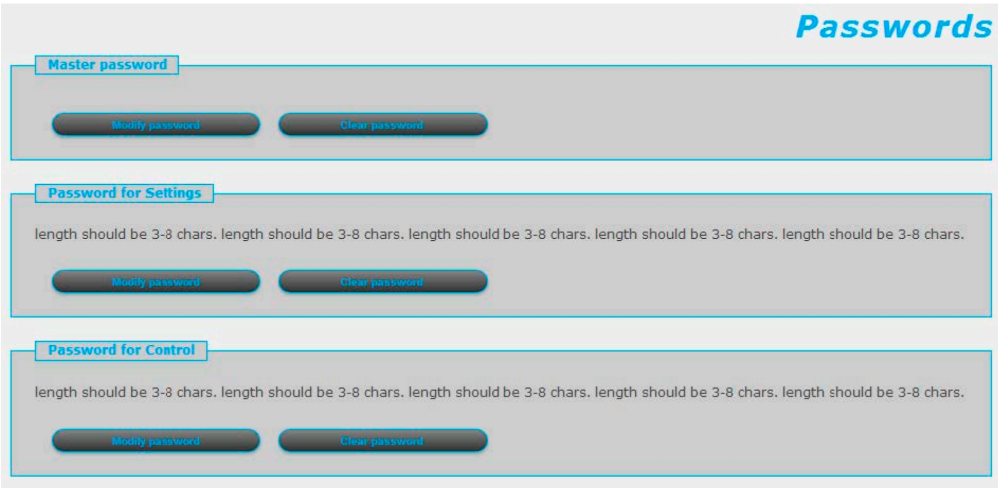


This menu displays the additional, more advanced options. You can set a password request before a user is allowed access to these options.

Password manager

You can modify and clear the three available passwords. The *master password* is used for accessing the Advanced menu. The *password for settings* is required when a user wants to set parameters or settings, or wants to clear counters in the Online data menu. The *password for control* is required when executing commands in the Commands menu. If no password has been created, you can create one with the Modify password button.

Figure. 5.4.3 - 30. Password manager.



Status/log

The Status/log submenu displays information from various logs. The log files are primarily meant for the manufacturer, but a user can also view them.

Figure. 5.4.3 - 31. Status/log.

The **Get report** button generates a .zip file that has all of the log files archived together. The files have valuable information and they can help in analyzing errors and malfunctions; see the table below for the different log types and their contents.

Table. 5.4.3 - 8. Log types.

Log name	Description
Relay CPU	Displays the logged events that are connected to the relay's CPU.
SPORT	Displays the log file from the SPORT communication interface.
System startup	Displays the events that have occurred when the system was started up.
Serial Comm	Displays the log file from the serial communication interface.
LCD display	Displays the log file about the events that have occurred with the LCD display.
IEC 61850	Displays the log file from the IEC 61850 communication interface.
Access	Displays information about the users who have accessed the device remotely through the embedded web browser interface.
Error	Displays the errors that have occurred with the remote user interface.

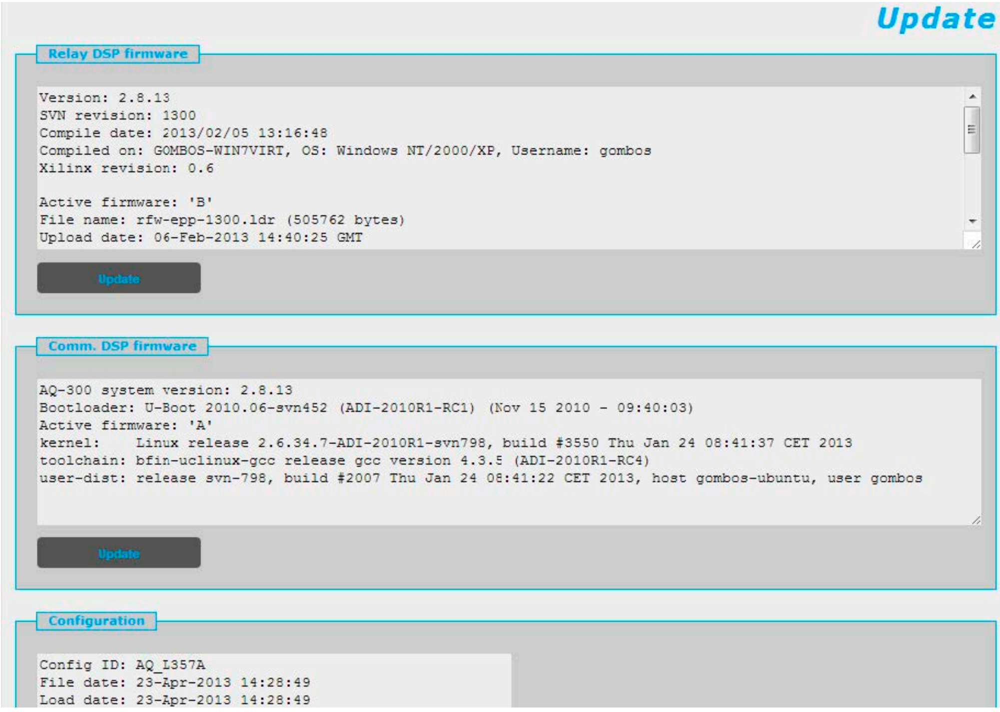
NOTICE!
All log files are in English, regardless of your language selection!

Update manager

When a new version of the firmware is available, it can be updated in this submenu. Click the **Update** button of the correct section to select the new firmware file and upload it into the device. Please make sure that you are updating the right firmware; for example, do not attempt to update the "Relay DSP firmware" section with a "Comm. DSP firmware" file!

This page also displays information about the firmware currently in use as well as of the configuration of the device.

Figure. 5.4.3 - 32. Update manager.



5.4.4 Troubleshooting

Some browsers have a tendency to handle and cache various JavaScript function improperly, and this may cause anomalies and errors in the interface. If you notice improper functionalities, try to clear both the browser history and cache, and refresh the web page.

If this does not clear the problem, please contact Arcteq for further instructions.

6 Software setup

6.1 Functions included in AQ-L3x9

In this chapter are presented the protection and control functions as well as the monitoring functions.

The implemented protection functions are listed in the table below. The function blocks are described in detail in following chapters.

Table. 6.1 - 9. Available protection functions

Function Name	IEC	ANSI	Description
IOC50	I >>>	50	Three-phase instantaneous overcurrent protection
TOC50_low TOC50_high	I> I>>	51	Three-phase time overcurrent protection
IOC50N	I0 >>>	50N	Residual instantaneous overcurrent protection
TOC51N_low TOC51N_high	I0> I0>>	51N	Residual time overcurrent protection
TOC67_low TOC67_high	Idir > Idir >>	67	Directional three-phase overcurrent protection
TOC67N_low TOC67N_high	I0dir > I0dir >>	67N	Directional residual overcurrent protection
INR2	I_{2h} >	68	Inrush detection and blocking
VCB60	I_{ub} >	46	Current unbalance protection
TTR49L	T >	49L	Line thermal overload protection
TOV59_low TOV59_high	U > U >>	59	Definite time overvoltage protection
TUV27_low TUV27_high	U < U <<	27	Definite time undervoltage protection
TOV59N_low TOV59N_high	U0> U0>>	59N	Residual voltage protection
TOF81_high TOF81_low	f > f >>	81O	Overfrequency protection
TUF81_high TUF81_low	f < f <<	81U	Underfrequency protection
FRC81_high FRC81_low	df/dt	81R	Rate of change of frequency protection
BRF50MV	CBFP	50BF	Breaker failure protection
DIFF87L	IdL >	87L	Line differential protection

PLSLIP78	ΔZ/Δt	78	Pole slip protection
SCH85	-	-	Teleprotection
STB50	-	-	Stub protection
DIS21 DIS21_MHO	Z <	21	Distance protection

Table. 6.1 - 10. Available control and monitoring functions

Name	IEC	ANSI	Description
TRC94	-	94	Trip logic
DLD	-	-	Dead line detection
VTS	-	60	Voltage transformer supervision
SYN25	SYNC	25	Synchro-check function Δf, ΔU, Δφ
REC79MV	0 → 1	79	Autoreclosing function
SOTF	-	-	Switch on to fault
DREC	-	-	Disturbance recorder

6.2 Measurements

6.2.1 Current measurement and scaling

If the factory configuration includes a current transformer hardware module, the current input function block is automatically configured among the software function blocks. Separate current input function blocks are assigned to each current transformer hardware module.

A current transformer hardware module is equipped with four special intermediate current transformers. As usual, the first three current inputs receive the three phase currents (IL1, IL2, IL3), the fourth input is reserved for zero sequence current, for the zero sequence current of the parallel line or for any additional current. Accordingly, the first three inputs have common parameters while the fourth current input needs individual setting.

The role of the current input function block is to

- set the required parameters associated to the current inputs,
- deliver the sampled current values for disturbance recording,
- perform the basic calculations
    - Fourier basic harmonic magnitude and angle,
    - True RMS value;
- provide the pre-calculated current values to the subsequent software function blocks,
- deliver the calculated Fourier basic component values for on-line displaying.

The current input function block receives the sampled current values from the internal operating system. The scaling (even hardware scaling) depends on parameter setting, see parameters Rated Secondary I1-3 and Rated Secondary I4. The options to choose from are 1A or 5A (in special applications, 0.2A or 1A). This parameter influences the internal number format and, naturally, accuracy. A small current is processed with finer resolution if 1A is selected.

If needed, the phase currents can be inverted by setting the parameter Starpoint I1-3. This selection applies to each of the channels IL1, IL2 and IL3. The fourth current channel can be inverted by setting the parameter Direction I4. This inversion may be needed in protection functions such as distance protection, differential protection or for any functions with directional decision.

Figure. 6.2.1 - 33. Example connection.

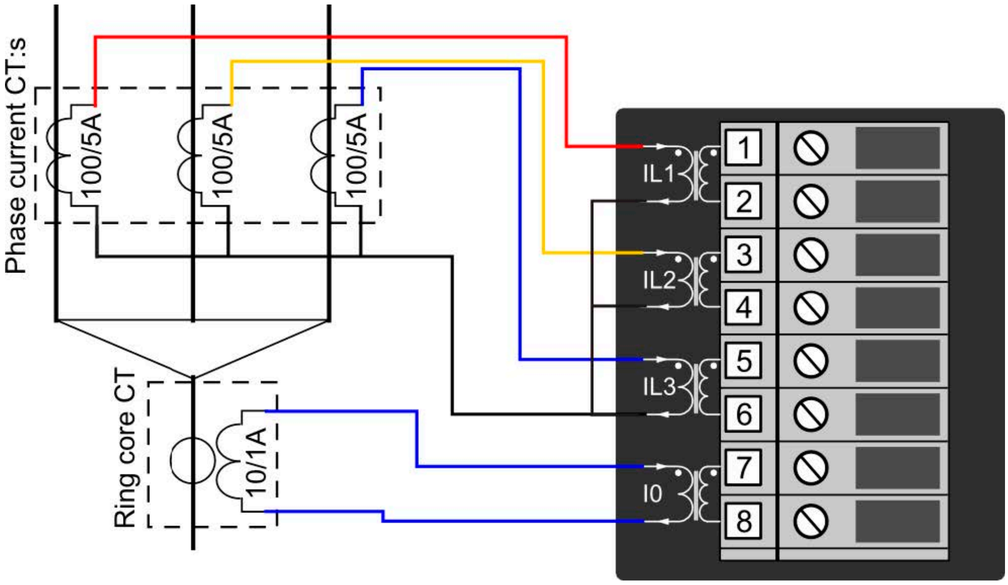


Table. 6.2.1 - 11. Values for the example above.

Phase current CT: CT primary 100A CT secondary 5A	Ring core CT in Input I0: I0CT primary 10A I0CT secondary 1A
Phase current CT secondary currents starpoint is towards the line.	

Figure. 6.2.1 - 34. Example connection with phase currents connectef into summing "Holmgren" connection into the IO residual input.

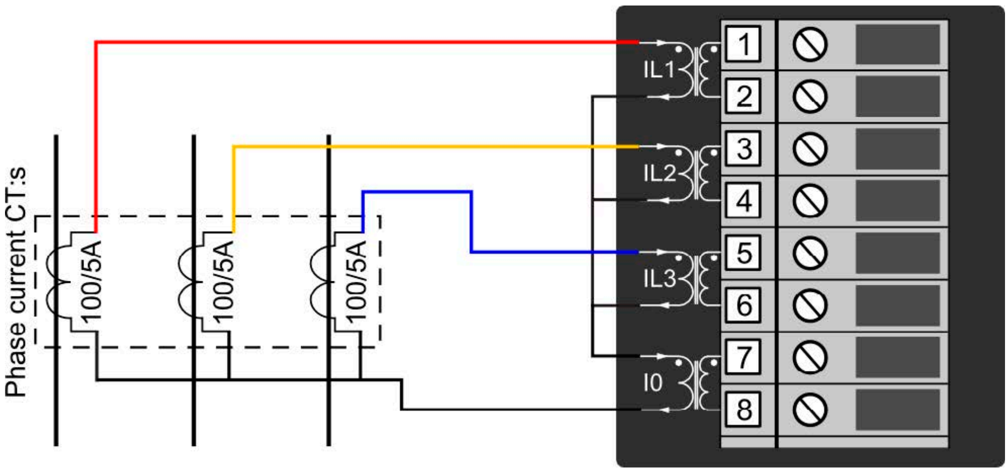


Table. 6.2.1 - 12. Values for the example above.

Phase current CT: CT primary 100A CT secondary 5A	Ring core CT in Input I0: I0CT primary 100A I0CT secondary 5A
Phase currents are connected to summing "Holmgren" connection into the I0 residual input.	

The sampled values are available for further processing and for disturbance recording.

The performed basic calculation results the Fourier basic harmonic magnitude and angle and the true RMS value. These results are processed by subsequent protection function blocks and they are available for on-line displaying as well.

The function block also provides parameters for setting the primary rated currents of the main current transformer (Rated Primary I1-3 and Rated Primary I4). This function block does not need that parameter settings. These values are passed on to function blocks such as displaying primary measured values, primary power calculation, etc.

Table. 6.2.1 - 13. Enumerated parameters of the current input function

Parameter name	Title	Selection range	Default
Rated secondary current of the first three input channels. 1A or 5A is selected by parameter setting, no hardware modification is needed.			
CT4_Ch13Nom_EPar_	Rated Secondary I1-3	1A,5A	1A
Rated secondary current of the fourth input channel. 1A or 5A (0.2A, 1A) is selected by parameter setting, no hardware modification is needed.			
CT4_Ch4Nom_EPar_	Rated Secondary I4	1A,5A (0.2A, 1A)	1A
Definition of the positive direction of the first three currents, given by location of the secondary star connection point			
CT4_Ch13Dir_EPar_	Starpoint I1-3	Line,Bus	Line
Definition of the positive direction of the fourth current, given as normal or inverted			
CT4_Ch4Dir_EPar_	Direction I4	Normal,Inverted	Normal

Table. 6.2.1 - 14. Floating point parameters of the current input function

Parameter name	Title	Dim.	Min	Max	Default
Rated primary current of channel1-3					
CT4_PriI13_FPar_	Rated Primary I1-3	A	100	4000	1000
Rated primary current of channel4					
CT4_PriI4_FPar_	Rated Primary I4	A	100	4000	1000

Table. 6.2.1 - 15. Online measurements of the current input function

Measured value	Dim.	Explanation
Current Ch - I1	A(secondary)	Fourier basic component of the current in channel IL1
Angle Ch - I1	degree	Vector position of the current in channel IL1
Current Ch - I2	A(secondary)	Fourier basic component of the current in channel IL2
Angle Ch - I2	degree	Vector position of the current in channel IL2
Current Ch - I3	A(secondary)	Fourier basic component of the current in channel IL3
Angle Ch - I3	degree	Vector position of the current in channel IL3
Current Ch - I4	A(secondary)	Fourier basic component of the current in channel I4
Angle Ch - I4	degree	Vector position of the current in channel I4

NOTICE!
The scaling of the Fourier basic component is such that if pure sinusoid 1A RMS of the rated frequency is injected, the displayed value is 1A. The displayed value does not depend on the parameter setting values “Rated Secondary”.

NOTICE!
The reference of the vector position depends on the device configuration. If a voltage input module is included, then the reference vector (vector with angle 0 degree) is the vector calculated for the first voltage input channel of the first applied voltage input module. If no voltage input module is configured, then the reference vector (vector with angle 0 degree) is the vector calculated for the first current input channel of the first applied current input module. (The first input module is the one, configured closer to the CPU module.)

6.2.2 Voltage measurement and scaling

If the factory configuration includes a voltage transformer hardware module, the voltage input function block is automatically configured among the software function blocks. Separate voltage input function blocks are assigned to each voltage transformer hardware module.

A voltage transformer hardware module is equipped with four special intermediate voltage transformers. As usual, the first three voltage inputs receive the three phase voltages (UL1, UL2, UL3), the fourth input is reserved for zero sequence voltage or for a voltage from the other side of the circuit breaker for synchro switching.

The role of the voltage input function block is to

- set the required parameters associated to the voltage inputs,
- deliver the sampled voltage values for disturbance recording,
- perform the basic calculations
    - Fourier basic harmonic magnitude and angle,
    - True RMS value;
- provide the pre-calculated voltage values to the subsequent software modules,
- deliver the calculated basic Fourier component values for on-line displaying.

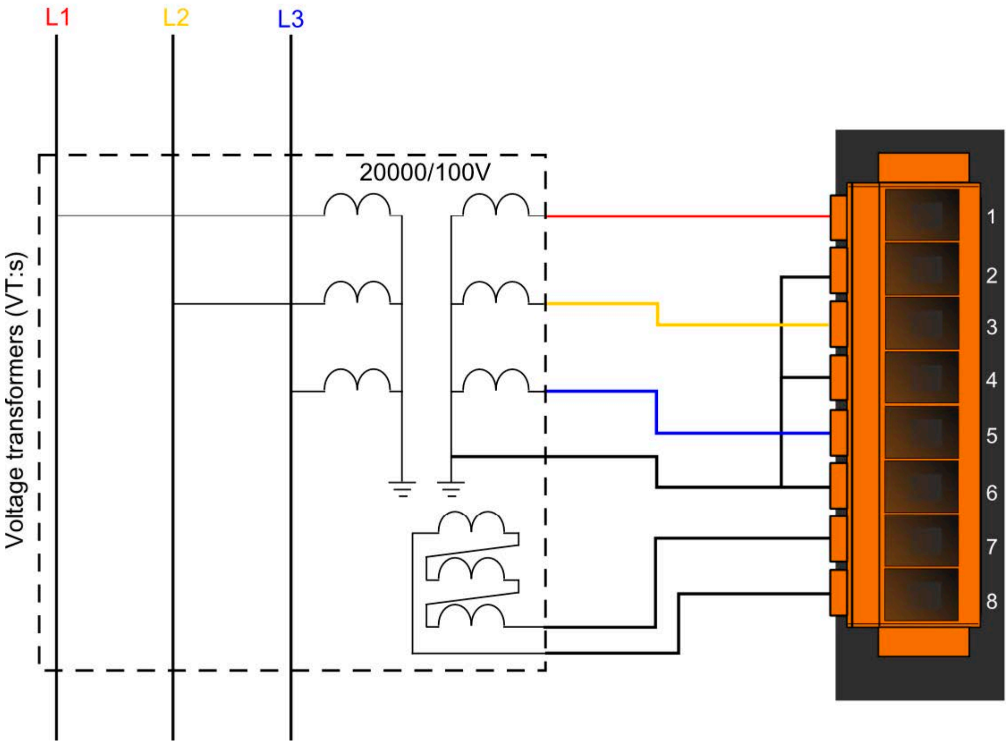
The voltage input function block receives the sampled voltage values from the internal operating system. The scaling (even hardware scaling) depends on a common parameter “Range” for type selection. The options to choose from are 100V or 200V, no hardware modification is needed. A small voltage is processed with finer resolution if 100V is selected. This parameter influences the internal number format and, naturally, accuracy.

There is a correction factor available if the rated secondary voltage of the main voltage transformer (e.g. 110V) does not match the rated input of the device. The related parameter is “VT correction“. As an example: if the rated secondary voltage of the main voltage transformer is 110V, then select Type 100 for the parameter “Range” and the required value to set here is 110%.

The connection of the first three VT secondary windings must be set to reflect actual physical connection of the main VTs. The associated parameter is “Connection U1-3“. The selection can be: Ph-N, Ph-Ph or Ph-N-Isolated.

The Ph-N option is applied in solidly grounded networks, where the measured phase voltage is never above 1.5-Un. In this case the primary rated voltage of the VT must be the value of the rated PHASE-TO-NEUTRAL voltage.

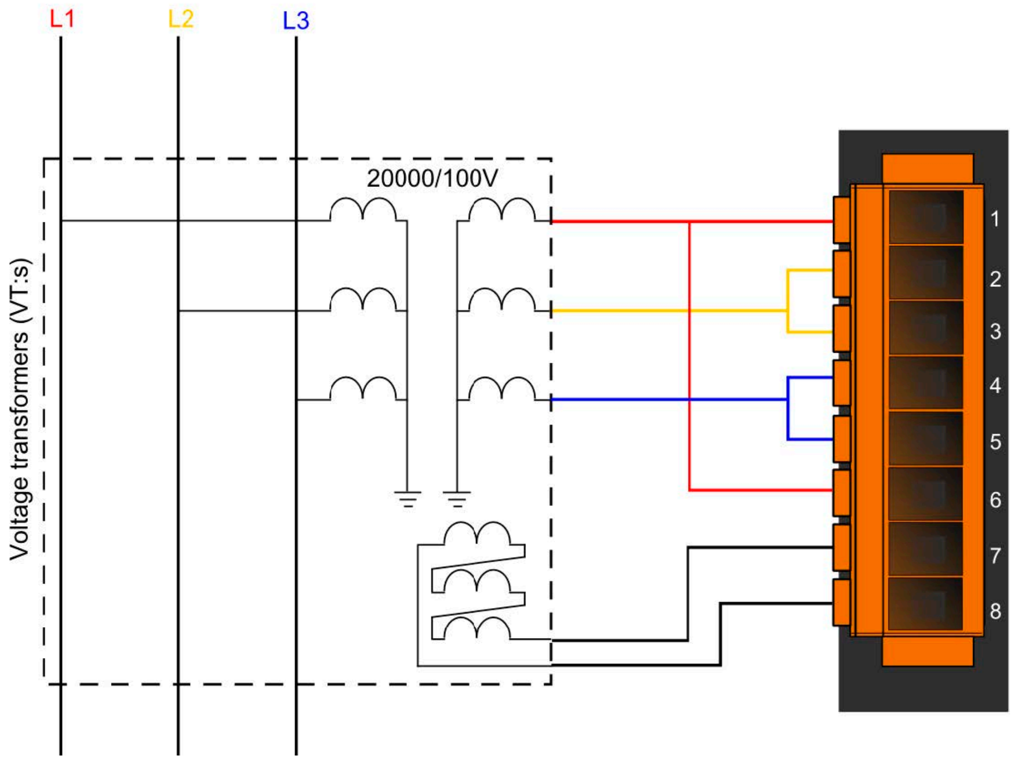
Figure. 6.2.2 - 35. Phase to neutral connection. Connection U1-3.



Ph-N Voltage: Rated Primary U1-3: 11.55kV (=20kV/√3) Range: Type 100	Residual voltage: Rated Primary U4: 11.54A

If phase-to-phase voltage is connected to the VT input of the device, then the Ph-Ph option is to be selected. Here, the primary rated voltage of the VT must be the value of the rated PHASE-TO-PHASE voltage. This option must not be selected if the distance protection function is supplied from the VT input.

Figure. 6.2.2 - 36. Phase-to-phase connection.



Ph-N Voltage: Rated Primary U1-3: 20kV Range: Type 100	Residual voltage: Rated Primary U4: 11.54A (=20kV/√3)

The fourth input is reserved for zero sequence voltage or for a voltage from the other side of the circuit breaker for synchron switching. Accordingly, the connected voltage must be identified with parameter setting “Connection U4“. Here, phase-to-neutral or phase-to-phase voltage can be selected: Ph-N, Ph-Ph.

If needed, the phase voltages can be inverted by setting the parameter “Direction U1-3“. This selection applies to each of the channels UL1, UL2 and UL3. The fourth voltage channel can be inverted by setting the parameter “Direction U4“. This inversion may be needed in protection functions such as distance protection or for any functions with directional decision, or for checking the voltage vector positions.

These modified sampled values are available for further processing and for disturbance recording.

The function block also provides parameters for setting the primary rated voltages of the main voltage transformers. This function block does not need that parameter setting but these values are passed on to function blocks such as displaying primary measured values, primary power calculation, etc.

Table. 6.2.2 - 16. Enumerated parameters of the voltage input function

Parameter name	Title	Selection range	Default
Rated secondary voltage of the input channels. 100 V or 200V type is selected by parameter setting, no hardware modification is needed.			
VT4_Type_EPar_	Range	Type 100,Type 200	Type 100
Connection of the first three voltage inputs (main VT secondary)			

Parameter name	Title	Selection range	Default
VT4_Ch13Nom_EPar_	Connection U1-3	Ph-N, Ph-Ph, Ph-N-Isolated	Ph-N
Selection of the fourth channel input: phase-to-neutral or phase-to-phase voltage			
VT4_Ch4Nom_EPar_	Connection U4	Ph-N,Ph-Ph	Ph-Ph
Definition of the positive direction of the first three input channels, given as normal or inverted			
VT4_Ch12Dir_EPar_	Direction U1-3	Normal,Inverted	Normal
Definition of the positive direction of the fourth voltage, given as normal or inverted			
VT4_Ch4Dir_EPar_	Direction U4	Normal,Inverted	Normal

Table. 6.2.2 - 17. Integer parameters of the voltage input function

Parameter name	Title	Unit	Min	Max	Step	Default
Voltage correction						
VT4_CorrFact_IPar_	VT correction	%	100	115	1	100

Table. 6.2.2 - 18. Float point parameters of the voltage input function

Parameter name	Title	Dim.	Min	Max	Default
Rated primary voltage of channel1					
VT4_PriU1_FPar_	Rated Primary U1	kV	1	1000	100
Rated primary voltage of channel2					
VT4_PriU2_FPar_	Rated Primary U2	kV	1	1000	100
Rated primary voltage of channel3					
VT4_PriU3_FPar_	Rated Primary U3	kV	1	1000	100
Rated primary voltage of channel4					
VT4_PriU4_FPar_	Rated Primary U4	kV	1	1000	100

NOTICE!
The rated primary voltage of the channels is not needed for the voltage input function block itself. These values are passed on to the subsequent function blocks.

Table. 6.2.2 - 19. On-line measured analogue values of the voltage input function

Measured value	Dim.	Explanation
Voltage Ch - U1	V(secondary)	Fourier basic component of the voltage in channel UL1
Angle Ch - U1	degree	Vector position of the voltage in channel UL1
Voltage Ch - U2	V(secondary)	Fourier basic component of the voltage in channel UL2

Measured value	Dim.	Explanation
Angle Ch - U2	degree	Vector position of the voltage in channel UL2
Voltage Ch - U3	V(secondary)	Fourier basic component of the voltage in channel UL3
Angle Ch - U3	degree	Vector position of the voltage in channel UL3
Voltage Ch - U4	V(secondary)	Fourier basic component of the voltage in channel U4
Angle Ch - U4	degree	Vector position of the voltage in channel U4

NOTICE!
The scaling of the Fourier basic component is such if pure sinusoid 57V RMS of the rated frequency is injected, the displayed value is 57V. The displayed value does not depend on the parameter setting values "Rated Secondary".

NOTICE!
The reference vector (vector with angle 0 degree) is the vector calculated for the first voltage input channel of the first applied voltage input module. The first voltage input module is the one, configured closer to the CPU module.

6.2.3 Line measurement

The input values of the AQ300 devices are the secondary signals of the voltage transformers and those of the current transformers.

These signals are pre-processed by the "Voltage transformer input" function block and by the "Current transformer input" function block. The pre-processed values include the Fourier basic harmonic phasors of the voltages and currents and the true RMS values. Additionally, it is in these function blocks that parameters are set concerning the voltage ratio of the primary voltage transformers and current ratio of the current transformers.

Based on the pre-processed values and the measured transformer parameters, the "Line measurement" function block calculates - depending on the hardware and software configuration - the primary RMS values of the voltages and currents and some additional values such as active and reactive power, symmetrical components of voltages and currents. These values are available as primary quantities and they can be displayed on the on-line screen of the device or on the remote user interface of the computers connected to the communication network and they are available for the SCADA system using the configured communication system.

Reporting the measured values and the changes

It is usual for the SCADA systems that they sample the measured and calculated values in regular time periods and additionally they receive the changed values as reports at the moment when any significant change is detected in the primary system. The "Line measurement" function block is able to perform such reporting for the SCADA system.

Operation of the line measurement function block

The inputs of the line measurement function are

- the Fourier components and true RMS values of the measured voltages and currents
- frequency measurement
- parameters.

The outputs of the line measurement function are

- displayed measured values
- reports to the SCADA system.

NOTICE!
The scaling values are entered as parameter setting for the “Voltage transformer input” function block and for the “Current transformer input” function block.

Measured values

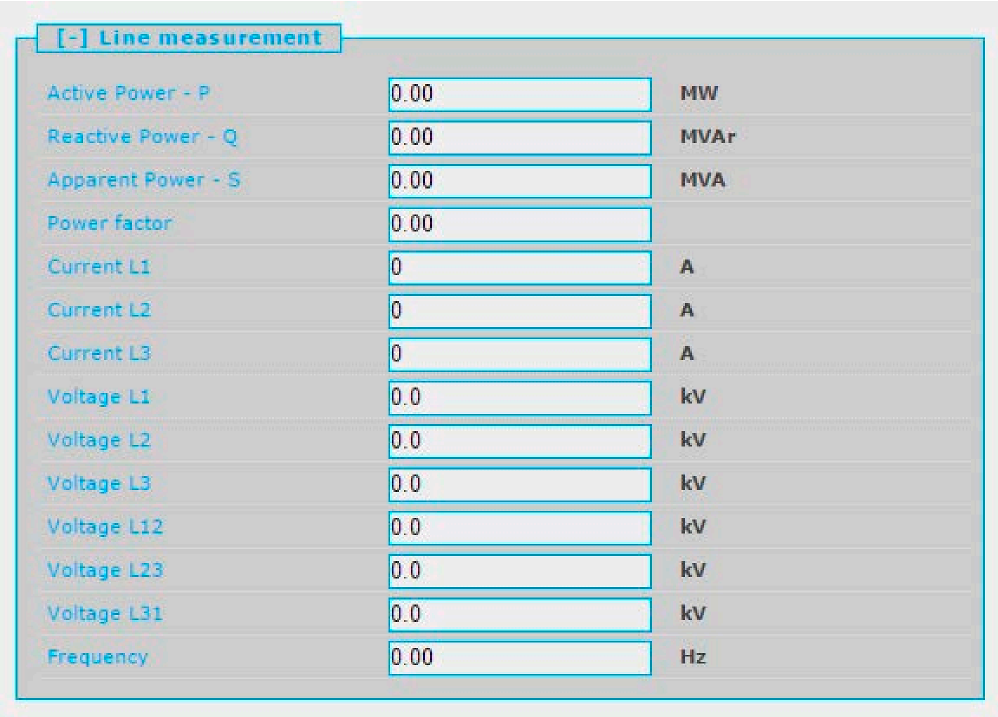
The measured values of the line measurement function depend on the hardware configuration. As an example, table shows the list of the measured values available in a configuration for solidly grounded networks.

Table. 6.2.3 - 20. Example: Measured values in a configuration for solidly grounded networks

Measured value	Explanation
MXU_P_OLM_	Active Power — P (Fourier base harmonic value)
MXU_Q_OLM_	Reactive Power — Q (Fourier base harmonic value)
MXU_S_OLM	Apparent Power — S (Fourier base harmonic value)
MXU_I1_OLM_	Current L1
MXU_I2_OLM_	Current L2
MXU_I3_OLM_	Current L3
MXU_U1_OLM_	Voltage L1
MXU_U2_OLM_	Voltage L2
MXU_U3_OLM_	Voltage L3
MXU_U12_OLM_	Voltage L12
MXU_U23_OLM_	Voltage L23
MXU_U31_OLM_	Voltage L31
MXU_f_OLM_	Frequency

Another example is in figure, where the measured values available are shown as on-line information in a configuration for compensated networks.

Figure. 6.2.3 - 37. Measured values in a configuration for compensated networks.



The available quantities are described in the configuration description documents.

Reporting the measured values and the changes

For reporting, additional information is needed, which is defined in parameter setting. As an example, in a configuration for solidly grounded networks the following parameters are available:

Table. 6.2.3 - 21. The enumerated parameters of the line measurement function.

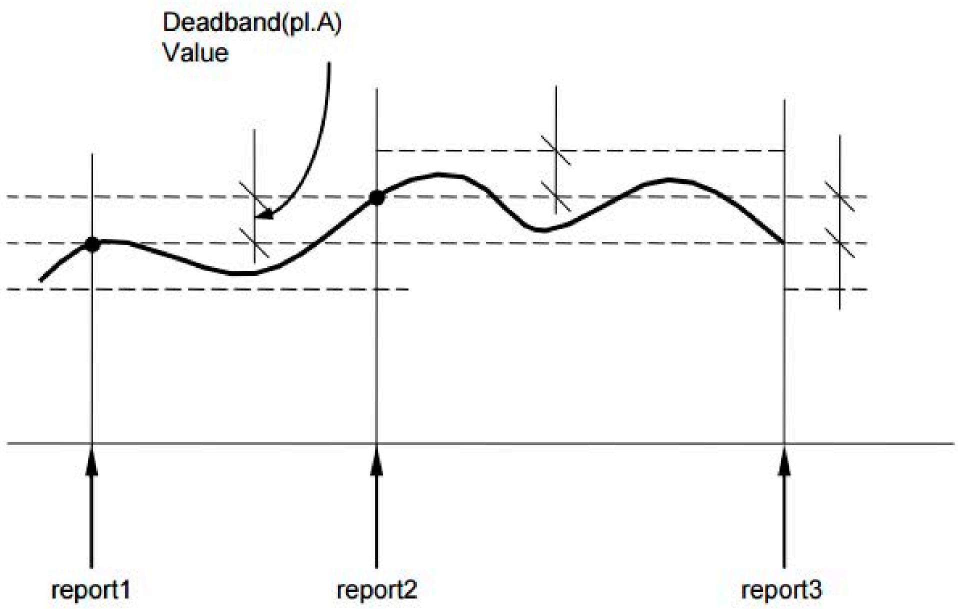
Parameter name	Title	Selection range	Default
Selection of the reporting mode for active power measurement			
MXU_PRepMode_EPar_	Operation ActivePower	Off, Amplitude, Integrated	Amplitude
Selection of the reporting mode for reactive power measurement			
MXU_QRepMode_EPar_	Operation ReactivePower	Off, Amplitude, Integrated	Amplitude
Selection of the reporting mode for apparent power measurement			
MXU_SRepMode_EPar_	Operation ApparPower	Off, Amplitude, Integrated	Amplitude
Selection of the reporting mode for current measurement			
MXU_IRepMode_EPar_	Operation Current	Off, Amplitude, Integrated	Amplitude
Selection of the reporting mode for voltage measurement			
MXU_URepMode_EPar_	Operation Voltage	Off, Amplitude, Integrated	Amplitude
Selection of the reporting mode for frequency measurement			
MXU_fRepMode_EPar_	Operation Frequency	Off, Amplitude, Integrated	Amplitude

The selection of the reporting mode items is explained in next chapters.

"Amplitude" mode of reporting

If the “Amplitude” mode is selected for reporting, a report is generated if the measured value leaves the deadband around the previously reported value. As an example, the figure below shows that the current becomes higher than the value reported in “report1” PLUS the Deadband value, this results “report2”, etc.

Figure. 6.2.3 - 38. Reporting when Amplitude mode is selected.



For this mode of operation, the Deadband parameters are explained in table below.

The “Range” parameters in the table are needed to evaluate a measurement as “out-of-range”.

Table. 6.2.3 - 22. The enumerated parameters of the line measurement function.

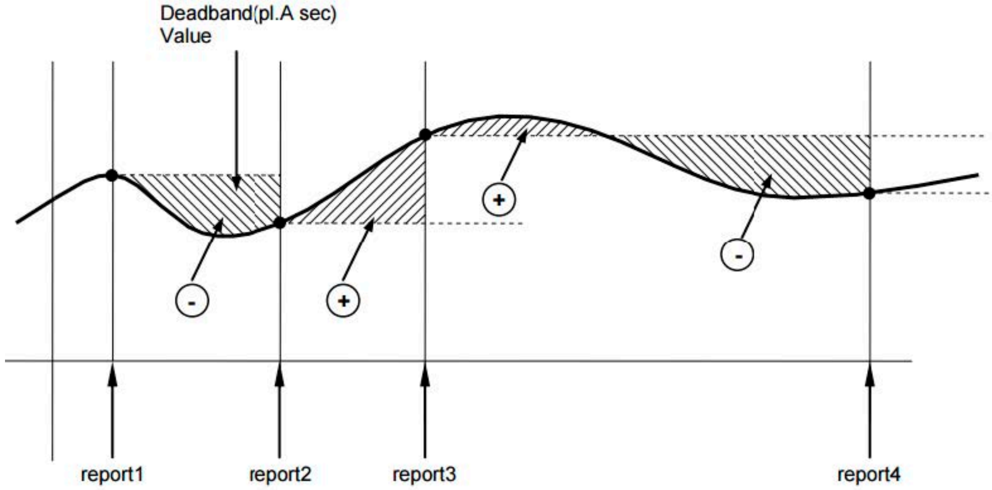
Parameter name	Title	Dim.	Min	Max	Step	Default
Deadband value for the active power						
MXU_PDeadB_FPar_	Deadband value - P	MW	0.1	100000	0.01	10
Range value for the active power						
MXU_PRange_FPar_	Range value - P	MW	1	100000	0.01	500
Deadband value for the reactive power						
MXU_QDeadB_FPar_	Deadband value - Q	MVar	0.1	100000	0.01	10
Range value for the reactive power						
MXU_QRange_FPar_	Range value - Q	MVar	1	100000	0.01	500
Deadband value for the apparent power						
MXU_SDeadB_FPar_	Deadband value - S	MVA	0.1	100000	0.01	10

Parameter name	Title	Dim.	Min	Max	Step	Default
Range value for the apparent power						
MXU_SRange_FPar_	Range value - S	MVA	0.1	100000	0.01	500
Deadband value for the current						
MXU_IDeadB_FPar_	Deadband value - I	A	1	2000	1	10
Range value for the current						
MXU_IRange_FPar_	Range value - I	A	1	5000	1	500
Deadband value for the phase-to-neutral voltage						
MXU_UPhDeadB_FPar_	Deadband value - U ph-N	kV	0.1	100	0.01	1
Range value for the phase-to-neutral voltage						
MXU_UPhRange_FPar_	Range value - U ph-N	kV	1	1000	0.1	231
Deadband value for the phase-to-phase voltage						
MXU_UPPDeadB_FPar_	Deadband value - U ph-ph	kV	0.1	100	0.01	1
Range value for the phase-to-phase voltage						
MXU_UPPRange_FPar_	Range value - U ph-ph	kV	1	1000	0.1	400
Deadband value for the frequency						
MXU_fDeadB_FPar_	Deadband value - f	Hz	0.01	1	0.01	0.02
Range value for the frequency						
MXU_fRange_FPar_	Range value - f	Hz	0.05	10	0.01	5

"Integral" mode of reporting

If the “Integrated” mode is selected for reporting, a report is generated if the time integral of the measured value since the last report gets becomes larger, in the positive or negative direction, then the (deadband*1sec) area. As an example, the figure below shows that the integral of the current in time becomes higher than the Deadband value multiplied by 1sec, this results “report2”, etc.

Figure. 6.2.3 - 39. Reporting when Integrated mode is selected.



Periodic reporting

Periodic reporting is generated independently of the changes of the measured values when the defined time period elapses.

Table. 6.2.3 - 23. The floating-point parameters of the line measurement function

Parameter name	Title	Dim.	Min	Max	Step	Default
Deadband value for the active power						
MXU_PDeadB_FPar_	Deadband value - P	MW	0.1	100000	0.01	10
Range value for the active power						
MXU_PRange_FPar_	Range value - P	MW	1	100000	0.01	500
Deadband value for the reactive power						
MXU_QDeadB_FPar_	Deadband value - Q	MVar	0.1	100000	0.01	10
Range value for the reactive power						
MXU_QRange_FPar_	Range value - Q	MVar	1	100000	0.01	500
Deadband value for the apparent power						
MXU_SDeadB_FPar_	Deadband value - S	MVA	0.1	100000	0.01	10
Range value for the apparent power						
MXU_SRange_FPar_	Range value - S	MVA	0.1	100000	0.01	500
Deadband value for the current						
MXU_IDeadB_FPar_	Deadband value - I	A	1	2000	1	10
Range value for the current						
MXU_IRange_FPar_	Range value - I	A	1	5000	1	500

Parameter name	Title	Dim.	Min	Max	Step	Default
Deadband value for the phase-to-neutral voltage						
MXU_UPhDeadB_FPar_	Deadband value - U ph-N	kV	0.1	100	0.01	1
Range value for the phase-to-neutral voltage						
MXU_UPhRange_FPar_	Range value - U ph-N	kV	1	1000	0.1	231
Deadband value for the phase-to-phase voltage						
MXU_UPPDeadB_FPar_	Deadband value - U ph-ph	kV	0.1	100	0.01	1
Range value for the phase-to-phase voltage						
MXU_UPPRange_FPar_	Range value - U ph-ph	kV	1	1000	0.1	400
Deadband value for the frequency						
MXU_fDeadB_FPar_	Deadband value - f	Hz	0.01	1	0.01	0.02
Range value for the frequency						
MXU_fRange_FPar_	Range value - f	Hz	0.05	10	0.01	5

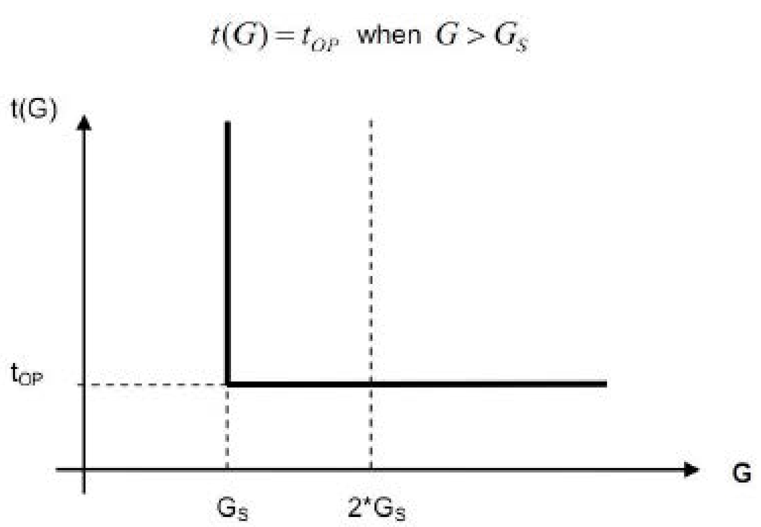
If the reporting time period is set to 0, then no periodic reporting is performed for this quantity. All reports can be disabled for a quantity if the reporting mode is set to “Off”.

6.3 Protection functions

6.3.1 Three-phase instantaneous overcurrent protection (I>; 50/51)

The instantaneous overcurrent protection function operates according to instantaneous characteristics, using the three sampled phase currents. The setting value is a parameter, and it can be doubled with dedicated input binary signal. The basic calculation can be based on peak value selection or on Fourier basic harmonic calculation, according to the parameter setting.

Figure. 6.3.1 - 40. Operating characteristics of the instantaneous overcurrent protection function.



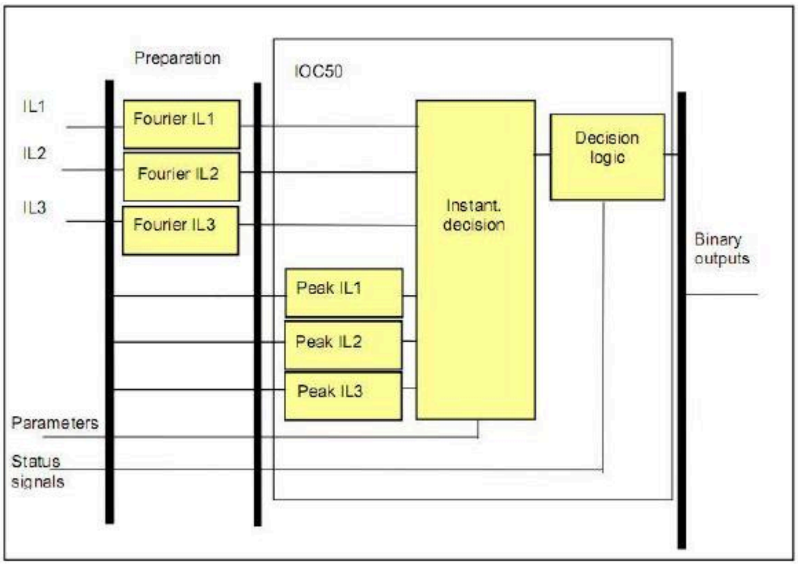
The variables in the image above are:

- t_{OP} (seconds) = theoretical operating time if G>G_S (without additional time delay)
- G = measured peak value or Fourier base harmonic of the phase currents
- G_S = pick-up setting value

The structure of the algorithm consists of following modules. Fourier calculation module calculates the RMS values of the Fourier components of the residual current. Peak selection module is an alternative for the Fourier calculation module and the peak selection module selects the peak values of the phase currents individually. Instantaneous decision module compares the peak- or Fourier basic harmonic components of the phase currents into the setting value. Decision logic module generates the trip signal of the function.

In the figure below. is presented the structure of the instantaneous overcurrent algorithm.

Figure. 6.3.1 - 41. The structure of the function's algorithm.



The algorithm generates a trip command without additional time delay based on the Fourier components of the phase currents or peak values of the phase currents in case if the user set pick-up value is exceeded. The operation of the function is phase wise and it allows each phase to be tripped separately. Standard operation is three poles.

The function includes a blocking signal input which can be configured by user from either IED internal binary signals or IED binary inputs through the programmable logic.

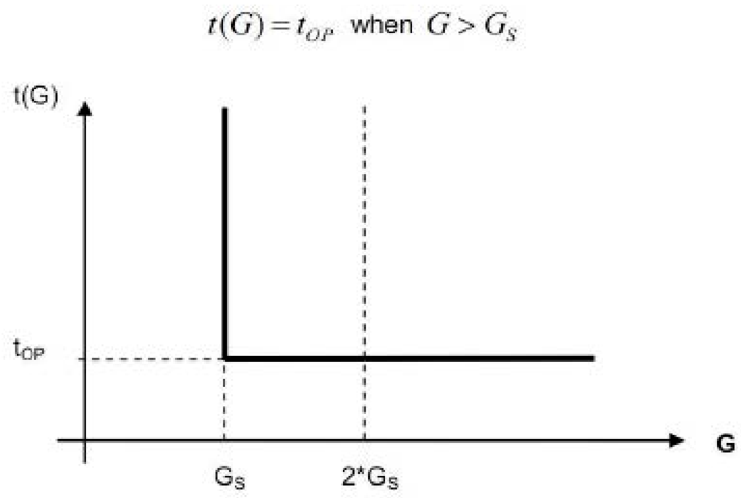
Table. 6.3.1 - 24. Setting parameters of the instantaneous overcurrent protection function.

Parameter	Setting value / range	Step	Default	Description
Operation	Off Peak value Fundamental value	-	Peak value	Operating mode selection of the function. Can be disabled, operating based into measured current peak values or operating based into calculated current fundamental frequency RMS values.
Start current	20…3000 %In	1 %In	200 %In	Pick-up setting of the function.

6.3.2 Residual instantaneous overcurrent protection (I0>; 50N/51N)

The residual instantaneous overcurrent protection function operates according to instantaneous characteristics, using the residual current (IN=3Io). The setting value is a parameter, and it can be doubled with dedicated input binary signal. The basic calculation can be based on peak value selection or on Fourier basic harmonic calculation, according to the parameter setting.

Figure. 6.3.2 - 42. Operating characteristics of the residual instantaneous overcurrent protection function.



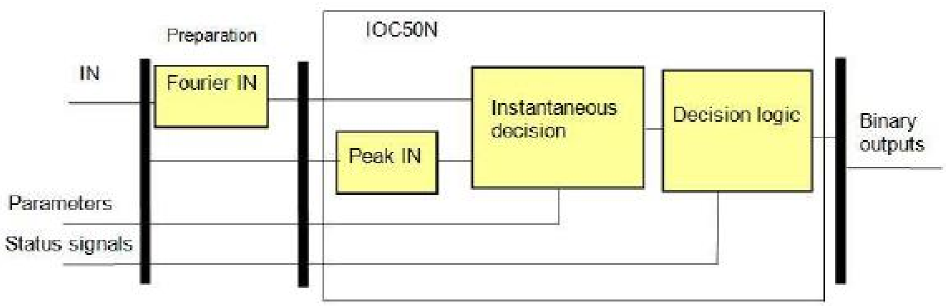
The variables in the image above are:

- t_{OP} (seconds) = theoretical operating time if $G>G_S$ (without additional time delay)
- G = measured peak value or Fourier base harmonic of the residual current
- G_S = pick-up setting value

The structure of the algorithm consists of following modules. Fourier calculation module calculates the RMS values of the Fourier components of the residual current. Peak selection module is an alternative for the Fourier calculation module and the peak selection module selects the peak values of the residual currents individually. Instantaneous decision module compares the peak- or Fourier basic harmonic components of the phase currents into the setting value. Decision logic module generates the trip signal of the function.

Below is presented the structure of the instantaneous residual overcurrent algorithm.

Figure. 6.3.2 - 43. The structure of the residual instantaneous overcurrent algorithm.



The algorithm generates a trip command without additional time delay based on the Fourier components of the phase currents or peak values of the phase currents in case if the user set pick-up value is exceeded. The operation of the function is phase wise and it allows each phase to be tripped separately. Standard operation is three poles.

The function includes a blocking signal input which can be configured by user from either IED internal binary signals or IED binary inputs through the programmable logic.

Table. 6.3.2 - 25. Setting parameters of the residual instantaneous overcurrent protection function.

Parameter	Setting value / range	Step	Default	Description
Operation	Off Peak value Fundamental value	-	Peak value	Operating mode selection of the function. Can be disabled, operating based into measured current peak values or operating based into calculated current fundamental frequency RMS values.
Start current	10…400 %In	1 %In	200 %In	Pick-up setting of the function.

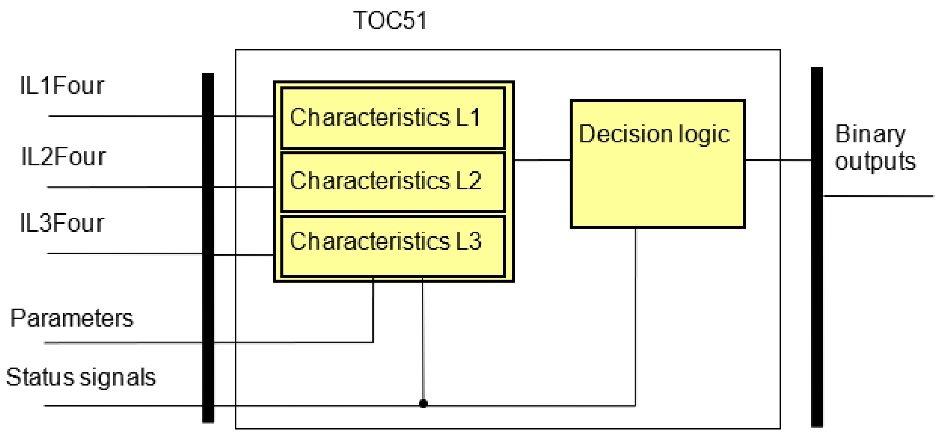
6.3.3 Three-phase time overcurrent protection (I>; 50/51)

Three phase time overcurrent function includes the definite time and IDMT characteristics according to the IEC and IEEE standards. The function measures the fundamental Fourier components of the measured three phase currents.

The structure of the algorithm consists of following modules. Fourier calculation module calculates the RMS values of the Fourier components of the 3-phase currents. Characteristics module compares the Fourier basic harmonic components of the phase currents into the setting value. Decision logic module generates the trip signal of the function.

In the figure below is presented the structure of the time overcurrent algorithm.

Figure. 6.3.3 - 44. The structure of the time overcurrent algorithm.



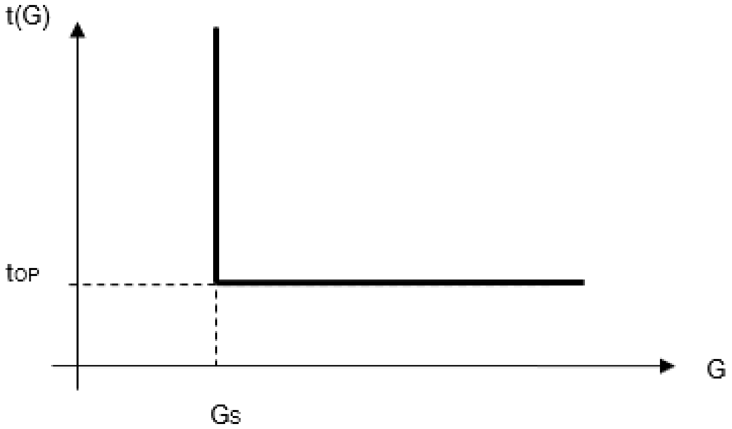
The algorithm generates a start signal based on the Fourier components of the phase currents or peak values of the phase currents in case if the user set pick-up value is exceeded. Trip signal is generated based into the selected definite time- or IDMT additional time delay is passed from the start conditions. The operation of the function is phase wise and it allows each phase to be tripped separately. Standard operation is three poles.

The function includes a blocking signal input which can be configured by user from either IED internal binary signals or IED binary inputs through the programmable logic.

Operating characteristics of the definite time is presented in the figure below.

Figure. 6.3.3 - 45. Operating characteristics of the instantaneous overcurrent protection function.

$$t(G) = t_{OP} \text{ when } G > G_S$$



The variables in the image above are:

- t_{OP} (seconds) = theoretical operating time if $G>G_S$ (without additional time delay)
- G = measured peak value or Fourier base harmonic of the phase currents
- G_S = pick-up setting value

IDMT operating characteristics depend on the selected curve family and curve type. All of the available IDMT characteristics follow

$$t(G) = TMS\left[\frac{k}{\left(\frac{G}{G_S}\right)^{\propto} - 1} + c\right]$$

The variables of the equation above are:

- t(G) (seconds) = theoretical operate time with constant value of G, when $G>G_S$
- k, c = contants characterizing the selected curve
- α = constant characterizing the selected curve
- G = measured value of the Fourier base harmonic of the phase currents
- G_S = pick-up setting value
- TMS = time dial setting / preset time multiplier

The parameters and operating curve types follow corresponding standards presented in the table below.

Table. 6.3.3 - 26. Parameters and operating curve types for the IDMT characteristics.

Curve family	Characteristics	k_r	c	α
IEC	NI (normally inverse)	0.14	0	0.02
IEC	VI (very inverse)	13.5	0	1
IEC	EI (extremely inverse)	80	0	2
IEC	LTI (long time inverse)	120	0	1
IEEE/ANSI	NI (normally inverse)	0.0086	0.0185	0.02
IEEE/ANSI	MI (moderately inverse)	0.0515	0.1140	0.02
IEEE/ANSI	VI (very inverse)	19.61	0.491	2
IEEE/ANSI	EI (extremely inverse)	28.2	0.1217	2
IEEE/ANSI	LTI (long time inverse)	0.086	0.185	0.02
IEEE/ANSI	LTVI (long time, very inverse)	28.55	0.712	2
IEEE/ANSI	LTEI (long time, extremely inverse)	64.07	0.250	2

In following figures the characteristics of IDMT curves are presented with minimum and maximum pick-up settings in respect of the IED measuring range.

Figure. 6.3.3 - 46. IEC - NI operating curves with minimum and maximum pick-up settings and TMS settings from 0.05 to 20.

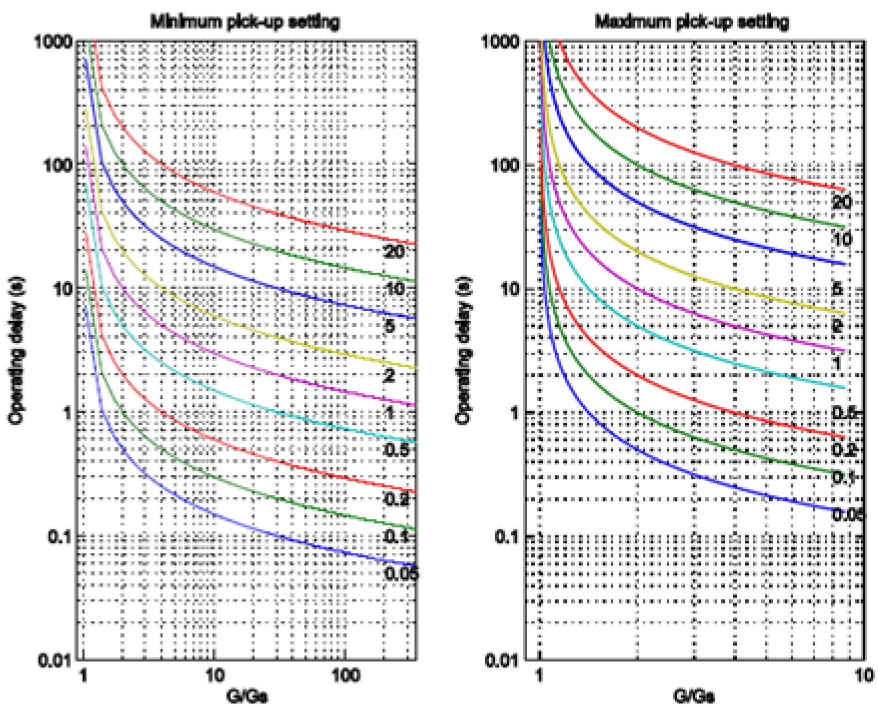


Figure. 6.3.3 - 47. IEC - VI operating curves with minimum and maximum pick-up settings and TMS settings from 0.05 to 20.

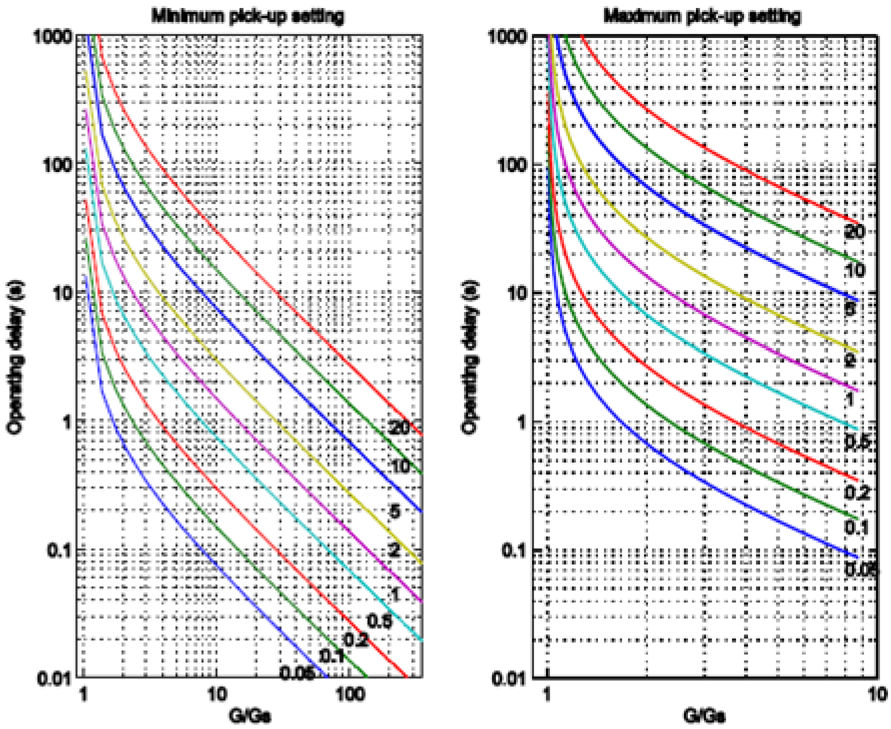


Figure. 6.3.3 - 48. IEC - EI operating curves with minimum and maximum pick-up settings and TMS settings from 0.05 to 20.

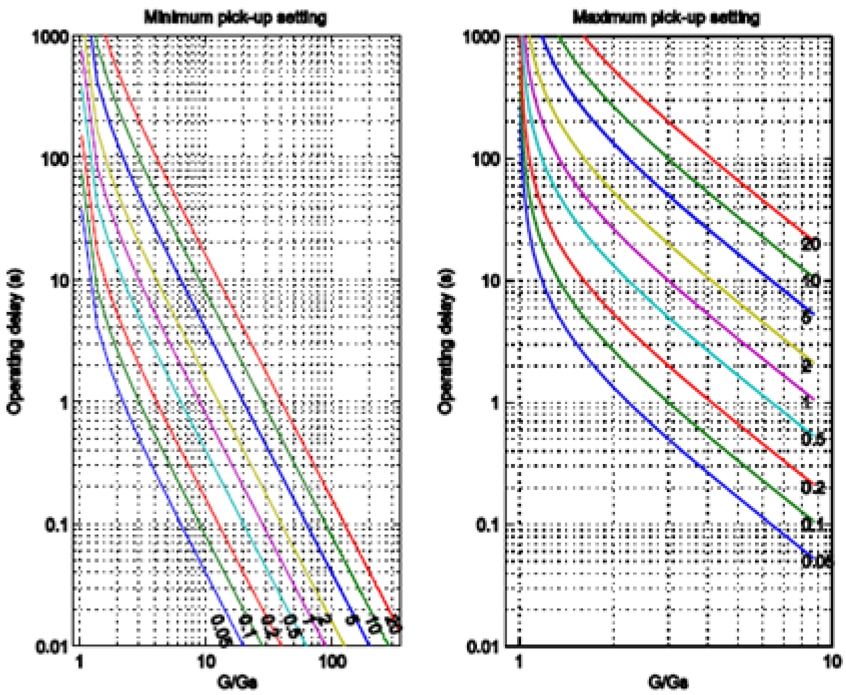


Figure. 6.3.3 - 49. IEC - LTI operating curves with minimum and maximum pick-up settings and TMS settings from 0.05 to 20.

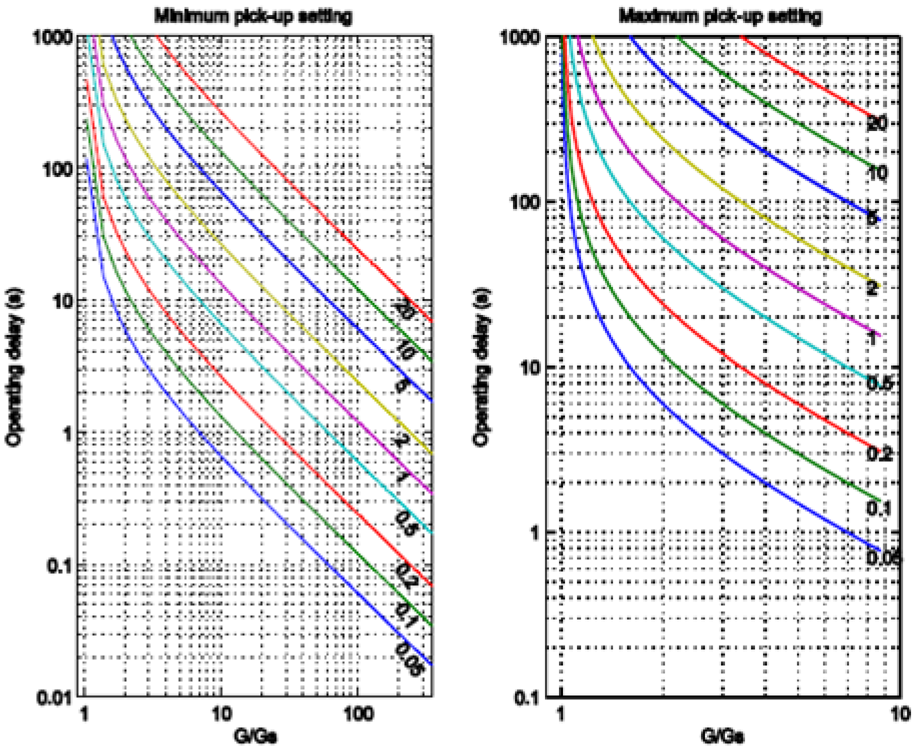


Figure. 6.3.3 - 50. IEEE/ANSI - NI operating curves with minimum and maximum pick-up settings and TMS settings from 0.05 to 20.

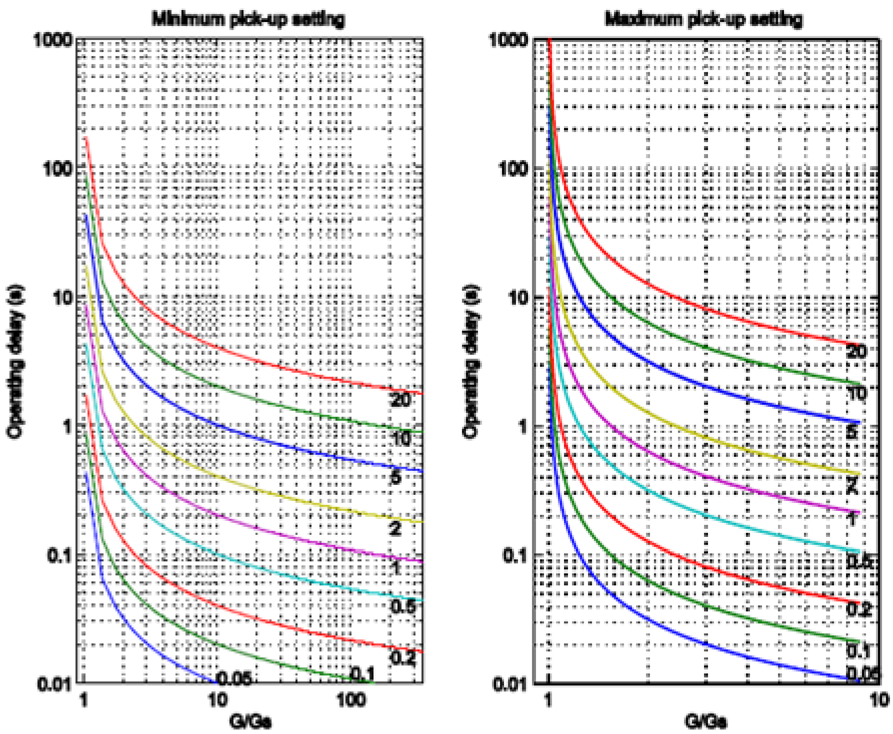


Figure. 6.3.3 - 51. IEEE/ANSI - MI operating curves with minimum and maximum pick-up settings and TMS settings from 0.05 to 20.

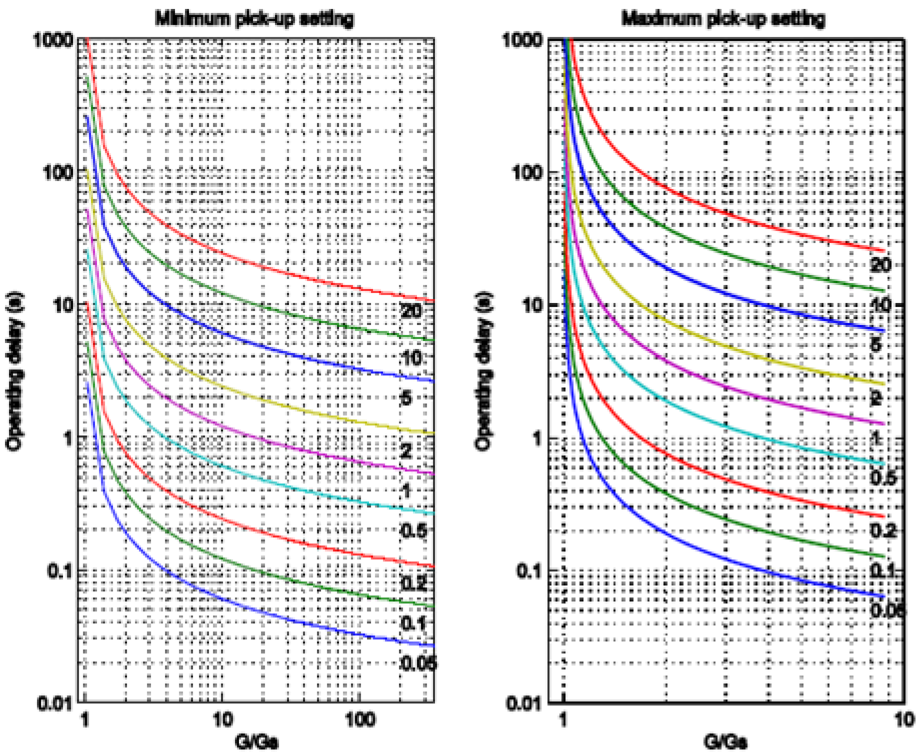


Figure. 6.3.3 - 52. IEEE/ANSI - VI operating curves with minimum and maximum pick-up settings and TMS settings from 0.05 to 20.

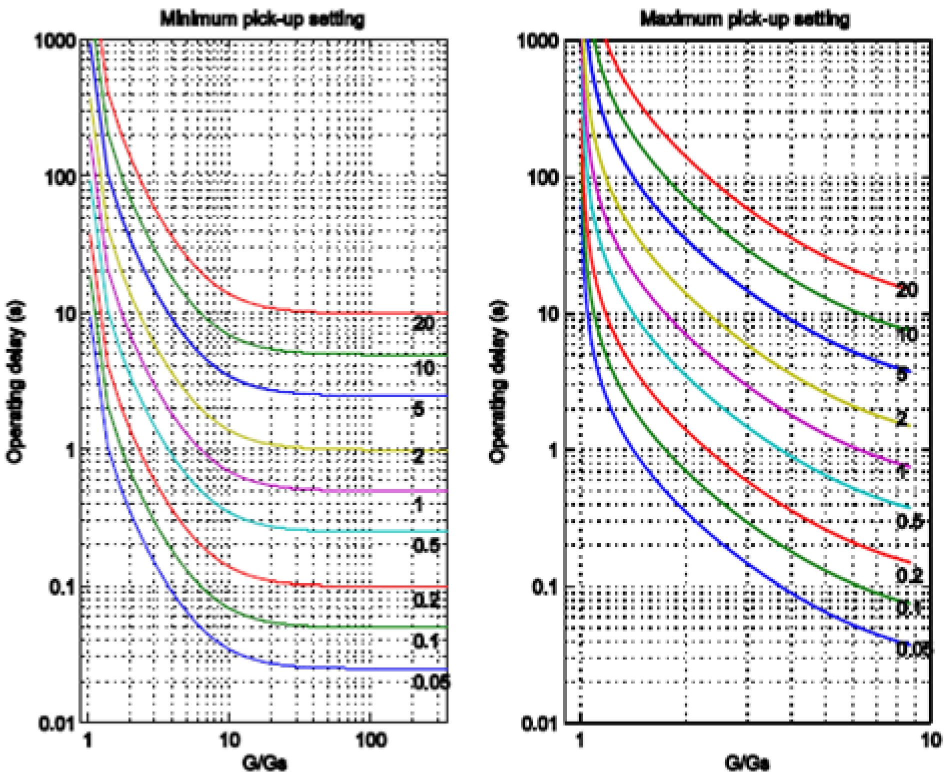


Figure. 6.3.3 - 53. IEEE/ANSI - EI operating curves with minimum and maximum pick-up settings and TMS settings from 0.05 to 20.

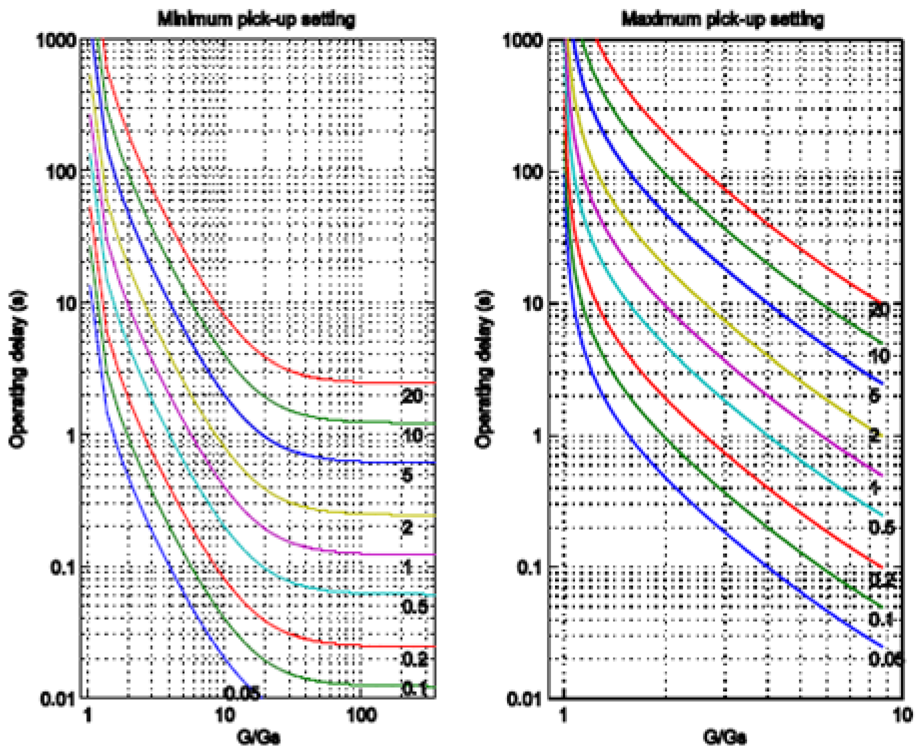


Figure. 6.3.3 - 54. IEEE/ANSI - LTI operating curves with minimum and maximum pick-up settings and TMS settings from 0.05 to 20.

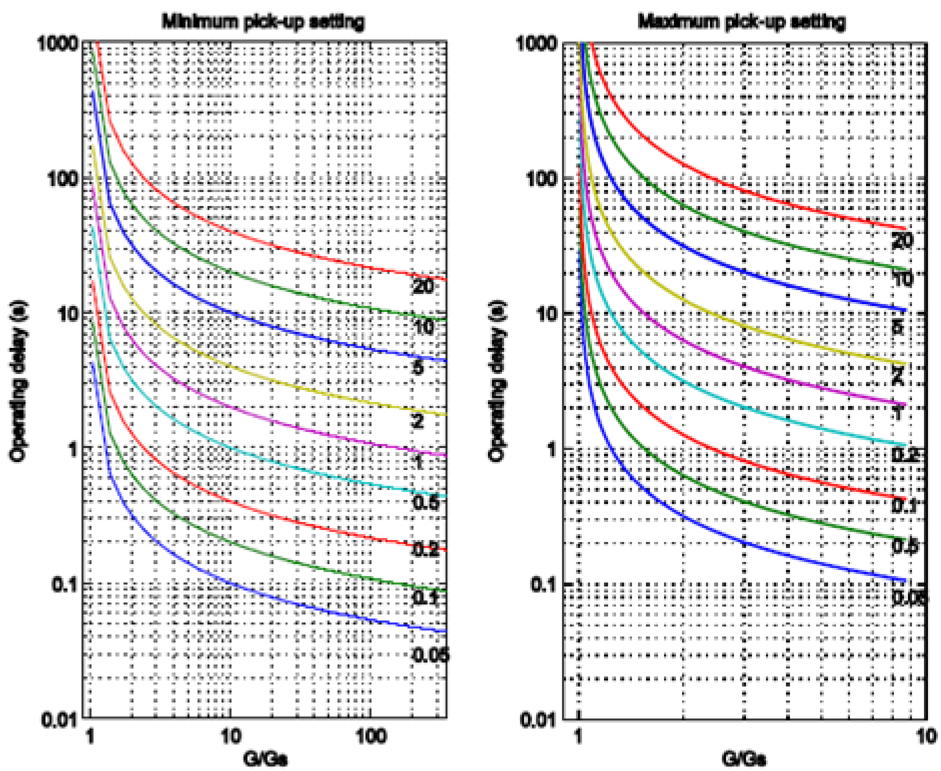


Figure. 6.3.3 - 55. IEEE/ANSI - LTVI operating curves with minimum and maximum pick-up settings and TMS settings from 0.05 to 20.

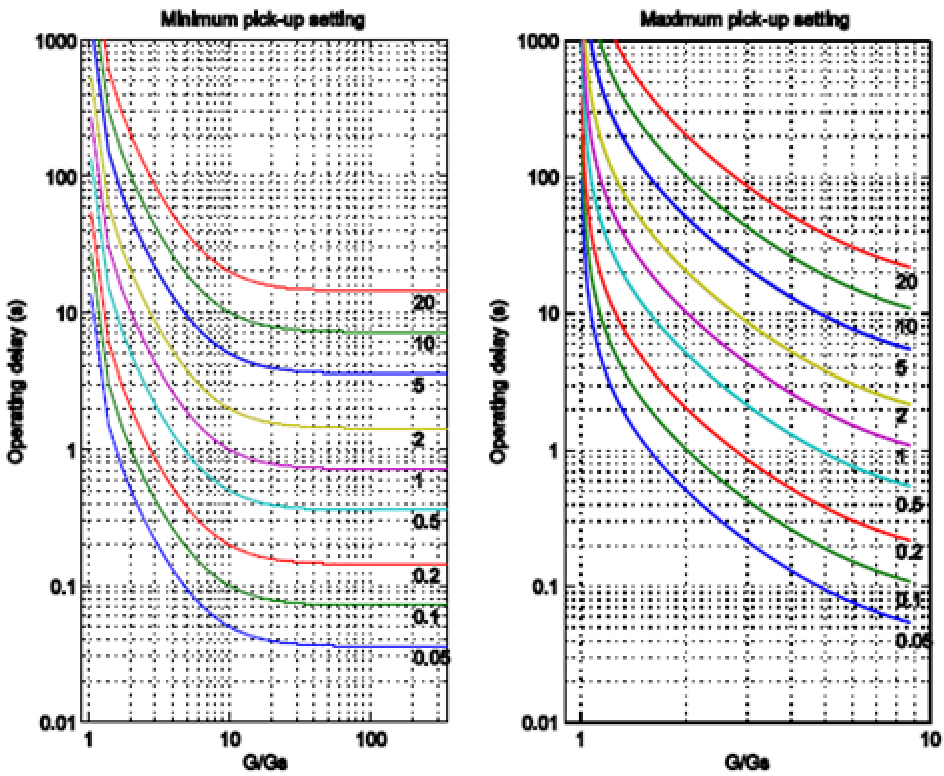
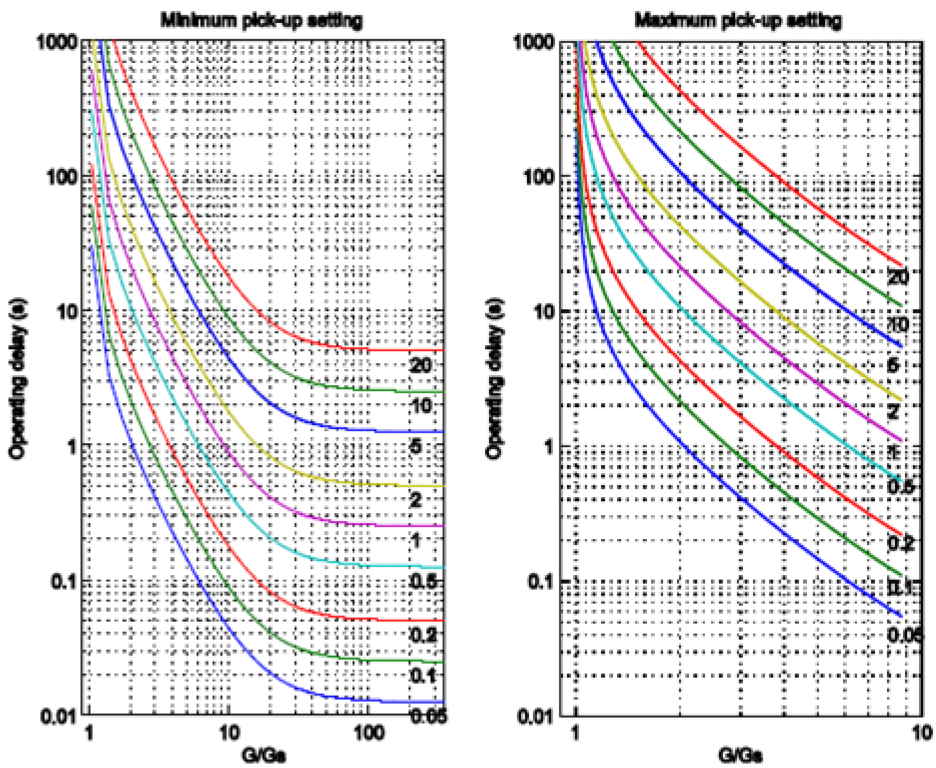


Figure. 6.3.3 - 56. IEEE/ANSI - LTEI operating curves with minimum and maximum pick-up settings and TMS settings from 0.05 to 20.



Resetting characteristics for the function depends on the selected operating time characteristics. For the IEC type IDMT characteristics the reset time is user settable and for the ANSI/IEEE type characteristics the resetting time follows equation below.

Figure. 6.3.3 - 57. Resetting characteristics for ANSI/IEEE IDMT.

$$t_r(G) = TMS\left[\frac{k_r}{1-\left(\frac{G}{G_S}\right)^{\alpha}}\right]$$

The variables in the equation above are:

- tr(G) (seconds) = theoretical reset time with constant value of G
- k_r = contants characterizing the selected curve
- α = constant characterizing the selected curve
- G = measured value of the Fourier base harmonic of the phase currents
- G_S = pick-up setting value
- TMS = time dial setting / preset time multiplier

The parameters and operating curve types follow corresponding standards presented in the table below.

Table. 6.3.3 - 27. Parameters and operating curve types for the IDMT characteristics.

Curve family	Characteristics	k_r	α
IEC	NI (normally inverse)	User settable fixed reset time	
IEC	VI (very inverse)		
IEC	EI (extremely inverse)		
IEC	LTI (long time inverse)		
IEEE/ANSI	NI (normally inverse)	0.46	2
IEEE/ANSI	MI (moderately inverse)	4.85	2
IEEE/ANSI	VI (very inverse)	21.6	2
IEEE/ANSI	EI (extremely inverse)	29.6	2
IEEE/ANSI	LTI (long time inverse)	4.6	2
IEEE/ANSI	LTVI (long time, very inverse)	13.46	2
IEEE/ANSI	LTEI (long time, extremely inverse)	30	2

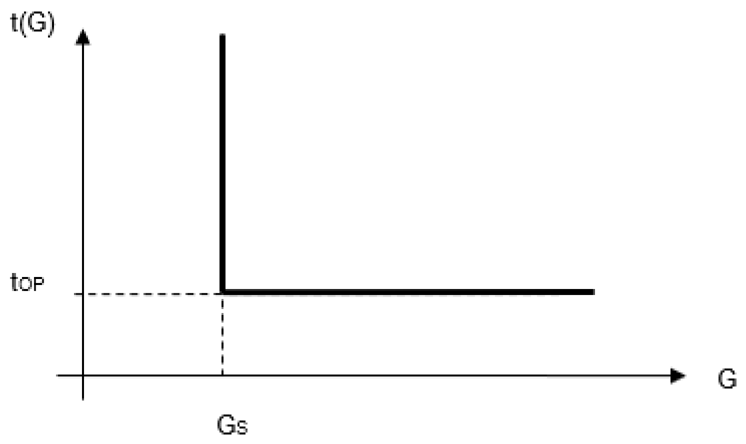
Table. 6.3.3 - 28. Setting parameters of the time overcurrent function.

Parameter	Setting value / range	Step	Default	Description
Operation	Off DefinitTime IEC Inv IEC VeryInv IEC ExtInv IEC LongInv ANSI Inv ANSI ModInv ANSI VeryInv ANSI ExtInv ANSI LongInv ANSI LongVeryInv ANSI LongExtInv	-	DefinitTime	Operating mode selection of the function. Can be disabled, Definite time or IDMT operation based IEC or ANSI/IEEE standards.
Start current	5…400 %In	1 %In	200 %In	Pick-up current setting of the function.
Min Delay	0…60 000 ms	1 ms	100 ms	Minimum operating delay setting for the IDMT characteristics.
Definite delay time	0…60 000 ms	1 ms	100 ms	Definite time operating delay setting.This parameter is not in use when IDMT characteristics is selected for the operation.
Reset delay	0…60 000 ms	1 ms	100 ms	Settable reset delay for definite time function and IEC IDMT operating characteristics. This parameter is in use with definite time and IEC IDMT characteristics.
Time Mult	0.05…999.0	0.01	-	Time multiplier / time dial setting of the IDMT operating characteristics. This parameter is not in use with definite time characteristics.

6.3.4 Residual time overcurrent protection (I0>; 50N/51N)

The residual definite time overcurrent protection function operates with definite time characteristics, using the RMS values of the fundamental Fourier component of the neutral or residual current (IN=3Io). In the figure below is presented the operating characteristics of the function.

$$t(G) = t_{OP} \text{ when } G > G_S$$



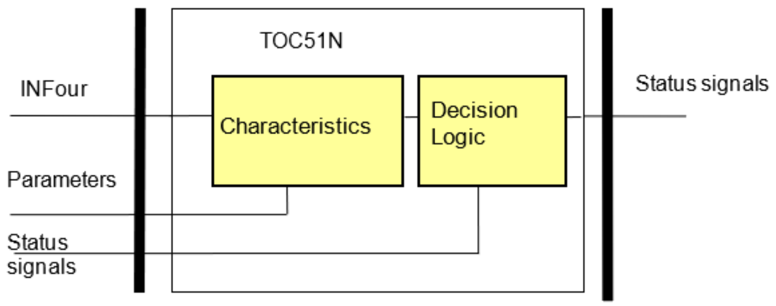
The variables in the image above are:

- t_{OP} (seconds) = theoretical operating time if G>G_S (without additional time delay)
- G = measured value of the Fourier base harmonic of the residual current
- G_S = pick-up setting

The structure of the algorithm consists of following modules. Fourier calculation module calculates the RMS values of the Fourier components of the residual current. Characteristics module compares the Fourier basic harmonic components of the residual current into the setting value. Decision logic module generates the trip signal of the function.

In the figure below is presented the structure of the residual time overcurrent algorithm.

Figure. 6.3.4 - 58. Structure of the residual time overcurrent protection algorithm.



The algorithm generates a start signal based on the Fourier components of the residual current in case if the user set pick-up value is exceeded. Trip signal is generated after the set definite time delay.

The function includes a blocking signal input which can be configured by user from either IED internal binary signals or IED binary inputs through the programmable logic.

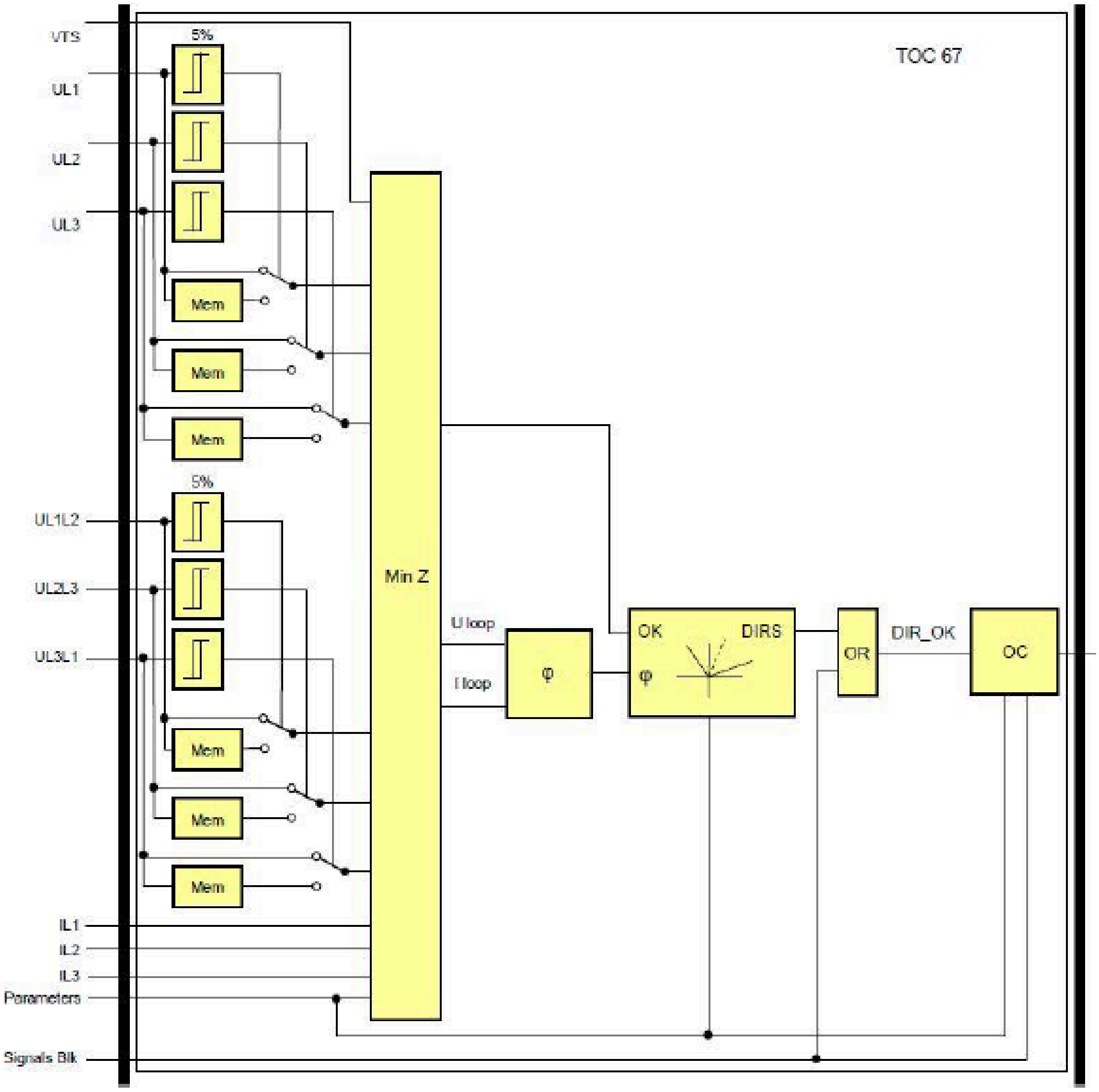
Table. 6.3.4 - 29. Setting parameters of the residual time overcurrent function.

Parameter	Setting value / Range	Step	Default	Description
Operation	Off DefinitTime IEC Inv IEC VeryInv IEC ExtInv IEC LongInv ANSI Inv ANSI ModInv ANSI VeryInv ANSI ExtInv ANSI LongInv ANSI LongVeryInv ANSI LongExtInv	-	DefinitTime	Operating mode selection of the function. Can be disabled, Definite time or IDMT operation based into IEC or ANSI/IEEE standards.
Start current	1…200 %In	1 %In	50 %In	Pick-up current setting of the function.
Min Delay	0…60 000 ms	1 ms	100 ms	Minimum operating delay setting for the IDMT characteristics.
Definite delay time	0…60 000 ms	1 ms	100 ms	Definite time operating delay setting. This parameter is not in use when IDMT characteristics is selected for the operation.
Reset time	0…60 000 ms	1 ms	100 ms	Settable reset delay for definite time function and IEC IDMT operating characteristics. This parameter is in use with definite time and IEC IDMT characteristics.
Time Mult	0.05…999.0	0.01	1.00	Time multiplier / time dial setting of the IDMT operating characteristics. This parameter is not in use with definite time characteristics.

6.3.5 Three-phase directional overcurrent protection (Idir>; 67)

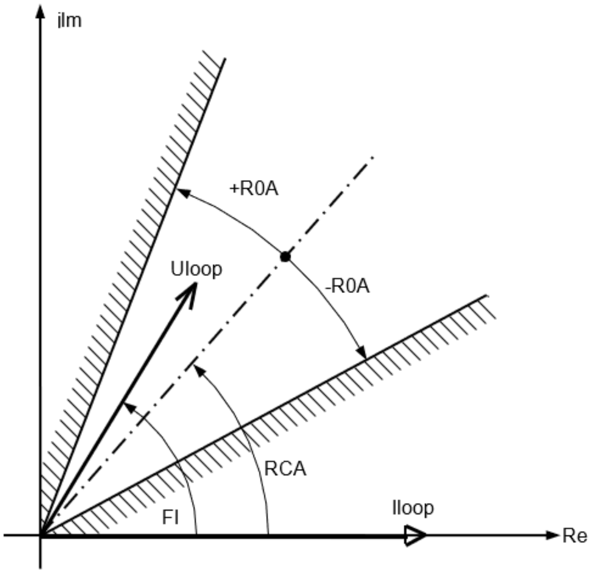
The directional three-phase overcurrent protection function can be applied on networks where the overcurrent protection must be supplemented with a directional decision. The inputs of the function are the Fourier basic harmonic components of the three phase currents and those of the three phase voltages. In the figure below is presented the structure of the directional overcurrent protection algorithm.

Figure. 6.3.5 - 59. The structure of the directional overcurrent protection algorithm.



Based on the measured voltages and currents the function block selects the lowest calculated loop impedance of the six loops (L1L2, L2L3, L3L1, L1N, L2N, L3N). Based on the loop voltage and loop current of the selected loop the directional decision is “Forward” if the voltage and the current is sufficient for directional decision, and the angle difference between the vectors is inside the set operating characteristics. If the angle difference between the vectors is outside of the set characteristics the directional decision is “Backward”.

Figure. 6.3.5 - 60. Directional decision characteristics.



The voltage must be above 5% of the rated voltage and the current must also be measurable. If the voltages are below 5% of the rated voltage then the algorithm substitutes the small values with the voltage values stored in the memory. The input signals are the RMS values of the fundamental Fourier components of the three-phase currents and three phase voltages and the three line-to-line voltages.

The internal output status signal for enabling the directional decision is true if both the three-phase voltages and the three-phase currents are above the setting limits. The RMS voltage and current values of the fundamental Fourier components of the selected loop are forwarded to angle calculation for further processing.

If the phase angle between the three-phase voltage and three-phase current is within the set range (defined by the preset parameter) or non-directional operation is selected by the preset parameter the function will operate according to the selected “Forward”, “Backward” or non directional setting.

Operating time of the function can be definite time or IDMT based on user selection. Operating characteristics of the IDMT function are presented in the "Three-phase time overcurrent protection (I>; 50/51)" chapter.

Table. 6.3.5 - 30. Setting parameters of the directional overcurrent function.

Parameter	Setting value / range	Step	Default	Description
Direction	NonDir Forward Backward	-	Forward	Direction mode selection.
Operating angle	30…90 deg	1 deg	60 deg	Operating angle setting. Defines the width of the operating characteristics in both sides of the characteristic angle. The default setting of 60 deg means that the total width of the operating angle is 120 deg.
Characteristic angle	40…90 deg	1 deg	60 deg	Characteristic angle setting. Defines the center angle of the characteristic.

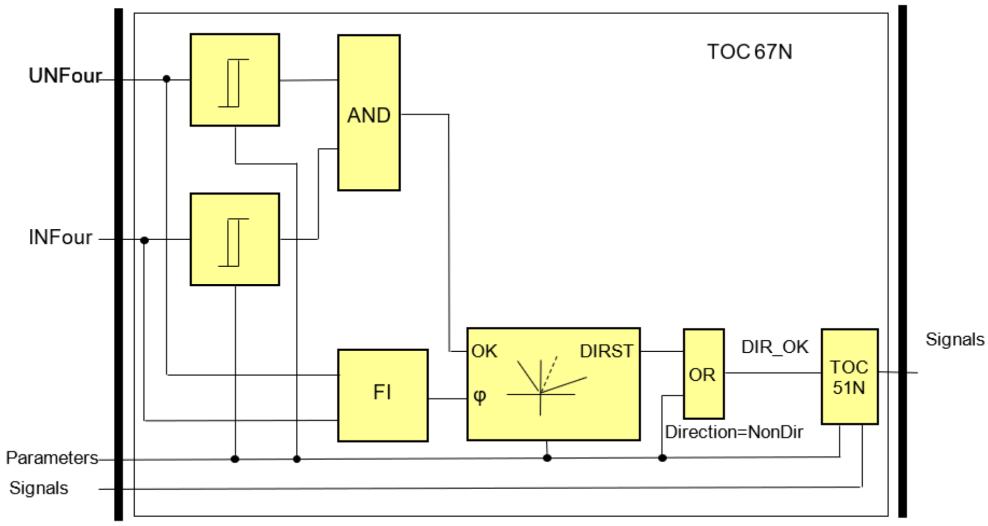
Parameter	Setting value / range	Step	Default	Description
Operation	Off DefinitTime IEC Inv IEC VeryInv IEC ExtInv IEC LongInv ANSI Inv ANSI ModInv ANSI VeryInv ANSI ExtInv ANSI LongInv ANSI LongVeryInv ANSI LongExtInv	-	DefinitTime	Operating mode selection of the function. Can be disabled, Definite time or IDMT operation based into IEC or ANSI/ IEEE standards.
Start current	5…1 000 %In	1 %In	50 %In	Pick-up current setting of the function.
Min Delay	0…60 000 ms	1 ms	100 ms	Minimum operating delay setting for the IDMT characteristics.
Definite delay time	0…60 000 ms	1 ms	100 ms	Definite time operating delay setting. This parameter is not in use when IDMT characteristics is selected for the operation.
Reset delay	0…60 000 ms	1 ms	100 ms	Settable reset delay for definite time function and IEC IDMT operating characteristics. This parameter is in use with definite time and IDMT characteristics.
Time Mult	0.05…999.00	0.01	1.00	Time multiplier / time dial setting of the IDMT operating characteristics. This parameter is not in use with definite time characteristics.

6.3.6 Residual directional overcurrent protection (I0dir>; 67N)

The main application area of the directional residual overcurrent protection function is earth-fault protection in all types of networks.

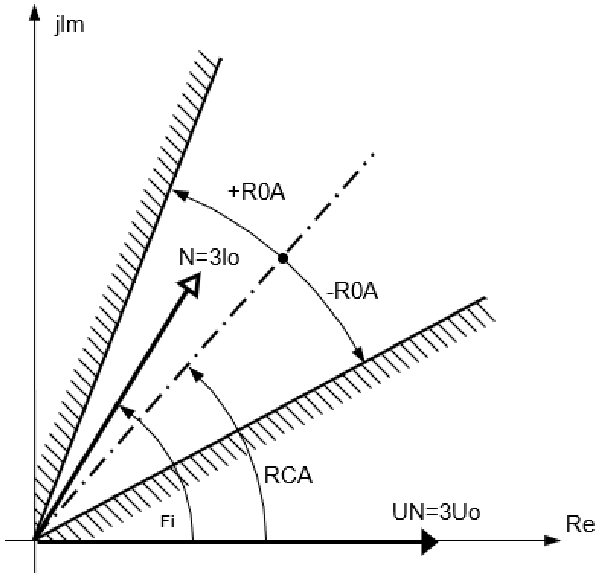
The inputs of the function are the Fourier basic harmonic components of the zero sequence current and those of the zero sequence voltage. In the figure below is presented the structure of the residual directional overcurrent algorithm.

Figure. 6.3.6 - 61. The structure of the residual directional overcurrent protection algorithm.



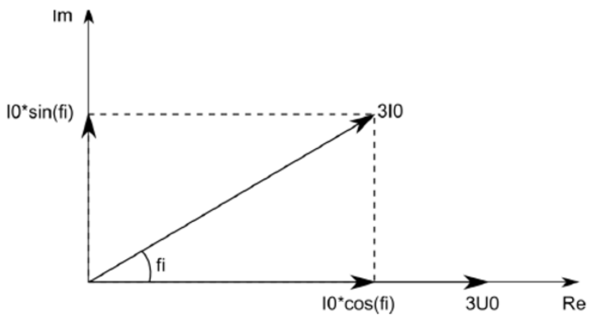
The block of the directional decision generates a signal of TRUE value if the UN=3Uo zero sequence voltage and the IN=-3Io current is sufficient for directional decision, and the angle difference between the vectors is within the preset range. This decision enables the output start and trip signal of the residual overcurrent protection function block.

Figure. 6.3.6 - 62. Directional decision characteristics of operating angle mode.



In the figure above is presented the directional decision characteristics. Measured U0 signal is the reference for measured -I0 signal. RCA setting is the characteristic angle and R0A parameter is the operating angle. In the figure FI parameter describes the measured residual current angle in relation to measured U0 signal and IN is the magnitude of the measured residual current. In the figure described situation the measured residual current is inside of the set operating sector and the status of the function would be starting in “Forward” mode.The protection function supports operating angle mode and also wattmetric and varmetric operating characteristics.

Figure. 6.3.6 - 63. Wattmetric and varmetric operating characteristics.



In the in the figure above are presented the characteristics of the wattmetric and varmetric operating principles in forward direction. For reverse operating direction the operating vectors are turned 180 degrees.

Table. 6.3.6 - 31. Setting parameters of the residual directional overcurrent function.

Parameter	Setting value / range	Step	Default	Description
Direction	NonDir Forward-Angle Backward-Angle Forward-I0*cos(fi) Backward-I0*cos(fi) Forward-I0*sin(fi) Backward-I0*sin(fi) Forward-I0*sin(fi+45) Backward-I0*sin(fi+45)	-	-	Direction mode selection of the function. By the direction mode selection also the operating characteristics is selected either non-directional, operating angle mode, wattmetric I0cos(fi) or varmetric I0sin(fi) mode.
U0 min	1…10 %	1 %	-	The threshold value for the 3U0 zero sequence voltage, below this setting no directionality is possible. % of the rated voltage of the voltage transformer input.
I0 min	1…50 %	1 %	-	The threshold value for the 3I0 zero sequence current, below this setting no operation is possible. % of the rated current of the current transformer input. *With 0.2A sensitive current module 2 mA secondary current pick-up sensitivity can be achieved. (ordering option)*
Operating Angle	30…90 deg	1 deg	-	Width of the operating characteristics in relation of the Characteristic Angle *(only in Forward/Backward-Angle mode).* Operating Angle setting value is ± deg from the reference Characteristic Angle setting. For example, with setting of Characteristic Angle = 0 deg and Operating Angle 30 deg Forward operating characteristic would be area inside +30 deg and –30 deg.
Characteristic Angle	–180…180 deg	1 deg	-	The base angle of the operating characteristics.

Parameter	Setting value / range	Step	Default	Description
Operation	Off DefinitTime IEC Inv IEC VeryInv IEC ExtInv IEC LongInv ANSI Inv ANSI ModInv ANSI VeryInv ANSI ExtInv ANSI LongInv ANSI LongVeryInv ANSI LongExtInv	-	DefinitTime	Selection of the function disabled and the timing characteristics. Operation when enabled can be either Definite time or IDMT characteristic.
Start current	1…200 %	1 %	-	Pick-up residual current
Time Mult	0.05…999	0.01	-	Time dial / multiplier setting used with IDMT operating time characteristics.
Min. Time	0…60 000 ms	1 ms	-	Minimum time delay for the inverse characteristics.
Def Time	0…60 000 ms	1 ms	-	Definite operating time
Reset Time	0…60 000 ms	1 ms	-	Settable function reset time

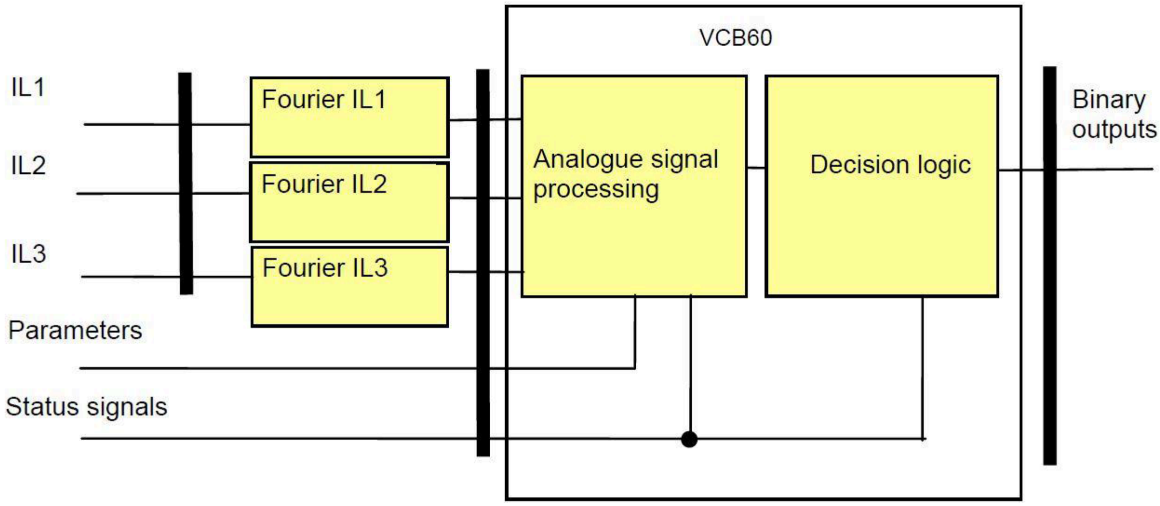
6.3.7 Current unbalance protection (60)

The current unbalance protection function can be applied to detect unexpected asymmetry in current measurement.

The applied method selects maximum and minimum phase currents (fundamental Fourier components). If the difference between them is above the setting limit, the function generates a start signal.

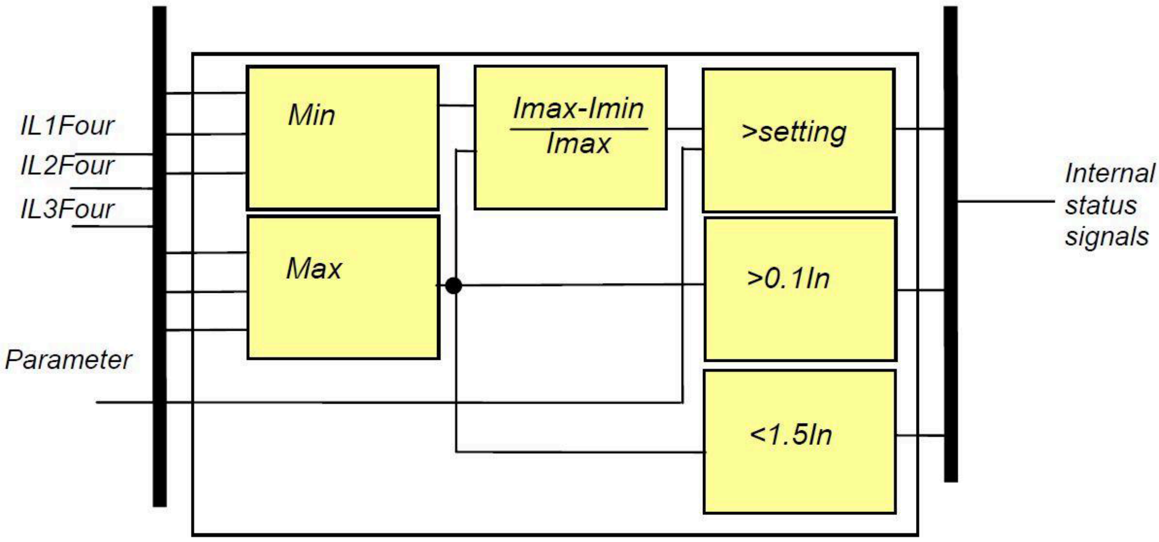
Structure of the current unbalance protection function is presented in the figure below

Figure. 6.3.7 - 64. The structure of the current unbalance protection algorithm.



The analogue signal processing principal scheme is presented in the figure below.

Figure. 6.3.7 - 65. Analogue signal processing for the current unbalance function.



The signal processing compares the difference between measured current magnitudes. If the measured relative difference between the minimum and maximum current is higher than the setting value the function generates a trip command. For stage to be operational the measured current level has to be in range of 10 % to 150 % of the nominal current. This precondition prevents the stage from operating in case of very low load and during other faults like shor tcircuit or earth faults.

The function can be disabled by parameter setting, and by an input signal programmed by the user.

The trip command is generated after the set defined time delay.

Table. 6.3.7 - 32. Setting parameters of the current unbalance function.

Parameter	Setting value / range	Step	Default	Description
Operation	On Off	-	On	Selection for the function enabled or disabled.
Start signal only	Activated Deactivated	-	Deactivated	Selection if the function issues either "Start" signal alone or both "Start" and after set time delay "Trip" signal.
Start current	10…90 %	1 %	50 %	Pick up setting of the current unbalance. Setting is the maximum allowed difference in between of the min and max phase currents.
Time delay	0…60 000 ms	1 ms	1 000 ms	Operating time delay setting for the "Trip" signal from the "Start" signal.

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

After a protection function generates a trip command, it is expected that the circuit breaker opens and/or the fault current drops below the pre-defined normal level. If not, then an additional trip command must be generated for all backup circuit breakers to clear the fault. At the same time, if required, a repeated trip command can be generated to the circuit breaker(s) which are expected to open. The breaker failure protection function can be applied to perform this task.

The starting signal of the breaker failure protection function is usually the trip command of any other protection function defined by the user. Dedicated timers start at the rising edge of the start signals, one for the backup trip command and one for the repeated trip command, separately for operation in the individual phases.

During the running time of the timers the function optionally monitors the currents, the closed state of the circuit breakers or both, according to the user's choice. When operation is based on current the set binary inputs indicating the status of the circuit breaker poles have no effect. If the operation is based on circuit breaker status the current limit values "Start current Ph" and "Start current N" have no effect on operation.

The breaker failure protection function resets only if all conditions for faultless state are fulfilled. If at the end of the running time of the backup timer the currents do not drop below the pre-defined level, and/or the monitored circuit breaker is still in closed position, then a backup trip command is generated in the phase(s) where the timer(s) run off.

The time delay is defined using the parameter "Backup Time Delay". If repeated trip command is to be generated for the circuit breakers that are expected to open, then the enumerated parameter "Retrip" must be set to "On". In this case, at the end of the timer(s) the delay of which is set by the timer parameter "Retrip Time Delay", a repeated trip command is also generated. The pulse duration of the trip command is shall the time defined by setting the parameter "Pulse length". The breaker failure protection function can be enabled or disabled by setting the parameter "Operation" to "Off".

Dynamic blocking is possible using the binary input "Block". The conditions can be programmed by the user.

Figure. 6.3.8 - 66. Operation logic of the CBFP function.

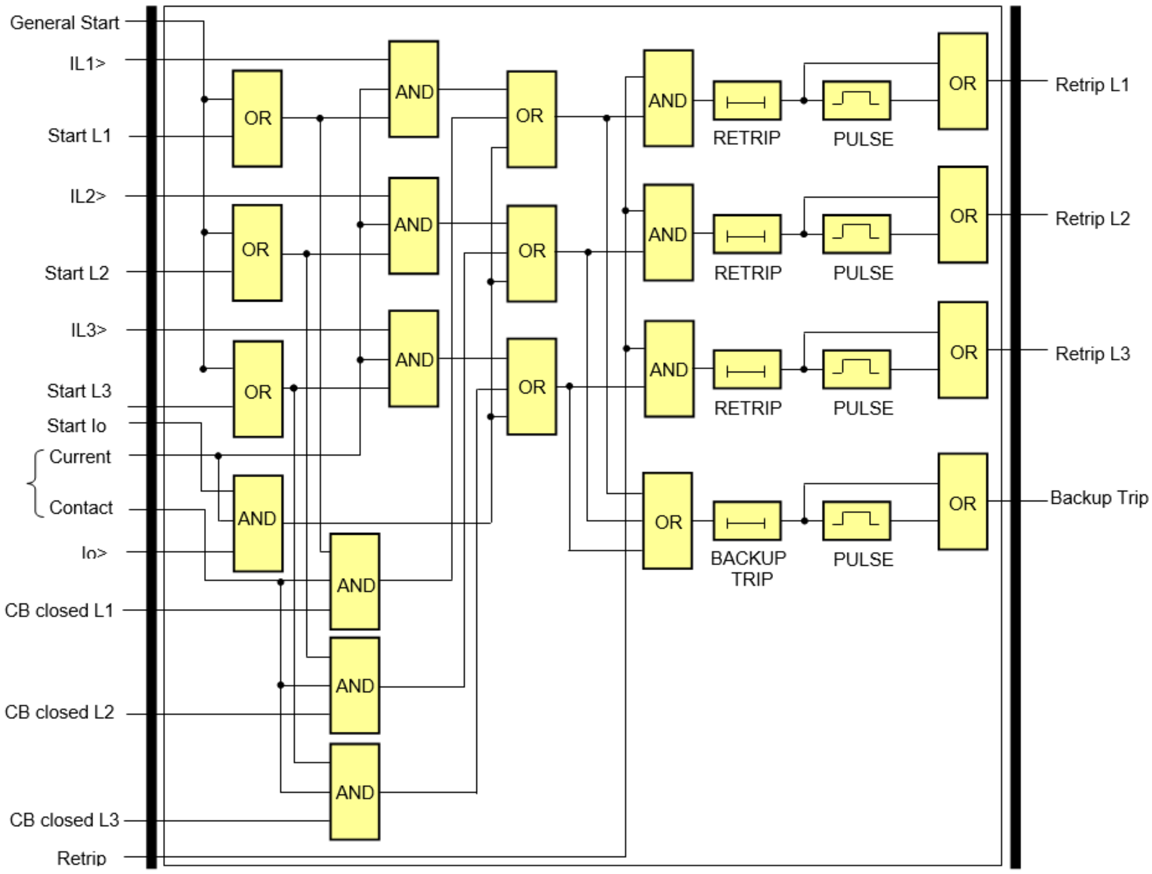


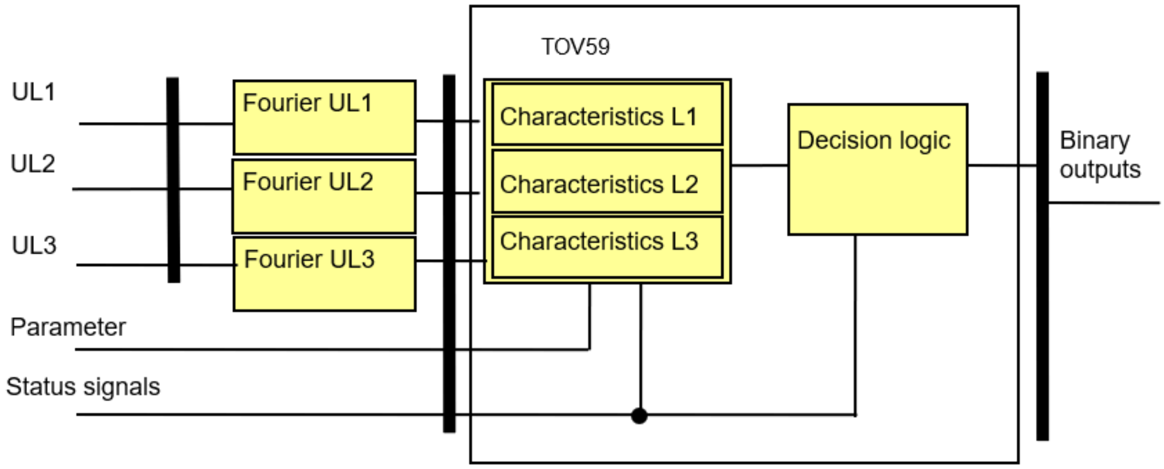
Table. 6.3.8 - 33. Setting parameters of the CBFP function.

Parameter	Setting value / range	Step	Default	Description
Operation	Off Current Contact Current/ Contact	-	Current	Operating mode selection for the function. Operation can be either disabled “Off” or monitoring either measured current or contact status or both current and contact status.
Start current Ph	20…200 %	1 %	30 %	Pick-up current for the phase current monitoring.
Start current N	10…200 %	1 %	30 %	Pick-up current for the residual current monitoring.
Backup Time Delay	60…1 000 ms	1 ms	200 ms	Time delay for CBFP tripping command for the back-up breakers from the pick-up of the CBFP function monitoring.
Pulse length	0…60 000 ms	1 ms	100 ms	CBFP pulse length setting.

6.3.9 Overvoltage protection (U>; 59)

The overvoltage protection function measures three phase to ground voltages. If any of the measured voltages is above the pick-up setting, a start signal is generated for the phases individually.

Figure. 6.3.9 - 67. The principal structure of the overvoltage function.



The general start signal is set active if the voltage in any of the three measured voltages is above the level defined by pick-up setting value. The function generates a trip command after the definite time delay has elapsed.

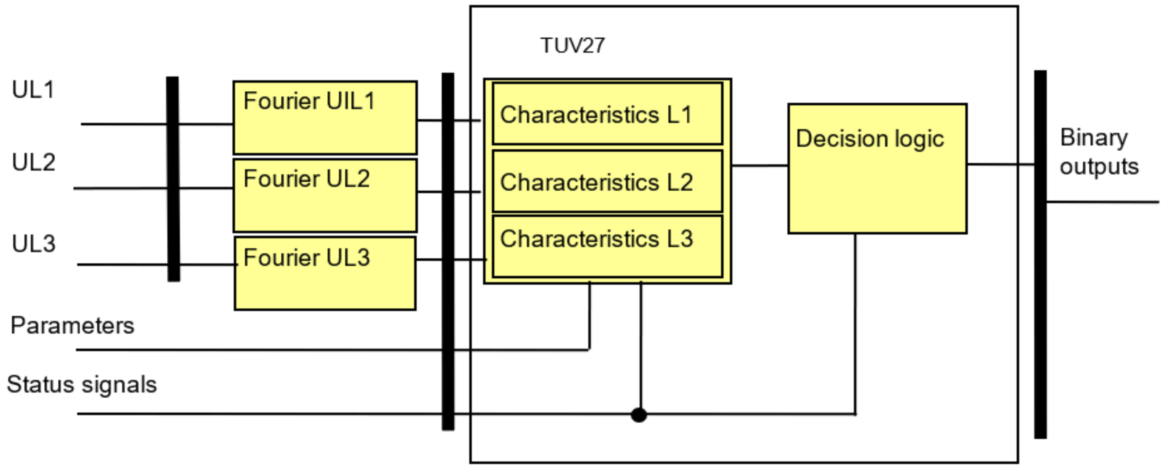
Table. 6.3.9 - 34.

Parameter	Setting value / range	Step	Default	Description
Operation	Off On	-	On	Operating mode selection for the function. Operation can be either enabled "On" or disabled "Off".
Start voltage	30…130 %	1 %	63 %	Voltage pick-up setting
Start signal only	Activated Deactivated	-	Deactivated	Selection if the function issues either “Start” signal alone or both “Start” and after set time delay “Trip” signal.
Reset ratio	1…10 %	1 %	5 %	Overvoltage protection reset ratio.
Time delay	0…60 000 ms	1 ms	100 ms	Operating time delay setting for the “Trip” signal from the “Start” signal.

6.3.10 Undervoltage protection (U<; 27)

The undervoltage protection function measures three voltages. If any of them is below the set pick-up value and above the defined minimum level, then a start signal is generated for the phases individually.

Figure. 6.3.10 - 68. The principal structure of the undervoltage function.



The general start signal is set active if the voltage of any of the three measured voltages is below the level defined by pick-up setting value. The function generates a trip command after the definite time delay has elapsed.

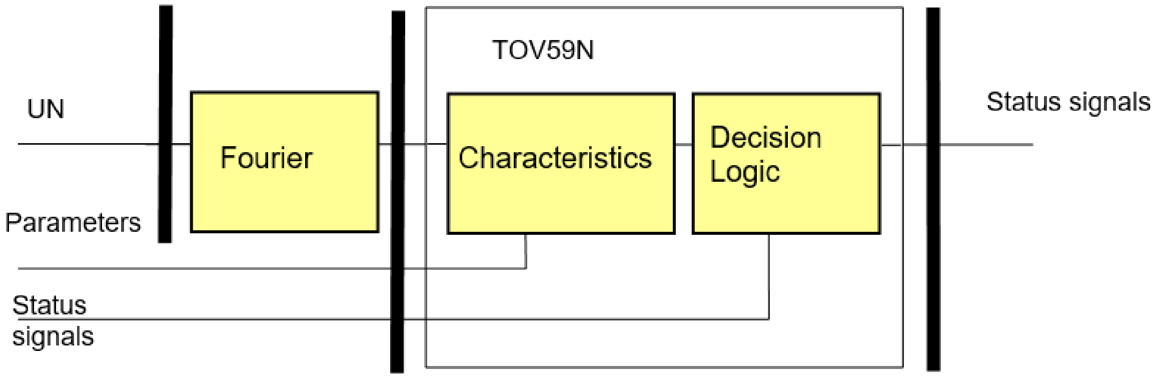
Table. 6.3.10 - 35. Setting parameters of the undervoltage function.

Parameter	Setting value / range	Step	Default	Description
Operation	Off 1 out of 3 2 out of 3 All	-	1 out of 3	Operating mode selection for the function. Operation can be either disabled “Off” or the operating mode can be selected to monitor single phase undervoltage, two phases undervoltage or all phases undervoltage condition.
Start voltage	30…130 %	1 %	90 %	Voltage pick-up setting
Block voltage	0…20 %	1 %	10 %	Undervoltage blocking setting. This setting prevents the function from starting in undervoltage condition which is caused for example from opened breaker.
Start signal only	Activated Deactivated	-	Deactivated	Selection if the function issues either “Start” signal alone or both “Start” and after set time delay “Trip” signal.
Reset ratio	1…10 %	1 %	5 %	Undervoltage protection reset ratio
Time delay	0…60 000 ms	1 ms	100 ms	Operating time delay setting for the "Trip" signal from the "Start" signal.

6.3.11 Residual overvoltage protection (U0>; 59N)

The residual definite time overvoltage protection function operates according to definite time characteristics, using the RMS values of the fundamental Fourier component of the zero sequence voltage (UN=3Uo).

Figure. 6.3.11 - 69. The principal structure of the residual overvoltage function.



The general start signal is set active if the measured residual voltage is above the level defined by pick-up setting value. The function generates a trip command after the set definite time delay has elapsed.

Table. 6.3.11 - 36. Setting parameters of the undervoltage function.

Parameter	Setting value / range	Step	Default	Description
Operation	Off On	-	On	Operating mode selection for the function. Operation can be either enabled "On" or disabled “Off”.
Start voltage	2…60 %	1 %	30 %	Voltage pick-up setting
Start signal only	Activated Deactivated	-	Deactivated	Selection if the function issues either “Start” signal alone or both “Start” and after set time delay “Trip” signal.
Reset ratio	1…10 %	1 %	5 %	Residual overvoltage protection reset ratio
Time delay	0…60 000 ms	1 ms	100 ms	Operating time delay setting for the "Trip" signal from the "Start" signal.

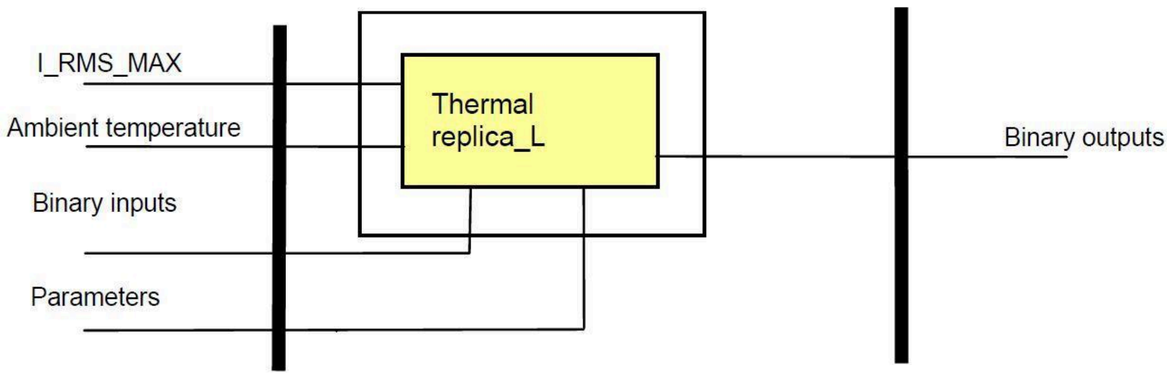
6.3.12 Thermal overload protection (T>; 49)

The line thermal protection measures basically the three sampled phase currents. TRMS values of each phase currents are calculated including harmonic components up to 10th harmonic, and the temperature calculation is based on the highest TRMS value of the compared three phase currents.

The basis of the temperature calculation is the step-by-step solution of the thermal differential equation. This method provides “overtemperature”, i.e. the temperature above the ambient temperature. Accordingly the final temperature of the protected object is the sum of the calculated “overtemperature” and the ambient temperature.

The ambient temperature can be set manually. If the calculated temperature (calculated “overtemperature”+ambient temperature) is above the threshold values, status signals are generated: Alarm temperature, Trip temperature and Unlock/restart inhibit temperature.

Figure. 6.3.12 - 70. The principal structure of the thermal overload function.



In the figure above is presented the principal structure of the thermal overload function. Theinputs of the function are the maximum of TRMS values of the phase currents, ambienttemperature setting, binary input status signals and setting parameters. Function outputsbinary signals for Alarm, Trip pulse and Trip with restart inhibit.

The thermal replica of the function follows the following equation.

$$H(t) = \frac{\theta(t)}{\theta_n} = \frac{I^2}{I_n^2}\left(1 - e^{-\frac{t}{T}}\right) + \frac{\theta_0}{\theta_n} e^{-\frac{t}{T}}$$

The equation's variables are as follows:

- H(t) = thermal level of the heated object; the temperature as a percentage of θ_n reference temperature
- θ_n = reference temperature above the ambient temperature, which can be measured in steady state in case of a continuous I_n refrence current
- I_n = reference current (can be considered as the nomincal current of the heated object); if the current flows continuously then the reference temperature can be measured in steady state
- I = measured current
- θ_0 = starting temperature
- T = heating time constant.

Table. 6.3.12 - 37. Setting parameters of the thermal overload function.

Parameter	Setting value / range	Step	Default	Description
Operation	Off Pulsed Locked	-	Pulsed	Operating mode selection. "Pulsed" operation means that the function gives tripping pulse when the calculated thermal load exceeds the set thermal load. "Locked" means that the trip signal releases when the calculated thermal load is cooled under the set Unlock temperature limit after the tripping.
Alarm temperature	60…200 deg	1 deg	80 deg	Temperature setting for the alarming of the overloading. When the calculated temperature exceeds the set alarm limit function issues an alarm signal.
Trip temperature	60…200 deg	1 deg	100 deg	Temperature setting for the tripping of the overloading. When the calculated temperature exceeds the set alarm limit function issues a trip signal.

Parameter	Setting value / range	Step	Default	Description
Rated temperature	60…200 deg	1 deg	100 deg	Rated temperature of the protected object.
Base temperature	0…40 deg	1 deg	40 deg	Rated ambient temperature of the device related to allowed temperature rise.
Unlock temperature	20…200 deg	1 deg	60 deg	Releasing of the function generated trip signal when the calculated thermal load is cooled under this setting. Restart inhibit release limit.
Ambient temperature	0…40 deg	1 deg	25 deg	Setting of the ambient temperature of the protected device.
Startup Term	0…60 %	1 %	0 %	On device restart starting used thermal load setting. When the device is restarted the thermal protection function will start calculating the thermal replica from this starting value.
Rated LoadCurrent	20…150 %	1 %	100 %	The rated nominal load of the protected device.
Time constant	1…999 min	1 min	10 min	Heating time constant of the protected device.

6.3.13 Line differential protection (87L) – transformer not in protected zone

The AQ 300 series has two kinds of line differential algorithms available, one with transformer in the protected zone and one without. The type of the protection function has to be specified when ordering, for more details refer to ordering information of the IED. This chapter explains the details of line differential protection without transformer in protected zone.

The line differential protection function provides main protection for two terminal transmission lines. The line differential protection function does not apply vector shift compensation, thus transformers must be excluded from the protected section.

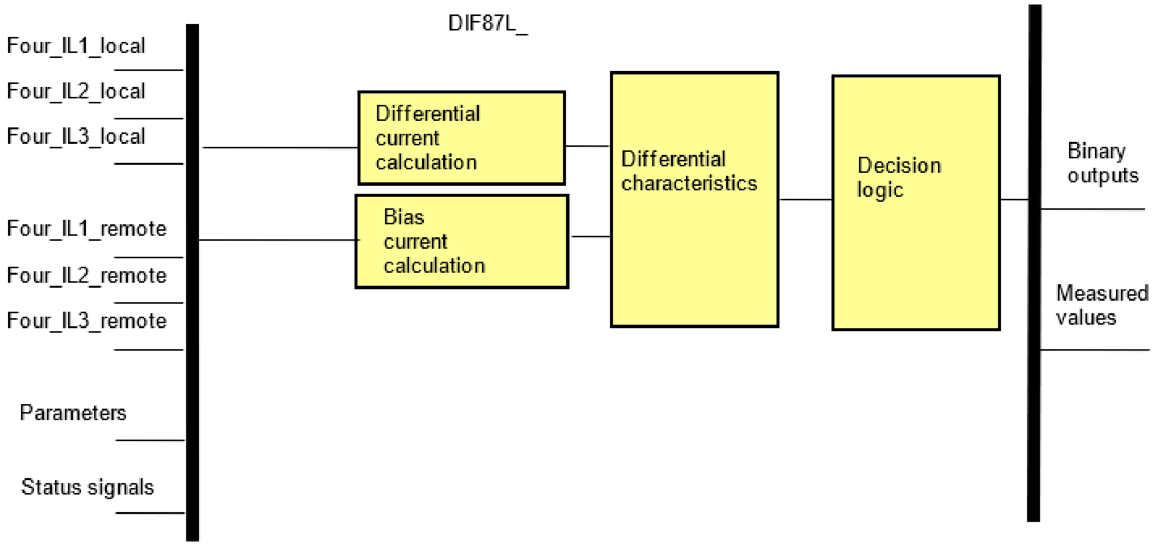
The operating principle is based on synchronized Fourier basic harmonic comparison between the line ends.

The devices at both line ends sample the phase currents and calculate the Fourier basic harmonic components. These components are exchanged between the devices synchronized via communication channels. The differential characteristic is a biased characteristic with two break points. Additionally, an unbiased overcurrent stage is applied, based on the calculated differential current.

The AQ 300 series protection IEDs communicate via fiber optic cables. Generally, mono-mode cables are required, but for distances below 2 km a multi-mode cable may be sufficient. The line differential protection can be applied up to the distance of 120 km. (The limiting factor is the damping of the fiber optic channel: up to 30 dB is permitted to prevent the disturbance of operation.)

The hardware module applied is the CPU module of the AQ 300 series protection IED. The two devices are interconnected via the “process bus”.

Figure. 6.3.13 - 71. Structure of the line differential protection algorithm.



The inputs are

- the Fourier base component values of three phase currents at the local line end
- the Fourier base component values of three phase currents received from the remote end
- parameters
- status signals.

The outputs are

- the binary output status signals
- the measured values for displaying.

The software modules of the line differential protection function:

- Differential current calculation
  This module calculates the differential current for phases L1, L2 and L3 separately, based on the basic Fourier components of the six line currents.
- Bias current calculation
  This module calculates the restraint current common to phases L1, L2 and L3, based on the basic Fourier components of the six line currents.
- Differential characteristics
  This module compares the points defined by the differential currents in phases L1, L2 and L3 separately and the restraint current with the differential characteristic, defined by parameter setting. The high-speed overcurrent protection function based on the line differential currents is also performed in this module.
- Decision logic
  The decision logic module decides if a general trip command is to be generated.The following description explains the details of the individual components.

Software module calculations

Differential current calculation

This module calculates the differential current for phases L1, L2 and L3 separately, based on the basic Fourier components of the six line currents.The differential current is the vector sum of the currents at the local line end and at the remote line end.The calculation is performed using the complex Fourier phasors and the result is the magnitude of the three differential currents.The parameters needed for the calculation are listed in table below.

Table. 6.3.13 - 38. Current compensation parameters.

Parameter	Setting range	Step	Default	Explanation
LocalRatio	0.10…2.00	0.01	1.00	Local end current ratio compensation factor.
RemoteRatio	0.10…2.00	0.01	1.00	Remote end current ratio compensatio factor.

These parameters can compensate the different current ratios if different current transformers are applied at the ends of the protected line. The meaning of these parameters is:

$$LocalRatio = \frac{Iref}{In\ local}$$

$$RemoteRatio = \frac{Iref}{In\ remote}$$

where:

Iref = an arbitrary reference current, which must be the same value in both formulas for the two devices at the line, ends
In local = the rated current of the local current transformer
In remote = the rated current of the remote current transformer; naturally, the values (remote and local) must be swapped for the respective devices as appropriate

Bias current calculation

The bias current is the maximum of the processed phase currents:

$$Ibias = (max(I)_{L1}local, I_{L1}remote, I_{L2}local, I_{L2}remote, I_{L3}local, I_{L3}remote)$$

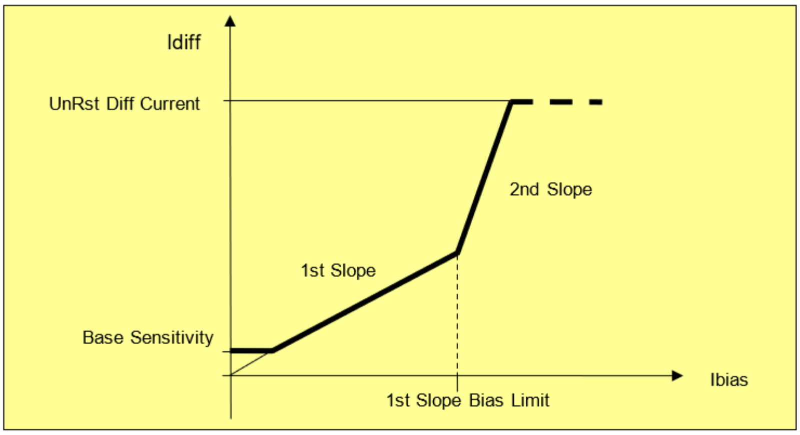
The calculation is performed using the complex Fourier phasors and the result is the bias current, the magnitude of the maximum of the six phase currents measured.

The parameters needed for the calculation are listed in the table above ("Current compensation parameters").

Line differential characteristics

The line differential characteristic is drawn in the figure below.

Figure. 6.3.13 - 72. The line differential protection characteristics.



Decision logic

The decision logic combines the following binary signals:

- Start signals of the line differential characteristic module
- Disabling status signal defined by the user, using equation editor for custom configurations.
- Custom configurations.

Additional binary signals

Blocking input signal

The line differential protection function has a binary input signal, which serves the purpose of disabling the function. The conditions of disabling are defined by the user, applying the equation editor.

Freely programmable binary signals

The line differential protection function block provides 12 input and 12 output signals that the user can apply freely. The output signals can be programmed by the user using AQtivate 300 software. These signals are listed in the table below.

Table. 6.3.13 - 39. Freely programmable binary signals.

Parameter	Explanation
SendCh01…Ch02	Free configurable signals to be sent via communication channel
ReceiveCh01…Ch02	Free configurable signals received via communication channel

Behavior during communication errors

In case of communication errors concerning single data, the line differential protection function is tolerant. Repeated errors are recognized and the function is disabled. This fact is signaled by the "CommFail" output signal.

In error state, if healthy signals are resumed, then the system restarts operation automatically.

Measured values

The measured and displayed values of the line differential protection function

Table. 6.3.13 - 40. Measured and displayed values of line differential function.

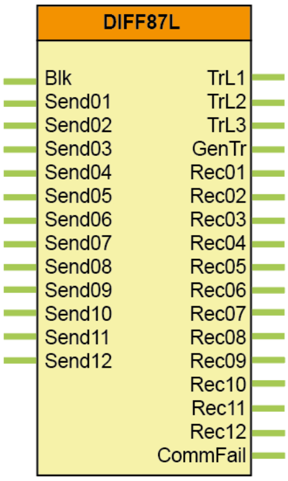
Measured value	Dim.	Explanation
I Diff L1	p.u.	Differential current in line L1
I Diff L2	p.u.	Differential current in line L2
I Diff L3	p.u.	Differential current in line L3
I Bias	p.u.	Restraint current

Note: The evaluated basic harmonic values of the measured input phase currents help the commissioning of the line differential protection function. The reference quantity of the per unit values is the rated current of the current input.

Function block

The function block of the line differential function is shown in figure bellow. This block shows all binary input and output status signals that are applicable in the AQtivate 300 software.

Figure. 6.3.13 - 73. The function block of the line differential function without transformer in protected zone.



The binary input and output status signals of the dead line detection function are listed intables below.

Table. 6.3.13 - 41. The binary input signals of the line differential function.

Binary input signal	Explanation
DIFF87L_DiffBlk_GrO_	Block
DIFF87L_Send01_GrO_	Free configurable signal to be sent via communication channel
...	...
DIFF87L_Send12_GrO_	Free configurable signal to be sent via communication channel

Table. 6.3.13 - 42. The binary output signals of the line differential function.

Binary output signal	Signal title	Explanation
Trip command of the line differential protection function		
DIFF87L_TrL1_Grl_	Trip L1	Trip command in line L1
DIFF87L_TrL2_Grl_	Trip L2	Trip command in line L2
DIFF87L_TrL3_Grl_	Trip L3	Trip command in line L3
DIFF87L_GenTr_Grl_		General trip command
Free configurable signals to be sent via communication channel		
DIFF87L_Rec01_Grl_	Received Ch01	Free configurable signal received via communication channel
...	...	...
DIFF87L_Rec12_Grl_	Received Ch12	Free configurable signal received via communication channel
Communication failure signal		
DIFF87L_CommFail_Grl_	CommFail	Signal indicating communication failure

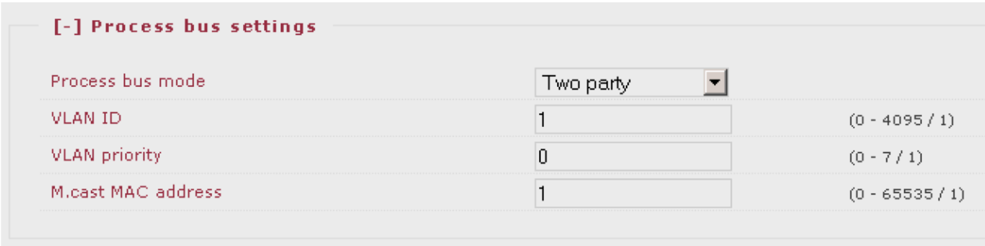
Setting parameters

Table. 6.3.13 - 43. Setting parameters of the line differential protection with transformer within protected zone.

Parameter	Setting range	Step	Default	Explanation
Operation	On Off	-	Off	Setting parameter to enable the line differential protection function.
Base Sensitivity	10…50 %	1 %	30 %	Base Sensitivity setting of the differential characteristics.
1st Slope	10…50 %	1 %	30 %	1st Slope setting
2nd Slope	50…100 %	1 %	70 %	2nd Slope setting
1st Slope Bias Limit	100…400 %	1 %	200 %	1st Slope Bias Limit (second turning point)
UnRst Diff Current	500…1 500 %	1 %	800 %	Unrestrained line differential protection current level
Local Ratio	0.10…2.00	0.01	1.00	Local end current ratio compensation factor
Remote Ratio	0.10…2.00	0.01	1.00	Remote end current ratio compensation factor

For the correct operation of the line differential protection function, the parameters for the process bus must be set. These parameters can be found on the “system settings” tab if the remote user interface communicates with the device. (For details see the document “Remote user interface description”.) Figure below shows the opened section for the “Process bus settings”. Select the parameters for both devices identically, as shown in this figure.

Figure. 6.3.13 - 74. Process bus settings for line differential protection.



6.3.14 Line differential protection (87L) – transformer in protected zone

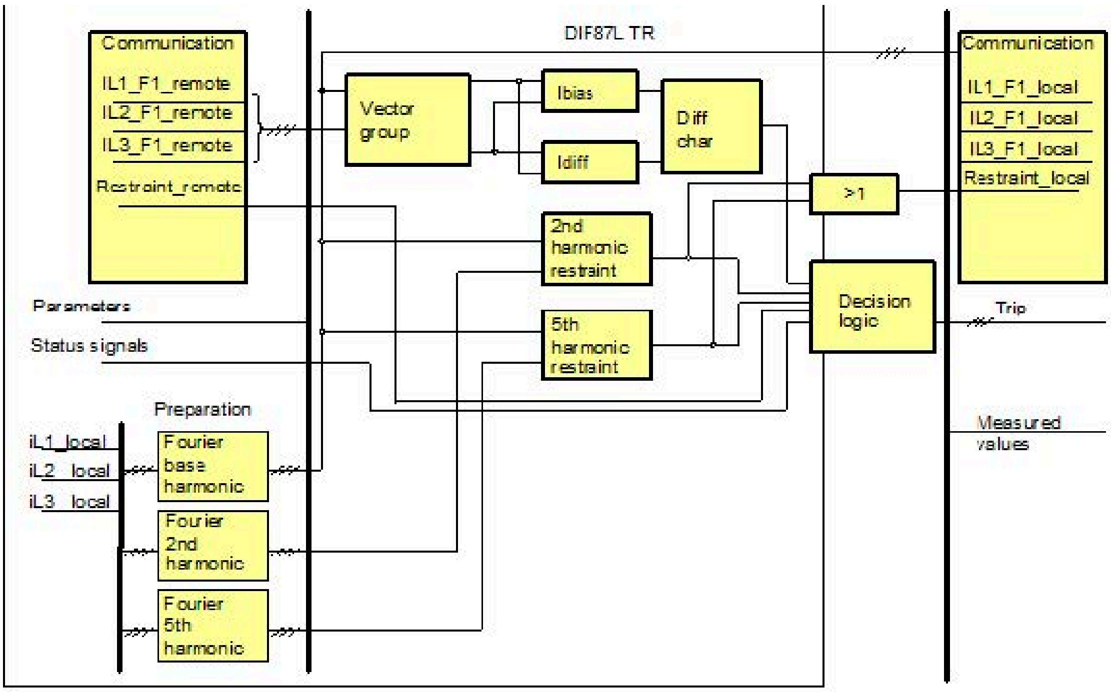
The AQ 300 series has two kinds of line differential algorithms available, one with transformer in the protected zone and one without. The type of the protection function has to be specified when ordering, for more details refer to ordering information of the IED. This chapter explains the details of line differential protection with transformer in protected zone.

The line differential protection function provides main protection for two terminal transmission lines. This version of the line differential protection function considers also vector shift compensation, thus transformers with two voltage levels can be included in the protected zone.

The operating principle is the same as in the function without transformer in the protected zone. Additionally this function applies inrush current restraint based on second harmonic detection. The restraint against transformer over-excitation uses fifth harmonic analysis.

The figure below shows the structure of the line differential protection (DIF87LTR_) algorithm to protect line and transformer in the protected zone.

Figure. 6.3.14 - 75. Structure of the line differential protection algorithm with transformer in protected zone.



The inputs are

- the Fourier base component values of three phase currents received from the remote end

- the harmonic restraint decision from the remote end
- the sampled values of three local phase currents
- parameters
- status signals.

The outputs are

- the binary output status signals
- the measured values for displaying
- the Fourier base component values of three phase currents measured at the local end, to be sent to the remote end
- the harmonic restraint decision based on the local measurement, to be sent to the remote end.

The software modules of the line differential protection function:

- Communication
  These modules send/receive the calculated base harmonic Fourier vectors to/from the remote end. The interchanged data include also the general restraint signals based on second and fifth harmonic analysis of the local measured currents.
- Fourier base harmonic
  This module calculates the base Fourier components of three local phase currents. These results are needed also for the high-speed differential current decision and for the second and fifth harmonic restraint calculation. This module belongs to the preparatory phase.
- Fourier 2nd harmonic
  This module calculates the second harmonic Fourier components of three local phase currents. These results are needed for the second harmonic restraint decision. This module belongs to the preparatory phase.
- Fourier 5th harmonic
  This module calculates the fifth harmonic Fourier components of three local phase currents. These results are needed for the fifth harmonic restraint decision. This module belongs to the preparatory phase.
- Vector group
  This module compensates the phase shift and turn's ratio of the transformer. The results of this calculation are the base Fourier components of the phase-shifted phase currents for both sides of the protected zone.
- Ibias
  This module calculates the bias currents needed for the differential characteristic decision.
- Idiff
  This module calculates the differential currents needed for the differential characteristic decision.
- 2nd harmonic restraint
  The differential current can be high in case of transformer energizing, due to the current distortion caused by the transformer iron core asymmetric saturation. In this case the second harmonic content of the local current is applied in this module to disable the operation of the differential protection function. The result of this calculation is needed for the decision logic.
- 5th harmonic restraint
  The differential current can be high in case of over-excitation of the transformer, due to the current distortion caused by the transformer iron core symmetric saturation. In this case the fifth harmonic content of the local current is applied in this module to disable the operation of the differential protection function. The result of this calculation is needed for the decision logic.
- Differential characteristics
  This module performs the necessary calculations for the evaluation of the "percentage differential characteristics". This curve is the function of the restraint current, which is calculated based on the magnitude of the phase-shifted phase currents. The result of this calculation is needed for the decision logic.

- Decision logic
  The decision logic module decides if the differential current of the individual phases is above the characteristic curve of the differential protection function. The second and fifth harmonic ratio of the local current, relative to the basic harmonic content can restrain the operation of the differential protection function. The restraint signal received from the remote end has the same influence. The high-speed overcurrent protection function based on the differential currents is performed in this module too.

Individual components

The vector shift and magnitude compensation

The three-phase power transformers transform the primary voltages and currents to the secondary side according to the turn's ratio and the vector group of the transformers. The Y (star) D (delta) or Z (zig-zag) connection of the three phase coils on the primary and on the secondary side causes vector shift of the voltages and currents. The conventional electromechanical or static electronic devices of the differential protection compensate the vector shift with appropriate connection of the current transformer secondary coils. The numerical differential protection function applies matrix transformation of the directly measured currents of one side of the transformer to match them with the currents of the other side.

In the transformer differential protection of Protecta the software module „Vector_group" calculates the matrix transformation and the turn's ratio matching. Here the target of the matrix transformation is the delta (D) side.

Principle of transformation to the D side

The conventional electromechanical or static electronic devices of the differential protection compensate the vector shift with appropriate connection of the current transformer coils. The principle is that the Y connected current transformers on the delta side of the transformer do not shift the currents flowing out of the transformer. The delta connected current transformers on the Y side of the transformer however result a phase shift. This means that the Y side currents are shifted according to the vector group of the transformer to match the delta side currents.

Additionally the delta connection of the current transformers eliminates the zero sequence current component, flowing on the grounded Y side of the transformer. As on the delta side no zero sequence current can be detected, this compensation is unavoidable for the correct operation of the differential protection.

If an external phase-to-ground fault occurs at the Y side of the transformer, then zero sequence current flows on the grounded Y side, but on the delta side no out-flowing zero sequence current can be detected. Without elimination of the zero sequence current component the differential protection generates a trip command in case of external ground fault. If the connection group of the current transformers on the Y side is delta however, then no zero sequence current flows out of the group. So the problem of zero sequence current elimination in case of external ground fault is solved.

Mathematical modeling of the current transformer's vector group connection

The numerical differential protection function applies numerical matrix transformation for modeling the delta connection of the current transformers. In the practice it means cyclical subtraction of the phase currents.

In the vector shift compensation the base Fourier components of the phase currents of the local side (IL1_F1_local, IL21_F1_local, IL3_F1_local) and those of the remote side ((IL1_F1_remote, IL2_F1_remote, IL3_F1_remote)) are transformed to (I1Rshift, I1Sshift, I1Tshift) and (I2Rshift, I2Sshift, I2Tshift) values of both sides respectively, using matrix transformation. The method of transformation is defined by the „Code" parameter, identifying the transformer vector group connection.

The table below summarizes the method of transformation, according to the connection group of the transformers with two voltage levels.

Table. 6.3.14 - 44. Vector shift compensation with transformation to the **delta** side.

Tr. conn. group	Code	Transformation of the local side currents	Transformation of the remote side currents
Dy1	00	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_local \\ IL2\_F1\_local \\ IL3\_F1\_local \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_remote \\ IL2\_F1\_remote \\ IL3\_F1\_remote \end{bmatrix}$
Dy5	01	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_local \\ IL2\_F1\_local \\ IL3\_F1\_local \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} -1 & 0 & 1 \\ 1 & -1 & 0 \\ 0 & 1 & -1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_remote \\ IL2\_F1\_remote \\ IL3\_F1\_remote \end{bmatrix}$
Dy7	02	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_local \\ IL2\_F1\_local \\ IL3\_F1\_local \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} -1 & 1 & 0 \\ 0 & -1 & 1 \\ 1 & 0 & -1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_remote \\ IL2\_F1\_remote \\ IL3\_F1\_remote \end{bmatrix}$
Dy11	03	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_local \\ IL2\_F1\_local \\ IL3\_F1\_local \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 0 & -1 \\ -1 & 1 & 0 \\ 0 & -1 & 1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_remote \\ IL2\_F1\_remote \\ IL3\_F1\_remote \end{bmatrix}$
Dd0	04	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_local \\ IL2\_F1\_local \\ IL3\_F1\_local \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_remote \\ IL2\_F1\_remote \\ IL3\_F1\_remote \end{bmatrix}$
Dd6	05	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_local \\ IL2\_F1\_local \\ IL3\_F1\_local \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_remote \\ IL2\_F1\_remote \\ IL3\_F1\_remote \end{bmatrix}$
Dz0	06	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_local \\ IL2\_F1\_local \\ IL3\_F1\_local \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} IL1\_F1\_remote \\ IL2\_F1\_remote \\ IL3\_F1\_remote \end{bmatrix}$
Dz2	07	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_local \\ IL2\_F1\_local \\ IL3\_F1\_local \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & -2 & 1 \\ 1 & 1 & -2 \\ -2 & 1 & 1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_remote \\ IL2\_F1\_remote \\ IL3\_F1\_remote \end{bmatrix}$
Dz4	08	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_local \\ IL2\_F1\_local \\ IL3\_F1\_local \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \frac{1}{3} \begin{bmatrix} -1 & -1 & 2 \\ 2 & -1 & -1 \\ -1 & 2 & -1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_remote \\ IL2\_F1\_remote \\ IL3\_F1\_remote \end{bmatrix}$
Dz6	09	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_local \\ IL2\_F1\_local \\ IL3\_F1\_local \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \frac{1}{3} \begin{bmatrix} -2 & 1 & 1 \\ 1 & -2 & 1 \\ 1 & 1 & -2 \end{bmatrix} \begin{bmatrix} IL1\_F1\_remote \\ IL2\_F1\_remote \\ IL3\_F1\_remote \end{bmatrix}$
Dz8	10	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_local \\ IL2\_F1\_local \\ IL3\_F1\_local \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \frac{1}{3} \begin{bmatrix} -1 & 2 & -1 \\ -1 & -1 & 2 \\ 2 & -1 & -1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_remote \\ IL2\_F1\_remote \\ IL3\_F1\_remote \end{bmatrix}$
Dz10	11	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_local \\ IL2\_F1\_local \\ IL3\_F1\_local \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & -2 \\ -2 & 1 & 1 \\ 1 & -2 & 1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_remote \\ IL2\_F1\_remote \\ IL3\_F1\_remote \end{bmatrix}$
Yy0	12	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 0 & -1 \\ -1 & 1 & 0 \\ 0 & -1 & 1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_local \\ IL2\_F1\_local \\ IL3\_F1\_local \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 0 & -1 \\ -1 & 1 & 0 \\ 0 & -1 & 1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_remote \\ IL2\_F1\_remote \\ IL3\_F1\_remote \end{bmatrix}$
Yy6	13	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 0 & -1 \\ -1 & 1 & 0 \\ 0 & -1 & 1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_local \\ IL2\_F1\_local \\ IL3\_F1\_local \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} -1 & 0 & 1 \\ 1 & -1 & 0 \\ 0 & 1 & -1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_remote \\ IL2\_F1\_remote \\ IL3\_F1\_remote \end{bmatrix}$
Yd1	14	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 0 & -1 \\ -1 & 1 & 0 \\ 0 & -1 & 1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_local \\ IL2\_F1\_local \\ IL3\_F1\_local \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_remote \\ IL2\_F1\_remote \\ IL3\_F1\_remote \end{bmatrix}$
Yd5	15	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_local \\ IL2\_F1\_local \\ IL3\_F1\_local \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{bmatrix} \begin{bmatrix} IL1\_F1\_remote \\ IL2\_F1\_remote \\ IL3\_F1\_remote \end{bmatrix}$

Tr. conn. group	Code	Transformation of the local side currents	Transformation of the remote side currents
Yd7	16	$\begin{bmatrix}I1Rshift\\I1Sshift\\I1Tshift\end{bmatrix}=\frac{1}{\sqrt{3}}\begin{bmatrix}1&0&-1\\-1&1&0\\0&-1&1\end{bmatrix}\begin{bmatrix}IL1\_F1\_local\\IL2\_F1\_local\\IL3\_F1\_local\end{bmatrix}$	$\begin{bmatrix}I2Rshift\\I2Sshift\\I2Tshift\end{bmatrix}=\begin{bmatrix}-1&0&0\\0&-1&0\\0&0&-1\end{bmatrix}\begin{bmatrix}IL1\_F1\_remote\\IL2\_F1\_remote\\IL3\_F1\_remote\end{bmatrix}$
Yd11	17	$\begin{bmatrix}I1Rshift\\I1Sshift\\I1Tshift\end{bmatrix}=\frac{1}{\sqrt{3}}\begin{bmatrix}1&-1&0\\0&1&-1\\-1&0&1\end{bmatrix}\begin{bmatrix}IL1\_F1\_local\\IL2\_F1\_local\\IL3\_F1\_local\end{bmatrix}$	$\begin{bmatrix}I2Rshift\\I2Sshift\\I2Tshift\end{bmatrix}=\begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix}\begin{bmatrix}IL1\_F1\_remote\\IL2\_F1\_remote\\IL3\_F1\_remote\end{bmatrix}$
Yz1	18	$\begin{bmatrix}I1Rshift\\I1Sshift\\I1Tshift\end{bmatrix}=\frac{1}{\sqrt{3}}\begin{bmatrix}1&0&-1\\-1&1&0\\0&-1&1\end{bmatrix}\begin{bmatrix}IL1\_F1\_local\\IL2\_F1\_local\\IL3\_F1\_local\end{bmatrix}$	$\begin{bmatrix}I2Rshift\\I2Sshift\\I2Tshift\end{bmatrix}=\frac{1}{3}\begin{bmatrix}2&-1&-1\\-1&2&-1\\-1&-1&2\end{bmatrix}\begin{bmatrix}IL1\_F1\_remote\\IL2\_F1\_remote\\IL3\_F1\_remote\end{bmatrix}$
Yz5	19	$\begin{bmatrix}I1Rshift\\I1Sshift\\I1Tshift\end{bmatrix}=\frac{1}{\sqrt{3}}\begin{bmatrix}1&-1&0\\0&1&-1\\-1&0&1\end{bmatrix}\begin{bmatrix}IL1\_F1\_local\\IL2\_F1\_local\\IL3\_F1\_local\end{bmatrix}$	$\begin{bmatrix}I2Rshift\\I2Sshift\\I2Tshift\end{bmatrix}=\frac{1}{3}\begin{bmatrix}-2&1&1\\1&-2&1\\1&1&-2\end{bmatrix}\begin{bmatrix}IL1\_F1\_remote\\IL2\_F1\_remote\\IL3\_F1\_remote\end{bmatrix}$
Yz7	20	$\begin{bmatrix}I1Rshift\\I1Sshift\\I1Tshift\end{bmatrix}=\frac{1}{\sqrt{3}}\begin{bmatrix}1&0&-1\\-1&1&0\\0&-1&1\end{bmatrix}\begin{bmatrix}IL1\_F1\_local\\IL2\_F1\_local\\IL3\_F1\_local\end{bmatrix}$	$\begin{bmatrix}I2Rshift\\I2Sshift\\I2Tshift\end{bmatrix}=\frac{1}{3}\begin{bmatrix}-2&1&1\\1&-2&1\\1&1&-2\end{bmatrix}\begin{bmatrix}IL1\_F1\_remote\\IL2\_F1\_remote\\IL3\_F1\_remote\end{bmatrix}$
Yz11	21	$\begin{bmatrix}I1Rshift\\I1Sshift\\I1Tshift\end{bmatrix}=\frac{1}{\sqrt{3}}\begin{bmatrix}1&-1&0\\0&1&-1\\-1&0&1\end{bmatrix}\begin{bmatrix}IL1\_F1\_local\\IL2\_F1\_local\\IL3\_F1\_local\end{bmatrix}$	$\begin{bmatrix}I2Rshift\\I2Sshift\\I2Tshift\end{bmatrix}=\frac{1}{3}\begin{bmatrix}2&-1&-1\\-1&2&-1\\-1&-1&2\end{bmatrix}\begin{bmatrix}IL1\_F1\_remote\\IL2\_F1\_remote\\IL3\_F1\_remote\end{bmatrix}$

Magnitude compensation

The differential currents are calculated using the (I1Rshift, I1Sshift, I1Tshift) and (I2Rshift, I2Sshift, I2Tshift) values and the DIF87L_TRPr_IPar (TR local) and DIF87L_TRSec_IPar (TR remote) parameters, defined by the turn's ratio of the transformer and that of the current transformers, resulting the currents with the apostrophe ('). (The positive direction of the currents is directed in on both sides.)

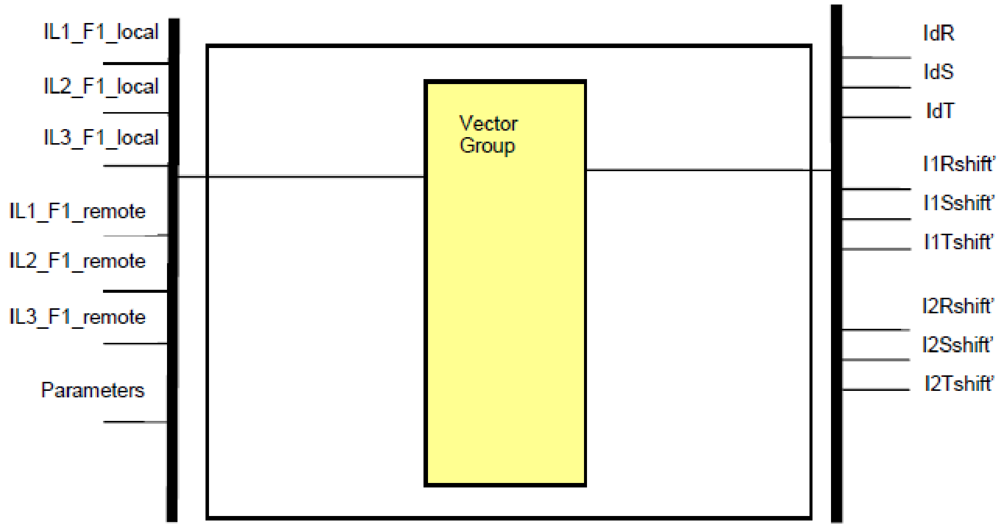
$$\begin{bmatrix}IdR\\IdS\\IdT\end{bmatrix}=\begin{bmatrix}I1Rshift'\\I1Sshift'\\I1Tshift'\end{bmatrix}+\begin{bmatrix}I2Rshift'\\I2Sshift'\\I2Tshift'\end{bmatrix}=\frac{100}{TR\_local}\begin{bmatrix}I1Rshift\\I1Sshift\\I1Tshift\end{bmatrix}+\frac{100}{TR\_remote}\begin{bmatrix}I2Rshift\\I2Sshift\\I2Tshift\end{bmatrix}$$

The current measuring software modules process these Fourier base harmonic values of the differential currents.

The principal scheme of the vector group compensation

Figure below shows the principal scheme of the vector shift compensation.

Figure. 6.3.14 - 76. Principal scheme of the vector shift compensation.



The inputs are:

- The three phase Fourier current vectors of the local side (IL1_F1_local,IL2_F1_local, IL3_F1_local)
- The three phase Fourier current vectors of the remote side (IL1_F1_remote,IL2_F1_ remote, IL3_F1_ remote)
- Parameters for vector shift and turn's ratio compensation.

The outputs are the phase-shifted currents:

The differential currents after phase-shift:

$$\begin{bmatrix} IdR \\ IdS \\ IdT \end{bmatrix}$$

The local currents after phase-shift:

$$\begin{bmatrix} I1Rshift' \\ I1Sshift' \\ I1Tshift' \end{bmatrix}$$

The remote currents after phase-shift:

$$\begin{bmatrix} I2Rshift' \\ I2Sshift' \\ I2Tshift' \end{bmatrix}$$

Harmonic restraint decision

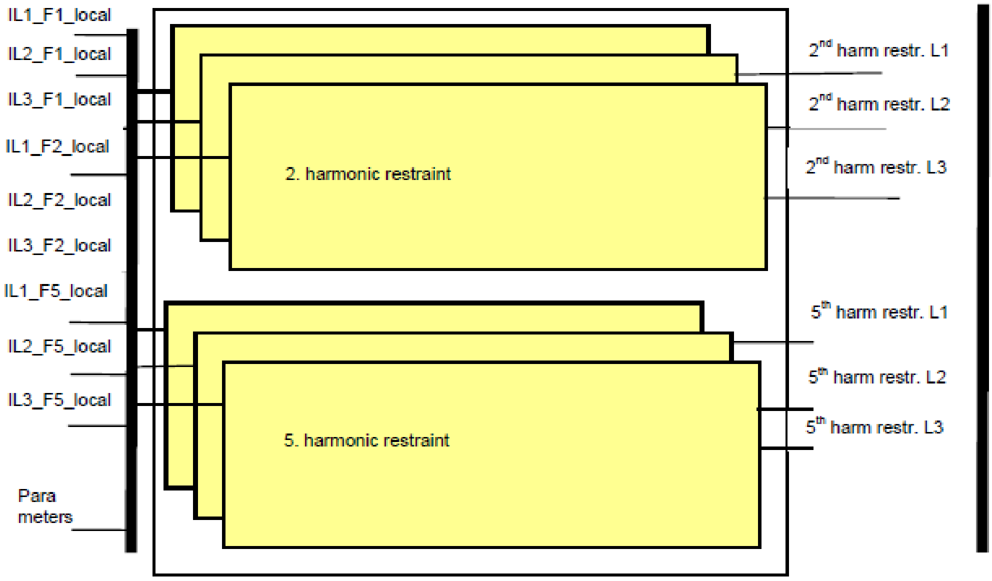
The phase currents and the differential currents can be high in case of transformerenergizing, due to the current distortion caused by the transformer iron core asymmetricsaturation. In this case the second harmonic content of the differential current is applied todisable the operation of the differential protection function.

The differential current can be high in case of over-excitation of the transformer, due to thecurrent distortion caused by the transformer iron core symmetric saturation. In this case thefifth harmonic content of the differential current is applied to disable the operation of thedifferential protection function.

The harmonic analysis block of modules consists of two sub-blocks, one for the secondharmonic decision and one for the fifth harmonic decision. Each sub-blocks include threeindividual software modules for the phases.

The software modules evaluate the harmonic content relative to the basic harmoniccomponent of the local phase currents, and compare the result with the parameter values,set for the second and fifth harmonic. If the content is high, then the assigned status signalis set to "true" value. If the duration of the active status is at least 25ms, then resetting ofthe status signal is delayed by additional 15ms.

Figure. 6.3.14 - 77. Principal scheme of the harmonic restraint decision.



<u>The inputs are the basic, the second and the fifth harmonic Fourier components of the differential currents:</u>

The basic harmonic Fourier components of the differental currents:

$$\begin{bmatrix} IL1\_F1\_local \\ IL2\_F1\_local \\ IL3\_F1\_local \end{bmatrix}$$

The second harmonic Fourier components of the differental currents:

$$\begin{bmatrix} IL1\_F2\_local \\ IL2\_F2\_local \\ IL3\_F2\_local \end{bmatrix}$$

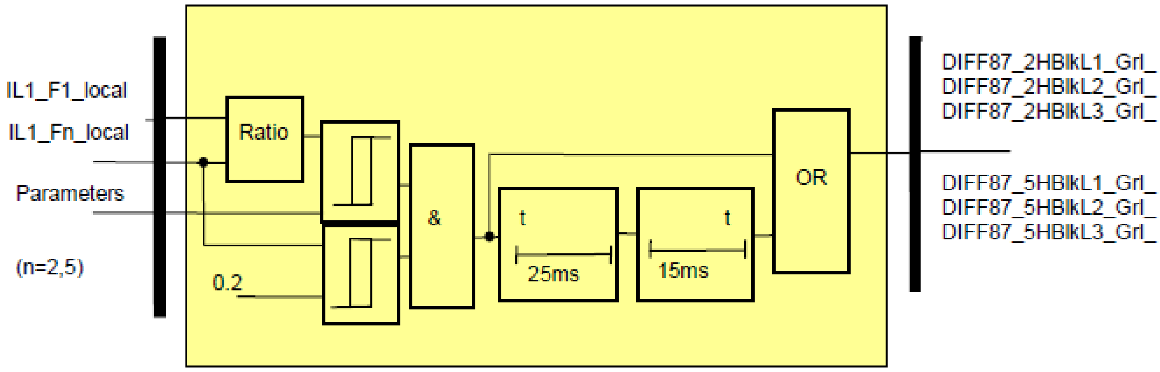
The fifth harmonic Fourier components of the differental currents:

$$\begin{bmatrix} IL1\_F5\_local \\ IL2\_F5\_local \\ IL3\_F5\_local \end{bmatrix}$$

Parameters

The outputs of the modules are the status signals for each phase and for second and fifth harmonics separately, indicating the restraint status caused by high harmonic contents.

Figure. 6.3.14 - 78. Logic scheme of the harmonic restraint decision.



The logic scheme is repeated for the second (n=2) and fifth (n=5) harmonic restraint decision, for all three phases separately (x=L1, L2, L3).

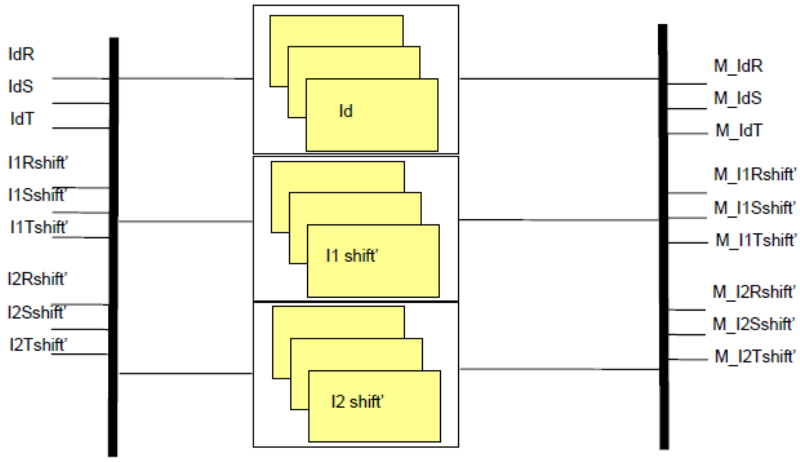
First the ratio of the harmonic and the base harmonic is calculated, and this ratio is compared to the parameter setting (second and fifth separately). In case of high ratio value the restraint signal is generated immediately, and at the same time a timer is started. If 25ms delay is over, and during the running time the high ratio was continuous, then a drop-off timer is started, which extends the duration of the restraint signal. So if the duration of the active status is at least 25 ms, then resetting of the status signal is delayed by additional 15ms.

The six status signals of the phases are connected in OR gate to result general second or fifth harmonic restraint status signals.

Current magnitude calculation

The module, which evaluates the differential characteristics, compares the magnitude of the differential currents and those of the restraint currents. For this calculation the current magnitudes are needed. These magnitudes are calculated in this module.

Figure. 6.3.14 - 79. Principal scheme of the current magnitude calculation.



The inputs are the Fourier vectors of the phase-shifted currents:

The differential currents after phase-shift:

$$\begin{bmatrix} IdR \\ IdS \\ IdT \end{bmatrix}$$

The local currents after phase-shift:

$$\begin{bmatrix} I1Rshift' \\ I1Sshift' \\ I1Tshift' \end{bmatrix}$$

The remote currents after phase-shift:

$$\begin{bmatrix} I2Rshift' \\ I2Sshift' \\ I2Tshift' \end{bmatrix}$$

The outputs are the magnitude of the calculated currents:

The magnitudes of the differential currents after phase-shift:

$$\begin{bmatrix} M\_IdR \\ M\_IdS \\ M\_IdT \end{bmatrix}$$

The magnitudes of the local currents after phase-shift:

$$\begin{bmatrix} M\_I1Rshift' \\ M\_I1Sshift' \\ M\_I1Tshift' \end{bmatrix}$$

The magnitudes of the remote currents after phase-shift:

$$\begin{bmatrix} M\_I2Rshift' \\ M\_I2Sshift' \\ M\_I2Tshift' \end{bmatrix}$$

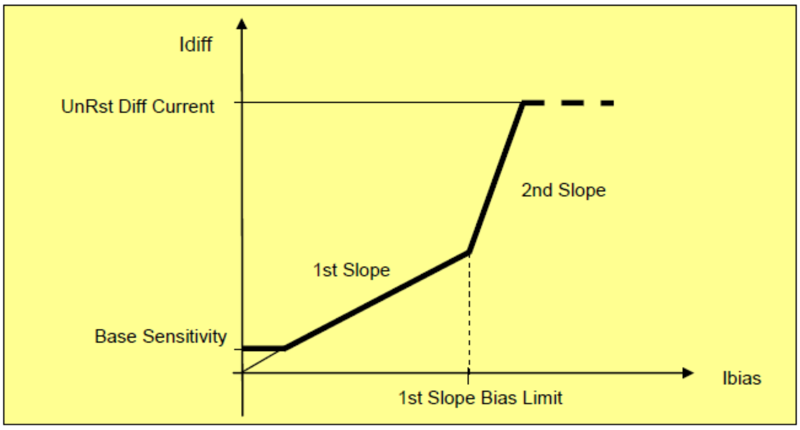
The restraint (bias) current for all phases is calculated as the maximum of the six currents:

M_Ibias = MAX(M_I1Rshift'; M_I2Rshift'; M_I1Sshift'; M_I2Sshift'; M_I1Tshift'; M_I2Tshift')

Differential characteristics

This module evaluates the differential characteristics. It compares the magnitude of the differential currents and those of the restraint currents. Based on the values of the restraint current magnitudes (denoted generally as “Ibias”) and the values of the differential current magnitudes (denoted generally as “Idiff”) the differential protection characteristics are shown in figure below.

Figure. 6.3.14 - 80. Differential protection characteristics.

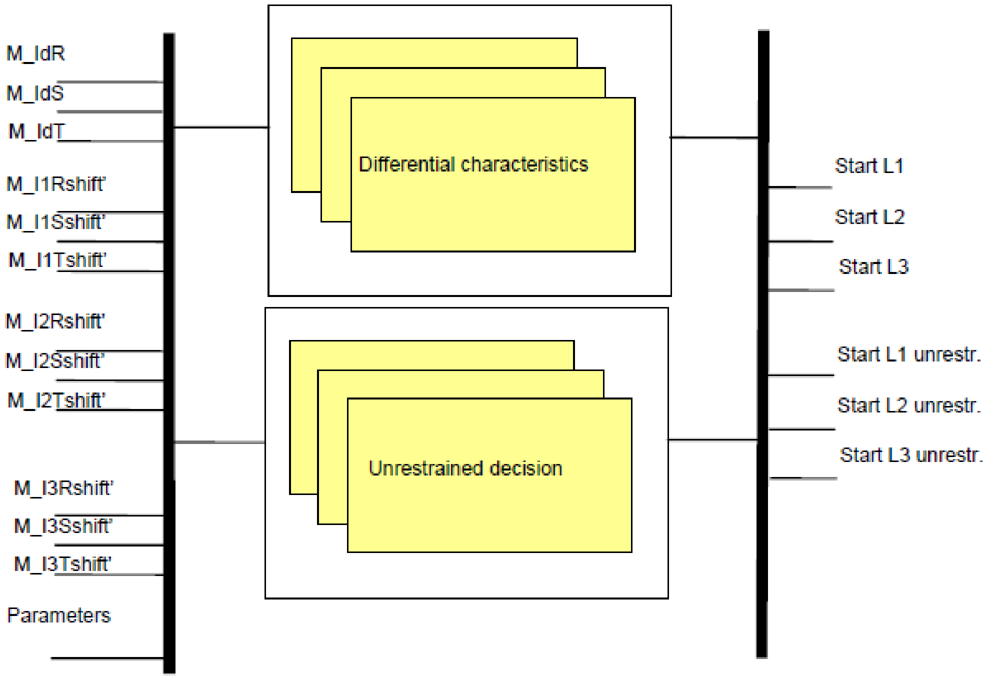


Unrestrained differential function

If the calculated differential current is very high then the differential characteristic is not considered anymore, because separate status-signals for the phases are set to “true” value if the differential currents in the individual phases are above the limit, defined by parameter setting.

The decisions of the phases are connected in OR gate to result the general start status signal.

Figure. 6.3.14 - 81. Principal scheme of evaluation of differential protection characteristics.



The inputs are the magnitude of the calculated currents:

The magnitudes of the differential currents after phase-shift:

$$\begin{bmatrix} M\_IdR \\ M\_IdS \\ M\_IdT \end{bmatrix}$$

The magnitudes of the local currents after phase-shift:

$$\begin{bmatrix} M\_I1Rshift' \\ M\_I1Sshift' \\ M\_I1Tshift' \end{bmatrix}$$

The magnitudes of the remote currents after phase-shift:

$$\begin{bmatrix} M\_I2Rshift' \\ M\_I2Sshift' \\ M\_I2Tshift' \end{bmatrix}$$

Decision logic

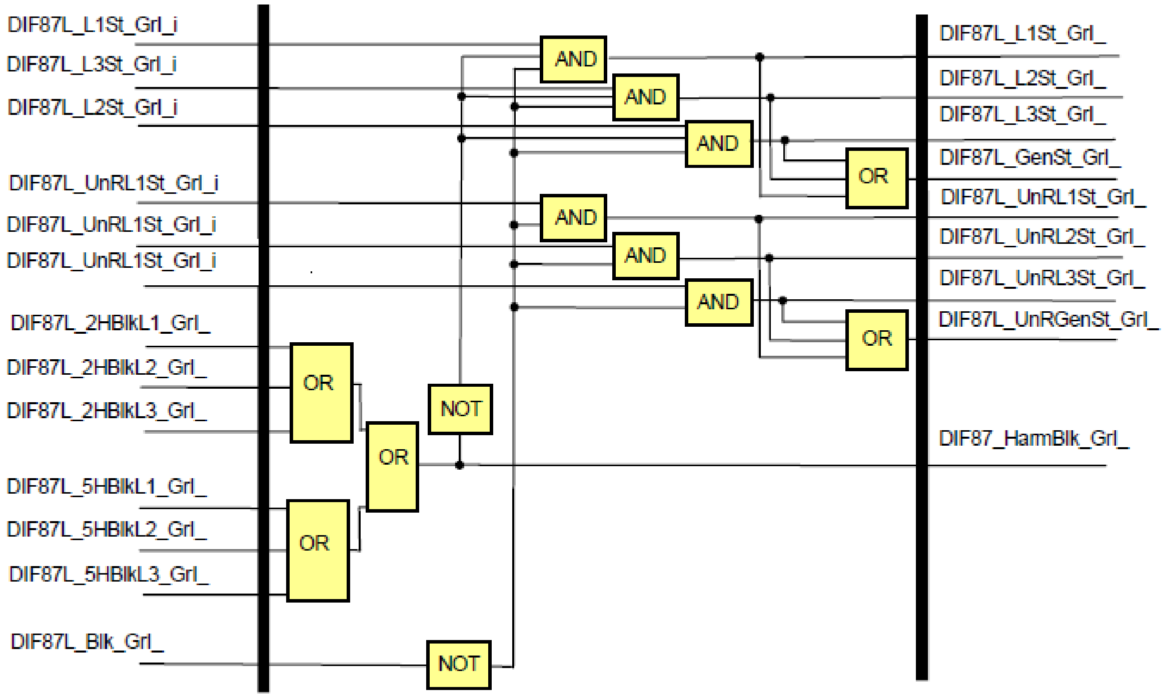
The decision logic combines the following binary signals:

- Start signals of the differential characteristic module
- Unrestrained start signals of the differential characteristic module
- Harmonic restraint signals of the 2nd harmonic restraint decision
- Harmonic restraint signals of the 5th harmonic restraint decision
- Disabling status signals defined by the user, using graphic equation editor DIF87L_Blk_GrO

The inputs are the internal calculated status signals of the differential characteristics module, those of the 2nd harmonic restraint and 5th harmonic restraint modules and binary input parameters.

These signals are processed by the decision logic of the device described in the following figure.

Figure. 6.3.14 - 82. Decision logic schema of the differential protection function.



Setting calculation example

Example data

Settings for a 120 kV line and a transformer:

Transformer data:

Sn = 125 MVA

U1/U2 = 132/11.5 kV/kV

Yd11

Current transformer:

Substation “A” CT120 — 600/1 A/A

Substation “B” CT11.5 — 6000/1 A/A

The rated current of the transformer:

I1np = 546 A (primary side)

I1n = 0.91 A (secondary side)

Calculated current on the secondary side of the transformer:

I2np = 132/11.5*546 A =6275 A

I2n = 1.05 A (secondary side)

Example setting parameters

Substation "A", 120 kV

TR local = 91 %

(This is a free choice, giving the currents of the 120 kV side current transformer's current, related to the rated current of the CT.)

TR remote = 105 %

(This is a direct consequence of selecting TR local; this is the current of the secondary side current transformer related to the rated current of the CT.)

The code value of the transformer's connection group (see Table 1-1) (Yd11):

VGroup = Yd11

Substation "B", 11.5 kV

TR local = 105 %

(Opposite to substation "A".)

TR remote = 91 %

(Opposite to substation "A".)

The code value of the transformer's connection group seen from the location of the current transformer (reference is the d side)

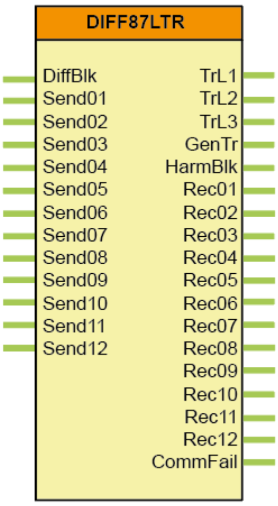
VGroup = Dy1

(Mirrored as compared to substation "A".)

Function block

The function block of the line differential function with transformer within protected zone is shown in figure bellow. This block shows all binary input and output status signals that are applicable in the AQtivate 300 software.

Figure. 6.3.14 - 83. Function block of the line differential protection function with transformer within protected zone.



The binary input and output status signals of the line differential function with transformerwithin protected zone are listed in tables below.

Table. 6.3.14 - 45. The binary input signals of the line differential function with transformer within protected zone.

Binary input signal	Explanation
DIFF87L_DiffBlk_GrO_	Block
DIFF87L_Send01_GrO_	Free configurable signal to be sent via communication channel
...	...
DIFF87L_Send12_GrO_	Free configurable signal to be sent via communication channel

Table. 6.3.14 - 46. The binary output signals of the line differential function with transformer within protected zone.

Binary output signal	Signal title	Explanation
Trip command of the line differential protection function		
DIFF87L_TrL1_GrI_	Trip L1	Trip command in line L1
DIFF87L_TrL2_GrI_	Trip L2	Trip command in line L2
DIFF87L_TrL3_GrI_	Trip L3	Trip command in line L3
DIFF87L_GenTr_GrI_		General trip command
Harmonic blocking		
DIFF87L_HarmBlk_GrI_	Harmonic restr.	Harmonic blocking
Free configurable signals to be sent via communication channel		
DIFF87L_Rec01_GrI_	Received Ch01	Free configurable signal received via communication channel
...	...	...

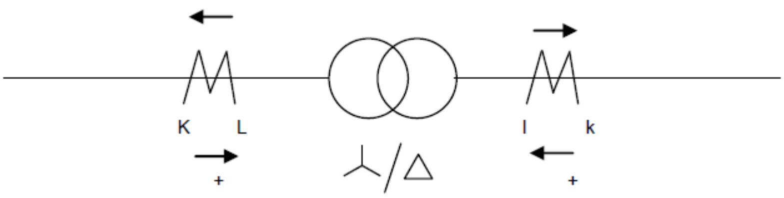
Binary output signal	Signal title	Explanation
DIFF87L_Rec12_GrI_	Received Ch12	Free configurable signal received via communication channel
Communication failure signal		
DIFF87L_CommFail_GrI_	CommFail	Signal indicating communication failure

Setting considerations of the line differential protection

Current distribution inside the Y/d transformers

For the explanation the following positive directions are applied:

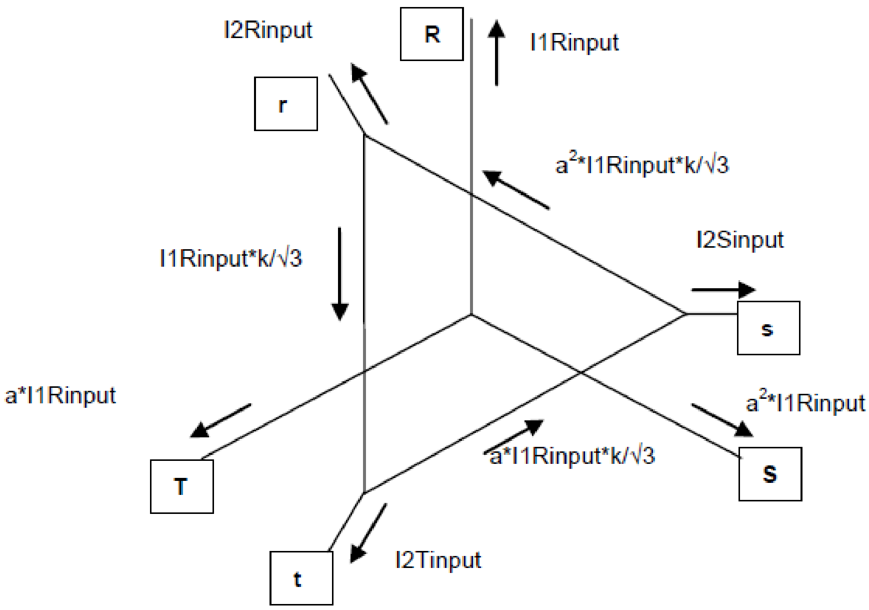
Figure. 6.3.14 - 84. Positive directions.



Three-phase fault (or normal load state)

The figure below shows the current distribution inside the transformers in case of three-phase fault or at normal, symmetrical load state:

Figure. 6.3.14 - 85. Currents in case of normal load (or three-phase fault).



On this figure *k* is the current ratio. The positive directions are supposed to be directed out of the transformer on both sides, as it is supposed by the differential protection. (If the directions suppose currents flowing through the transformer, then

I2R input = kI/√3(1-a²)

This indicates that the connection group of this transformer is Yd11.)

Here the primary currents form a symmetrical system:

$$\begin{bmatrix} I1Rinput \\ I1Sinput \\ I1Tinput \end{bmatrix} = I \begin{bmatrix} 1 \\ a^2 \\ a \end{bmatrix}$$

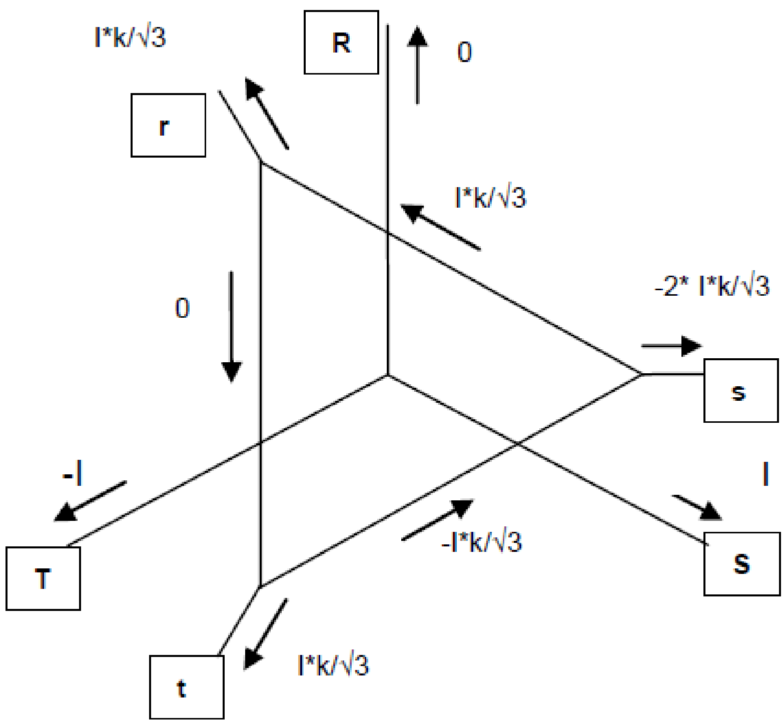
The secondary currents can be seen on the figure (please consider the division factor √3 in the effective turn's ratio):

$$\begin{bmatrix} I2Rinput \\ I2Sinput \\ I2Tinput \end{bmatrix} = k * I \frac{1}{\sqrt{3}} \begin{bmatrix} (a^2 - 1) \\ (a - a^2) \\ (1 - a) \end{bmatrix}$$

Phase-to-phase fault on the Y side

Assume I current on the primary Y side between phases S and T.

Figure. 6.3.14 - 86. Currents inside the transformer at ST fault on the Y side.



On this figure *k* is the current ratio.

The Y side currents are:

$$\begin{bmatrix} I1Rinput \\ I1Sinput \\ I1Tinput \end{bmatrix} = I \begin{bmatrix} 0 \\ 1 \\ -1 \end{bmatrix}$$

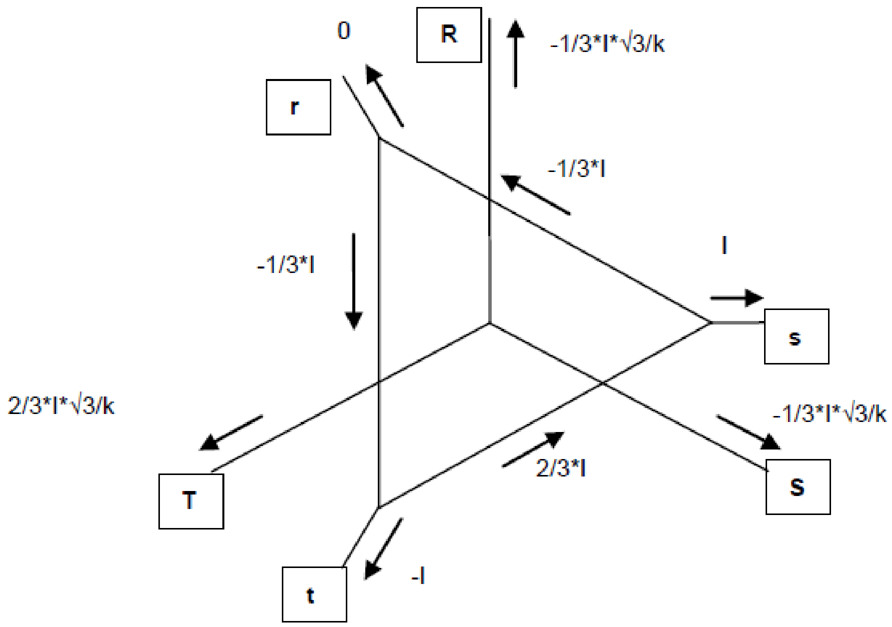
The delta side currents can be seen on this figure:

$$\begin{bmatrix} I2Rinput \\ I2Sinput \\ I2Tinput \end{bmatrix} = k * \frac{1}{\sqrt{3}} * I \begin{bmatrix} 1 \\ -2 \\ 1 \end{bmatrix}$$

Phase-to-phase fault on the delta side

Assume I current on the secondary delta side between phases "s" and "t".

Figure. 6.3.14 - 87. Currents inside the transformer at "st" fault on the delta side.



On this figure *k* is the current ratio.

The secondary currents are:

$$\begin{bmatrix} I2Rinput \\ I2Sinput \\ I2Tinput \end{bmatrix} = I \begin{bmatrix} 0 \\ 1 \\ -1 \end{bmatrix}$$

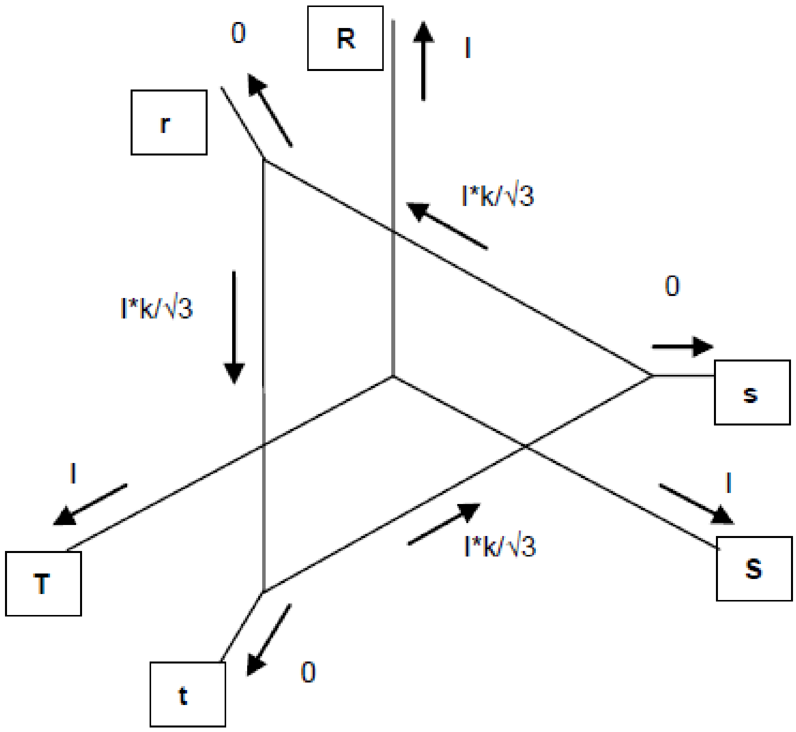
These are distributed in the delta supposing 2/3: 1/3 distribution factor. So the primary Y side currents can be seen on this figure:

$$\begin{bmatrix} I1Rinput \\ I1Sinput \\ I1Tinput \end{bmatrix} = k * \frac{1}{\sqrt{3}} * I \begin{bmatrix} -1 \\ -1 \\ 2 \end{bmatrix}$$

Single phase external fault on the Y side

Assume I fault current on the phase R in case of solidly grounded network. No power supply is supposed at the delta side:

Figure. 6.3.14 - 88. Currents inside the transformer at single phase fault at the Y side (Bauch effect).



On this figure *k* is the current ratio.

The primary Y side currents are:

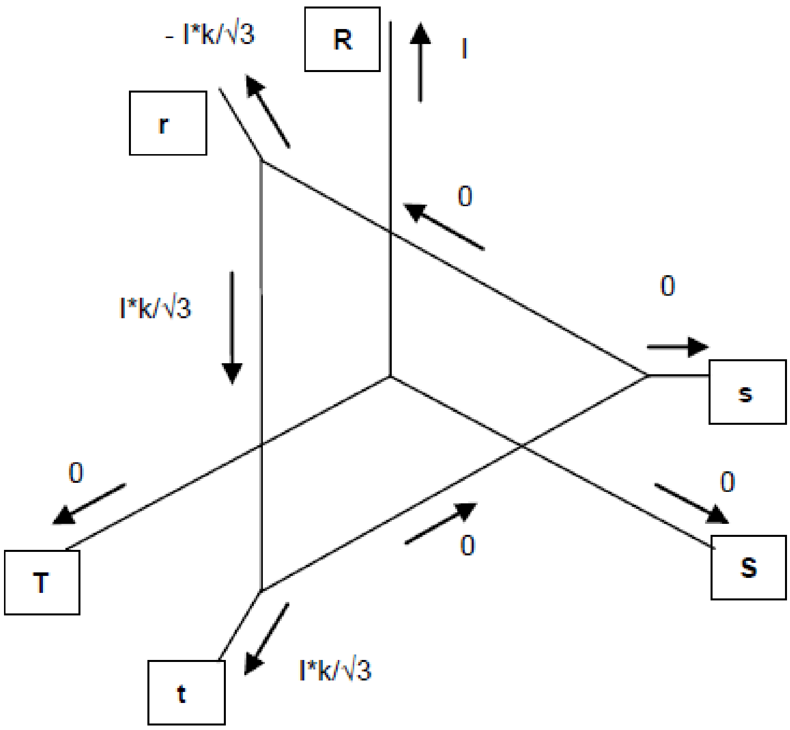
$$\begin{bmatrix} I1Rinput \\ I1Sinput \\ I1Tinput \end{bmatrix} = I \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}$$

On the delta side there are no currents flowing out of the transformer:

$$\begin{bmatrix} I2Rinput \\ I2Sinput \\ I2Tinput \end{bmatrix} = I \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

Assume I fault current at the Y side in phase R in case of solidly grounded neutral. Assume the power supply at the delta side:

Figure. 6.3.14 - 89. Currents inside the transformer at single phase fault at the Y side, supply at the delta side.



On this figure *k* is the current ratio.

The primary Y side currents are:

$$\begin{bmatrix} I1Rinput \\ I1Sinput \\ I1Tinput \end{bmatrix} = I \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

The delta side currents can be seen on this figure:

$$\begin{bmatrix} I2Rinput \\ I2Sinput \\ I2Tinput \end{bmatrix} = k * \frac{1}{\sqrt{3}} * I \begin{bmatrix} -1 \\ 0 \\ 1 \end{bmatrix}$$

Checking in case of symmetrical rated load currents

For the checking the positive directions defined in the Appendix is applied:

Based on the figure "Currents in case of normal load (or three-phase fault)", the primary currents are:

$$\begin{bmatrix} I1Rinput \\ I1Sinput \\ I1Tinput \end{bmatrix} = I1np * \frac{1}{600} \begin{bmatrix} 1 \\ a^2 \\ a \end{bmatrix}$$

The transformed values of the primary side:

$$\begin{bmatrix} I1Rshift` \\ I1Sshift` \\ I1Tshift` \end{bmatrix} = \frac{100}{TR\_local}\frac{1}{\sqrt{3}}\begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix}\begin{bmatrix} I1Rinput \\ I1Sinput \\ I1Tinput \end{bmatrix} = \frac{1}{\sqrt{3}} I1np * \frac{1}{600} * \frac{100}{TR\_local}\begin{bmatrix} (1-a^2) \\ (a^2-a) \\ (a-1) \end{bmatrix}$$

$$\begin{bmatrix} I1Rshift` \\ I1Sshift` \\ I1Tshift` \end{bmatrix} = \frac{1}{\sqrt{3}} I1np * 0.00183 \begin{bmatrix} (1-a^2) \\ (a^2-a) \\ (a-1) \end{bmatrix}$$

The secondary currents are drawn in the above-mentioned figure (consider the division by √3 as defined by the turn's ratio):

$$\begin{bmatrix} I2Rinput \\ I2Rinput \\ I2Rinput \end{bmatrix} = I1np * \frac{132}{11.5} * \frac{1}{\sqrt{3}} * \frac{1}{6000}\begin{bmatrix} (a^2-1) \\ (a-a^2) \\ (1-a) \end{bmatrix}$$

The secondary currents are transformed by the unit matrix. It means that only the turn's ratio is considered:

$$\begin{bmatrix} I2Rshift` \\ I2Sshift` \\ I2Tshift` \end{bmatrix} = \frac{100}{TR\_remote} * I1np * \frac{132}{11.5} * \frac{1}{\sqrt{3}} * \frac{1}{6000} * \begin{bmatrix} (a^2-1) \\ (a-a^2) \\ (1-a) \end{bmatrix}$$

$$\begin{bmatrix} I2Rshift` \\ I2Sshift` \\ I2Tshift` \end{bmatrix} = -\frac{1}{\sqrt{3}} I1np * 0.00182 \begin{bmatrix} (1-a^2) \\ (a^2-a) \\ (a-1) \end{bmatrix}$$

These currents are the same (with the round-off errors of. 0.5%) as the primary transformed currents, but multiplied by „-1”. As the differential currents are the sum of the shifted phase currents, these all result zero, the differential protection is balanced.

Checking for Y side external phase-to-phase fault

Assume *I* fault current at the Y side of the transformer in phases S and T.

According to the figure titled "Currents inside the transformer at ST fault on the Y side", the input currents from the primary side of the transformer:

$$\begin{bmatrix} I1Rinput \\ I1Sinput \\ I1Tinput \end{bmatrix} = \frac{1}{600} * I * \begin{bmatrix} 0 \\ 1 \\ -1 \end{bmatrix}$$

Transforming these currents:

$$\begin{bmatrix} I1Rshift` \\ I1Sshift` \\ I1Tshift` \end{bmatrix} = \frac{1}{\sqrt{3}} * \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} I1Rinput \\ I1Sinput \\ I1Tinput \end{bmatrix} = \frac{1}{\sqrt{3}} * I * \frac{1}{600} * \frac{100}{TR\_local} \begin{bmatrix} -1 \\ 2 \\ -1 \end{bmatrix}$$

$$\begin{bmatrix} I1Rshift` \\ I1Sshift` \\ I1Tshift` \end{bmatrix} = \frac{1}{\sqrt{3}} * I * 0.00183 \begin{bmatrix} -1 \\ 2 \\ -1 \end{bmatrix}$$

The input currents from the secondary side of the transformer can be seen in the above-mentioned figure:

$$\begin{bmatrix} I2Rinput \\ I2Sinput \\ I2Tinput \end{bmatrix} = \frac{1}{6000} * \frac{132}{11.5} * \frac{1}{\sqrt{3}} * I * \begin{bmatrix} 1 \\ -2 \\ 1 \end{bmatrix}$$

These secondary side currents are transformed with the unit matrix, so only the turn's ratio has to be considered:

$$\begin{bmatrix} I2Rshift` \\ I2Sshift` \\ I2Tshift` \end{bmatrix} = \frac{100}{TR\_remote} * I * \frac{132}{11.5} * \frac{1}{\sqrt{3}} * \frac{1}{6000} * \begin{bmatrix} 1 \\ -2 \\ 1 \end{bmatrix}$$

$$\begin{bmatrix} I2Rshift` \\ I2Sshift` \\ I2Tshift` \end{bmatrix} = -\frac{1}{\sqrt{3}} I * 0.00182 \begin{bmatrix} -1 \\ 2 \\ -1 \end{bmatrix}$$

These currents are the same (with the round-off errors of. 0.5%) as the primary transformed currents, but multiplied by „-1”. As the differential currents are the sum of the shifted phase currents, these all result zero, the differential protection is balanced.

Here the attention must be drawn to the multiplication factor „2” in phase S. The consequences must be analyzed in a separate chapter.

Checking for D side external phase-to-phase fault

Assume I fault current at the D side of the transformer in phases S and T.

According to the figure titled "Currents inside the transformer at “st” fault on the delta side", the input currents to the differential protection are:

$$\begin{bmatrix} I2Rinput \\ I2Sinput \\ I2Tinput \end{bmatrix} = \frac{1}{6000} * I * \begin{bmatrix} 0 \\ 1 \\ -1 \end{bmatrix}$$

These secondary side currents are transformed with the unit matrix, so only the turn's ratio has to be considered:

$$\begin{bmatrix} I2Rshift` \\ I2Sshift` \\ I2Tshift` \end{bmatrix} = \frac{100}{TR\_remote} * I \frac{1}{6000} * \begin{bmatrix} 0 \\ 1 \\ -1 \end{bmatrix}$$

$$\begin{bmatrix} I2Rshift` \\ I2Sshift` \\ I2Tshift` \end{bmatrix} = 0.1587 * 10^{-3} * I \begin{bmatrix} 0 \\ 1 \\ -1 \end{bmatrix}$$

The input currents from the primary Y side can be seen in the above-mentioned figure:

$$\begin{bmatrix} I1Rinput \\ I1Sinput \\ I1Tinput \end{bmatrix} = \frac{1}{600} * \frac{11.5}{132} * \sqrt{3} * I * \frac{1}{3} \begin{bmatrix} -1 \\ -1 \\ 2 \end{bmatrix}$$

The transformation of these Y side currents:

$$\begin{bmatrix} I1Rshift` \\ I1Sshift` \\ I1Tshift` \end{bmatrix} = \frac{1}{\sqrt{3}} * \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} I1Rinput \\ I1Sinput \\ I1Tinput \end{bmatrix} = \frac{1}{\sqrt{3}} * I * \frac{1}{600} * \frac{100}{TR\_local} * \frac{11.5}{132} \begin{bmatrix} 0 \\ -1 \\ 1 \end{bmatrix}$$

$$\begin{bmatrix} I1Rshift` \\ I1Sshift` \\ I1Tshift` \end{bmatrix} = -I * 0.1596 * 10^{-3} * \begin{bmatrix} 0 \\ 1 \\ -1 \end{bmatrix}$$

These currents are the same (with the round-off errors of. 0.5%) as the secondary transformed currents, but multiplied by „-1”. As the differential currents are the sum of the shifted phase currents, these all result zero, the differential protection is balanced.

Here the attention must be drawn to the multiplication factor „-1” and „1” in phases S and T, respectively. The consequences must be analyzed in a separate chapter.

Checking for Y side external phase-to-ground fault

If the neutral point of the transformer is grounded, an R phase to ground primary I fault current can be supposed. Suppose additionally that no supply from the delta side can be expected.

Based on the figure titled "Currents inside the transformer at single phase fault at the Y side (Bauch effect)", the input currents from the Y side are:

$$\begin{bmatrix} I1Rinput \\ I1Sinput \\ I1Tinput \end{bmatrix} = \frac{1}{600} * I * \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}$$

The transformation of the primary currents:

$$\begin{bmatrix} I1Rshift` \\ I1Sshift` \\ I1Tshift` \end{bmatrix} = \frac{1}{\sqrt{3}} * \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} I1Rinput \\ I1Sinput \\ I1Tinput \end{bmatrix} = \frac{1}{\sqrt{3}} * I * \frac{1}{600} * \frac{100}{TR\_primary} \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

The secondary currents can be seen in the above-mentioned figure:

$$\begin{bmatrix} I2Rinput \\ I2Sinput \\ I2Tinput \end{bmatrix} = \frac{1}{6000} * \frac{132}{11.5} * \frac{1}{\sqrt{3}} * I * \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

These secondary currents are transformed with the unit matrix, so only the turn's ratio is considered:

$$\begin{bmatrix} I2Rshift` \\ I2Sshift` \\ I2Tshift` \end{bmatrix} = \frac{1}{\sqrt{3}} * I * \frac{1}{6000} * \frac{100}{TR\_primary} * \frac{132}{11.5} \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

Because of zero currents, the differential protection is stable.

Now suppose I fault current in phase R on the external primary side of the transformer, if the neutral is grounded. The fault is supplied in this case from the delta side:

Based on the figure titled "Currents inside the transformer at single phase fault at the Y side, supply at the delta side", the input currents from the primary side are:

$$\begin{bmatrix} I1Rinput \\ I1Sinput \\ I1Tinput \end{bmatrix} = \frac{1}{600} * I * \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

The transformation of these primary currents:

$$\begin{bmatrix} I1Rshift` \\ I1Sshift` \\ I1Tshift` \end{bmatrix} = \frac{1}{\sqrt{3}} * \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} I1Rinput \\ I1Sinput \\ I1Tinput \end{bmatrix} = \frac{1}{\sqrt{3}} * I * \frac{1}{600} * \frac{100}{TR\_primary} \begin{bmatrix} 1 \\ 0 \\ -1 \end{bmatrix}$$

$$\begin{bmatrix} I1Rshift` \\ I1Sshift` \\ I1Tshift` \end{bmatrix} = \frac{1}{\sqrt{3}} * I * 0.00183 \begin{bmatrix} 1 \\ 0 \\ -1 \end{bmatrix}$$

The input currents from the delta side, based on the above-mentioned figure:

$$\begin{bmatrix} I2Rinput \\ I2Sinput \\ I2Tinput \end{bmatrix} = \frac{1}{6000} * \frac{132}{11.5} * \frac{1}{\sqrt{3}} * I * \begin{bmatrix} -1 \\ 0 \\ 1 \end{bmatrix}$$

These secondary currents are transformed with the unit matrix, so only the turn's ratio is considered:

$$\begin{bmatrix} I2Rshift` \\ I2Sshift` \\ I2Tshift` \end{bmatrix} = \frac{100}{TR\_secondary} * I * \frac{132}{11.5} * \frac{1}{\sqrt{3}} * \frac{1}{6000} * \begin{bmatrix} -1 \\ 0 \\ 1 \end{bmatrix}$$

$$\begin{bmatrix} I2Rshift` \\ I2Sshift` \\ I2Tshift` \end{bmatrix} = -\frac{1}{\sqrt{3}} I * 0.00182 \begin{bmatrix} 1 \\ 0 \\ -1 \end{bmatrix}$$

The currents are balanced; the differential protection does not generate a trip command.

Setting parameters

Table. 6.3.14 - 47. Setting parameters of the line differential protection with transformer within protected zone.

Parameter	Setting range	Step	Default	Explanation
Operation	On Off	-	Off	Setting parameter to enable the line differential protection function.
Base Sensitivity	10…50 %	1 %	30 %	Base Sensitivity setting of the differential characteristics.
1st Slope	10…50 %	1 %	30 %	1st Slope setting
2nd Slope	50…100 %	1 %	70 %	2nd Slope setting
1st Slope Bias Limit	100…400 %	1 %	200 %	1st Slope Bias Limit (second turning point)
UnRst Diff Current	500…1 500 %	1 %	800 %	Unrestrained line differential protection current level
2nd Harm Ratio	5…50 %	1 %	15 %	2nd harmonic restraint setting
5th Harm Ratio	5…50 %	1 %	25 %	5th harmonic restraint setting
TR Local	20…500 %	0.01 %	100 %	Local end current ratio compensation setting in percentage of the rated input current.
TR Remote	20…500 %	0.01 %	100 %	Remote end current ratio compensation setting in percentage of the rated input current.
VGroup	Dy1, Dy5, Dy7, Dy11 Dd0, Dd6 Dz0, Dz2, Dz4, Dz6, Dz8, Dz10 Yy0, Yy6 Yd1, Yd5, Yd7, Yd11 Yz1, Yz5, Yz7, Yz11	-	Dd0	Transformer connection group of the coils in primary-secondary relation.

6.3.15 Overfrequency protection (f>; 81O)

The deviation of the frequency from the rated system frequency indicates unbalancebetween the generated power and the load demand. If the available generation is largecompared to the consumption by the load connected to the power system, then the systemfrequency is above the rated value.

The over-frequency protection function is usually applied to decrease generation to control the system frequency. Another possible application is the detection of unintended island operation of distributed generation and some consumers. In the island, there is low probability that the power generated is the same as consumption; accordingly, the detection of high frequency can be an indication of island operation. Accurate frequency measurement is also the criterion for the synchro-check and synchro-switch functions.

The frequency measurement is based on channel No. 1 (line voltage) and channel No. 4 (busbar voltage) of the voltage input module. In some applications, the frequency is measured based on the weighted sum of the phase voltages. The accurate frequency measurement is performed by measuring the time period between two rising edges at zero crossing of a voltage signal.

For the confirmation of the measured frequency, at least four subsequent identical measurements are needed. Similarly, four invalid measurements are needed to reset the measured frequency to zero. The basic criterion is that the evaluated voltage should be above 30% of the rated voltage value. The over-frequency protection function generates a start signal if at least five measured frequency values are above the preset level.

Table. 6.3.15 - 48. Setting parameters of the overfrequency protection function.

Parameter	Setting value / range	Step	Default	Description
Operation	Off On	-	On	Operating mode selection for the function. Operation can be either enabled "On" or disabled "Off".
Start signal only	Activated Deactivated	-	Deactivated	Selection if the function issues either “Start” signal alone or both “Start” and after set time delay “Trip” signal.
Start frequency	40.00…60.00 Hz	0.01 Hz	51 Hz	Pick-up setting of the function. When the measured frequency value exceeds the setting value function initiates "Start" signal.
Time delay	0…60 000 ms	1 ms	200 ms	Operating time delay setting for the “Trip” signal from the“Start” signal.

6.3.16 Underfrequency protection (f<; 81U)

The deviation of the frequency from the rated system frequency indicates unbalance between the generated power and the load demand. If the available generation is small compared to the consumption by the load connected to the power system, then the system frequency is below the rated value.

The under-frequency protection function is usually applied to increase generation or for load shedding to control the system frequency. Another possible application is the detection of unintended island operation of distributed generation and some consumers. In the island, there is low probability that the power generated is the same as consumption; accordingly, the detection of low frequency can be an indication of island operation. Accurate frequency measurement is also the criterion for the synchro-check and synchro-switch functions.The frequency measurement is based on channel No. 1 (line voltage) and channel No. 4 (busbar voltage) of the voltage input module. In some applications, the frequency is measured based on the weighted sum of the phase voltages. The accurate frequency measurement is performed by measuring the time period between two rising edges at zero crossing of a voltage signal.

For the confirmation of the measured frequency, at least four subsequent identical measurements are needed. Similarly, four invalid measurements are needed to reset the measured frequency to zero. The basic criterion is that the evaluated voltage should be above 30% of the rated voltage value. The under-frequency protection function generates a start signal if at least five measured frequency values are below the setting value.

Table. 6.3.16 - 49. Setting parameters of the underfrequency protection function.

Parameter	Setting value / range	Step	Default	Description
Operation	Off On	-	On	Operating mode selection for the function. Operation can be either enabled "On" or disabled "Off".
Start signal only	Activated Deactivated	-	Deactivated	Selection if the function issues either “Start” signal alone orboth “Start” and after set time delay “Trip” signal.
Start frequency	40.00…60.00 Hz	0.01 Hz	49 Hz	Pick-up setting of the function. When the measured frequency value exceeds the setting value function initiates "Start" signal.
Time delay	0…60 000 ms	1 ms	200 ms	Operating time delay setting for the “Trip” signal from the“Start” signal.

6.3.17 Rate-of-change of frequency protection (fd/ft>/<; 81R)

The deviation of the frequency from the rated system frequency indicates unbalance between the generated power and the load demand. If the available generation is small compared to the consumption by the load connected to the power system, then the system frequency is below the rated value. If the unbalance is large, then the frequency changes rapidly. The rate of change of frequency protection function is usually applied to reset the balance between generation and consumption to control the system frequency. Another possible application is the detection of unintended island operation of distributed generation and some consumers. In the island, there is low probability that the power generated is the same as consumption; accordingly, the detection of a high rate of change of frequency can be an indication of island operation. Accurate frequency measurement is also the criterion for the synchro-switch function.

The source for the rate of change of frequency calculation is an accurate frequency measurement. The frequency measurement is based on channel No. 1 (line voltage) and channel No. 4 (busbar voltage) of the voltage input module. In some applications, the frequency is measured based on the weighted sum of the phase voltages. The accurate frequency measurement is performed by measuring the time period between two rising edges at zero crossing of a voltage signal.

For the confirmation of the measured frequency, at least four subsequent identical measurements are needed. Similarly, four invalid measurements are needed to reset the measured frequency to zero. The basic criterion is that the evaluated voltage should be above 30% of the rated voltage value. The rate of change of frequency protection function generates a start signal if the df/dt value is above the setting vale. The rate of change of frequency is calculated as the difference of the frequency at the present sampling and at three cycles earlier.

Table. 6.3.17 - 50. Setting parameters of the rate-of-change of frequency function.

Parameter	Setting value / range	Step	Default	Description
Operation	Off On	-	On	Operating mode selection for the function. Operation can be either enabled "On" or disabled "Off".

Parameter	Setting value / range	Step	Default	Description
Start signal only	Activated Deactivated	-	Deactivated	Selection if the function issues either "Start" signal alone orboth "Start" and after set time delay "Trip" signal.
Start df/dt	–5…5 Hz/s	0.01 Hz/s	0.5 Hz/s	Pick-up setting of the function. When the measured frequency value exceeds the setting value function initiates "Start" signal.
Time delay	0…60 000 ms	1 ms	200 ms	Operating time delay setting for the "Trip" signal from the"Start" signal.

6.3.18 Pole slip (78)

The pole slipping protection function can be applied mainly for synchronous machines. If a machine falls out of synchronism, then the voltage vector induced by the machine rotates slower or with a higher speed as compared to voltage vectors of the network. The result is that according to the frequency difference of the two vector systems, the cyclical voltage difference on the current carrying elements of the network are overloaded cyclically. To protect the stator coils from the harmful effects of the high currents and to protect the network elements, a disconnection is required.

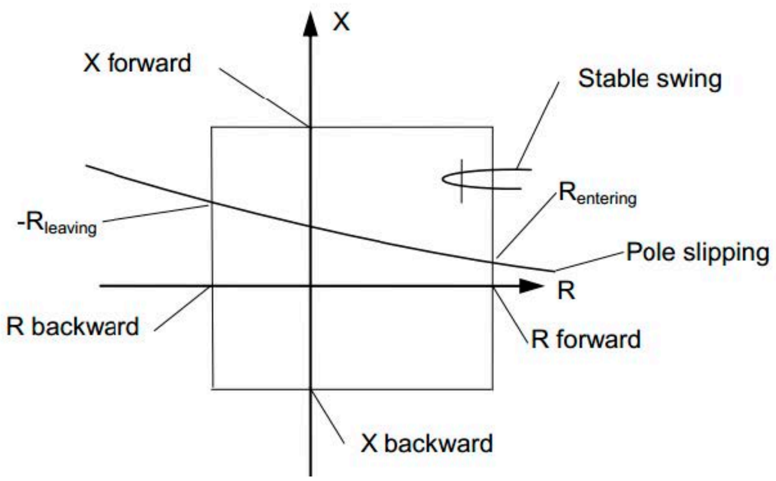
The pole slipping protection function is designed for this purpose.

Principle of operation

The principle of operation is the impedance calculation

When a machine falls out of synchronism, then the voltage vector induced by the machine rotates slower or with a higher speed as compared to voltage vectors of the network. The result is that according to the frequency difference of the two vector systems the cyclical voltage difference on the current carrying elements of the network draws cyclically high currents. The calculated impedance moves along lines "Pole slipping" as it is indicated in figure below on the impedance plane. (The stable swings return to the same quadrant of the impedance plane along lines "Stable swing".)

Figure. 6.3.18 - 90. Pole slipping.



The characteristic feature of pole slipping is that the impedance locus leaves the characteristic at a location, where the sign of the calculated resistance (e.g –Rleaving) is opposite to that of the entering location (e.g. $+R_{entering}$).If basically other protections on the network are expected to stop the pole slipping, then more than one vector revolution is permitted. In this case the number of the revolution can be set higher then 1, and the subsequent revolution is expected within a defined “Dead time”, also set by parameter.The duration of the generated trip pulse is a parameter value.

Main features

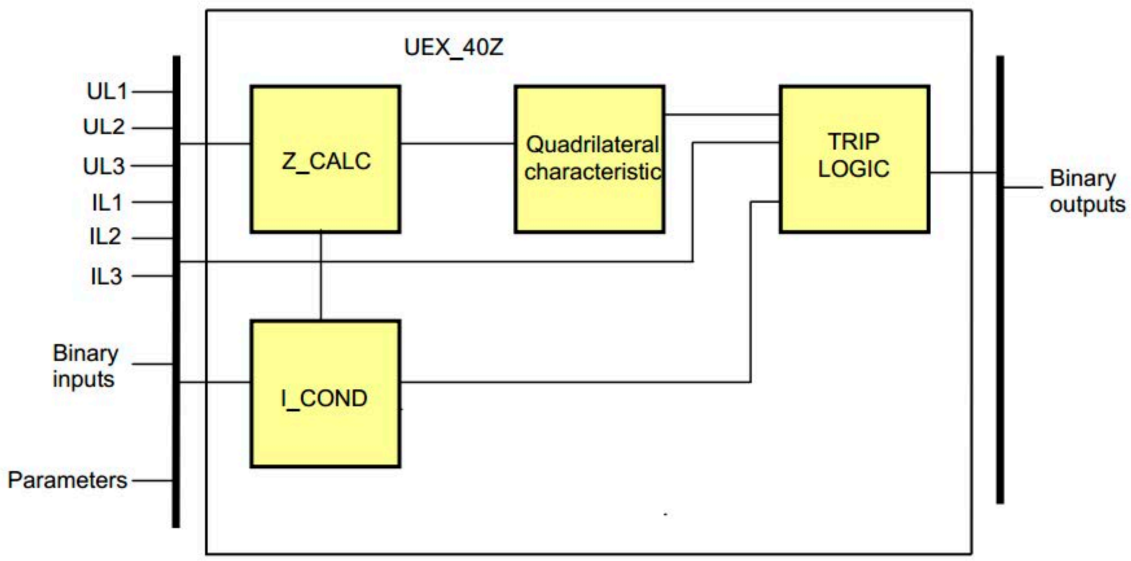
The main features of the pole slipping protection function are as follows:

- A full-scheme system provides continuous measurement of impedances separately in three independent phase-to-phase measuring loops.
- Impedance calculation is conditional on the values of the positive sequence currents being above a defined value.
- A further condition of the operation is that the negative sequence current component is less than 1/6 of the value defined for the positive sequence component.
- The operate decision is based on quadrilateral characteristics on the impedance plane using four setting parameters.
- The number of vector revolutions can be set by a parameter.
- The duration of the trip signal is set by a parameter.
- Blocking/enabling binary input signal can influence the operation.

Structure of the pole slipping protection

The figure below shows the structure of the pole slipping protection function with quadrilateral characteristic.

Figure. 6.3.18 - 91. Structure of the pole slipping algorithm.



The inputs are

- the Fourier components of three phase voltages
- the Fourier components of three phase currents
- binary inputs
- parameters.

The outputs are

- the binary output status signals.

The software modules of the pole slipping protection function are as follows:

Z_CALC calculates the impedances (R+jX) of the three phase-phase measuring current loops.

Quadrilateral characteristic compares the calculated impedances with the setting values of the quadrilateral characteristics. The result is the decision for all three measuring loops if the impedance is within the offset circle.

TRIP LOGIC is the algorithm to decide to generate the trip command.

I_COND calculates the current conditions necessary for the impedance calculation.

The following description explains the details of the individual components.

Impedance calculation (Z_CALC)

The impedance protection supplied by Arcteq Ltd. continuously measures the impedances in the three line-to-line measuring loops. The calculation is performed in the phase-to-phase loops based on the line-to-line voltages and the difference of the affected phase currents. The formulas are summarized in the table below. The result of this calculation is the positive sequence impedance of the current loops.

Table. 6.3.18 - 51. Formulas for the calculation of the impedance to fault.

Loop	Calculation of Z
L1L2	$Z_{L1L2} = (U_{L1}–U_{L2})/(I_{L1}–I_{L2})$
L2L3	$Z_{L2L3} = (U_{L2}–U_{L3})/(I_{L2}–I_{L3})$
L3L1	$Z_{L3L1} = (U_{L3}–U_{L1})/(I_{L3}–I_{L1})$

The numerical processes apply the simple R-L model.

For the equivalent impedance elements of the measuring loop, the following differential equation can be written:

$$u = Ri + L\frac{di}{dt}$$

If current and voltage values sampled at two separate sampling points in time are substituted in this equation, two equations are derived with the two unknown values R and L, so they can be calculated.

This basic principle is realized in the algorithm by substituting the Fourier fundamental component values of the line-to-line voltages for u and the difference of the Fourier fundamental components of two phase currents:

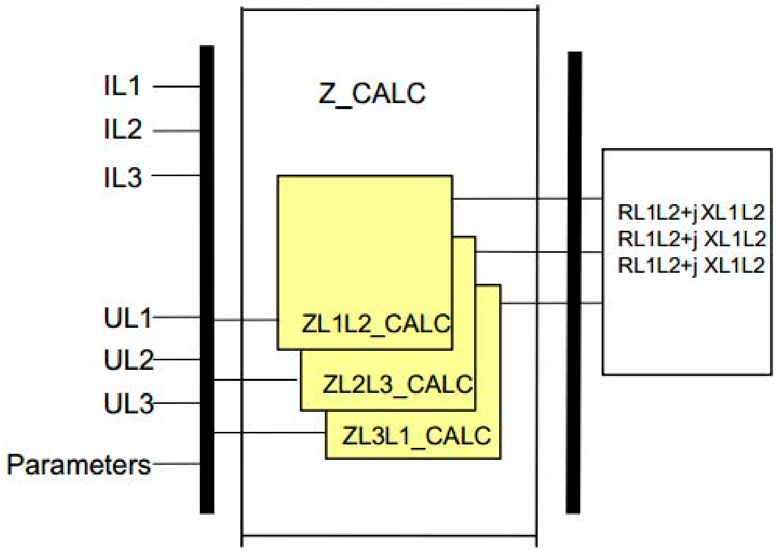
$$u_{L2} - u_{L3} = R_1(i_{L2} - i_{L3}) + L_1\frac{d(i_{L2} - i_{L3})}{dt}$$

where:

R_1 = the positive sequence resistance of the line or cable section between the fault location and the relay location
L_1 = the positive sequence inductance of the line or cable section between the fault location and the relay location
L1, L2, L3 = the three phases

The applied numerical method is solving the differential equation of the faulty loop, based on the orthogonal components of the Fourier fundamental component vectors. The calculation results complex impedances on the network frequency.

Figure. 6.3.18 - 92. Principal scheme of the impedance calculation Z_CALC.



The inputs are the Fourier components of:

- the Fourier components of three phase voltages
- the Fourier components of three phase currents, parameters.

The outputs are the calculated positive sequence impedances (R+jX) of the three measuring loops:

- Impedances of the three phase-to-phase loops.

The calculated impedances of the Z_CALC module

Table. 6.3.18 - 52. The measured (calculated) values of the Z_CALC module.

Calculated value	Dim.	Explanation
RL1L2+j XL1L2	ohm	Measured positive sequence impedance in the L1L2 loop
RL2L3+j XL2L3	ohm	Measured positive sequence impedance in the L2L3 loop
RL3L1+j XL3L1	ohm	Measured positive sequence impedance in the L3L1 loop

Z_CALC includes three practically identical software modules for impedance calculation. The three routines for the phase-to-phase loops get line-to-line voltages calculated from the sampled phase voltages and they get differences of the phase currents.

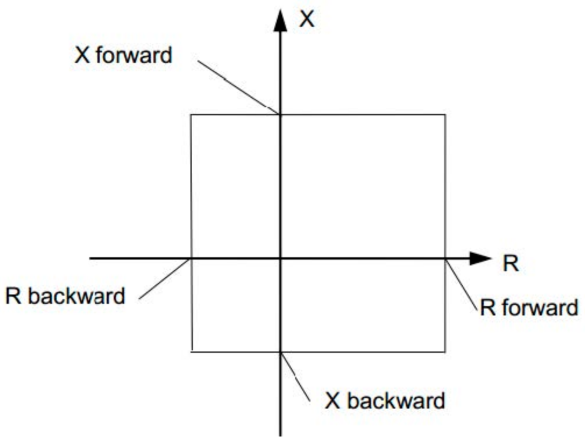
The characteristics of the pole slip protection function (Quadrilateral characteristics)

The method is an impedance-based comparison.

The operate decision is based on quadrilateral characteristics.

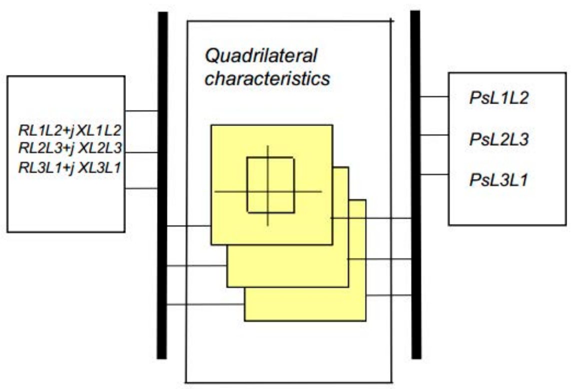
The calculated R1 and X1= L1 co-ordinate values of the three measuring loops define three points on the complex impedance plane. These impedances are the positive sequence impedances. The protection compares these points with the quadrilateral characteristics of the pole slip protection, shown in the figure below. Parameter settings decide the size and the position of the rectangle. The parameters are: R forward, X forward, R backward, X backward.

Figure. 6.3.18 - 93. The quadrilateral characteristic.



If the measured impedance enters the rectangle, then the algorithm stores the sign of the R impedance component. At leaving, the sign of the R component is evaluated again. If it is opposite to the stored value then an instable power swing, i.e. pole slip is detected.At the moment the impedance leaves the rectangle at the opposite R side, a timer is started. If the setting requires more than one vector revolutions (according to parameter “Max. cycle number”), the subsequent impedance value is required to enter into the rectangle within the running time of the timer. The running time is a parameter setting (“Dead time”).The procedure is processed for each line-to-line loop. The result is the setting of three internal status variables. This indicates that the calculated impedance performed the required number of pole slips.

Figure. 6.3.18 - 94. Principal scheme of the quadrilateral characteristic decision.



Input values

The input values are calculated by the module Z_CALC.

Table. 6.3.18 - 53. The input calculated impedances of the quadrilateral characteristics module.

Calculated value	Dim.	Explanation
RL1L2+j XL1L2	ohm	Calculated impedance in the fault loop L1L2
RL2L3+j XL2L3	ohm	Calculated impedance in the fault loop L2L3
RL3L1+j XL3L1	ohm	Calculated impedance in the fault loop L3L1

Output values

Table. 6.3.18 - 54. The output status signals of the quadrilateral characteristic module.

Output value	Explanation
PsL1L2_1	The impedance in the fault loop L1L2 performed the given number of pole slips.
PsL2L3_1	The impedance in the fault loop L2L3 performed the given number of pole slips.
PsL3L1_1	The impedance in the fault loop L3L1 performed the given number of pole slips.

The parameters needed in the characteristic evaluation procedure of the pole slip function are explained in the following Tables.

Table. 6.3.18 - 55. Parameters needed in the characteristic evaluation procedure.

Parameter	Setting value / range	Step	Description
Max. cycle number	1…10 cycles	1	Definition of the number of the vector revolution up to the trip command.
R forward	0.10…150.00 Ω	0.01 Ω	R setting of the impedance characteristics in forward direction
X forward	0.10…150.00 Ω	0.01 Ω	X setting of the impedance characteristics in forward direction
R backward	0.10…150.00 Ω	0.01 Ω	R setting of the impedance characteristics in backward direction
X backward	0.10…150.00 Ω	0.01 Ω	X setting of the impedance characteristics in backward direction

The trip logic (TRIP LOGIC) and timing

Table. 6.3.18 - 56. Dead time parameter of the trip logic.

Parameter	Setting value / range	Step	Description
Dead time	1 000…60 000 ms	1 ms	Time delay for waiting the subsequent revolution

The trip logic module decides to generate the trip command. The condition is that at least two out of three phase-to-phase loops detect pole slip in a number required by parameter setting. And the function is not blocked or disabled.

The duration of the trip pulse is defined by parameter setting

Table. 6.3.18 - 57. Trip pulse parameter setting.

Parameter	Setting value / range	Description
Operation	Off On	Parameter for disabling the function.

Table. 6.3.18 - 58. The input values.

Input value	Explanation
Operation signals from the quadrilateral characteristics module (these signals are not published)	
PsL1L2_1	The impedance in the fault loop L1L2 performed the given number of pole slips.
PsL2L3_1	The impedance in the fault loop L2L3 performed the given number of pole slips.
PsL3L1_1	The impedance in the fault loop L3L1 performed the given number of pole slips.
Impedance function start conditions generated by I_COND module (these signals are not published)	
PSLIP78_cL1_GrI_	The current in phase L1 is sufficient for impedance calculation.
PSLIP78_cL2_GrI_	The current in phase L2 is sufficient for impedance calculation.
PSLIP78_cL3_GrI_	The current in phase L3 is sufficient for impedance calculation.
Binary status signal	**Explanation**
Start	Start signal of the function
Trip	Trip command of the function
Block	Blocking of the pole slipping function

The current conditions of the pole slip function

The pole slip protection function can operate only if the positive sequence current component is above a certain value, defined for by a parameter value. A further condition of the operation is that the negative sequence current component is less than 1/6 of the value defined for the positive sequence component. This condition excludes the operation in case of asymmetrical faults. This module performs this preliminary decision.

Table. 6.3.18 - 59. Binary output signals.

Binary output signal	Explanation
Impedance function start conditions generated by the I_COND module (these signal are not published)	
I L1 condition	The current in phase L1 is sufficient for impedance calculation
I L2 condition	The current in phase L2 is sufficient for impedance calculation
I L3 condition	The current in phase L3 is sufficient for impedance calculation

Table. 6.3.18 - 60. Minimal current enabling.

Parameter	Setting value / range	Step	Description
IPh Base Sens	10…30	1	Definition of minimal current enabling impedance calculation

The positive sequence current is considered to be sufficient if it is above the level set by parameter PSLIP78_Imin_IPar_ (IPh Base Sens). At the same time the negative sequence component should be below 1/6 of this parameter value.

The symbol of the function in the AQtivate 300 software

Figure. 6.3.18 - 95. The function block of the pole slip function.

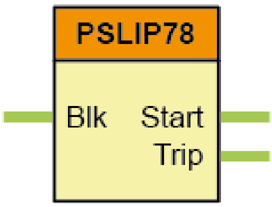


Table. 6.3.18 - 61. Binary I/O signals.

Parameter	Explanation
Start	Start signal of the function
Trip	Trip command of the function
Block	Blocking of the pole slipping function

6.3.19 Teleprotection (85)

The non-unit protection functions, generally distance protection, can have two, three or even more zones available. These are usually arranged so that the shortest zone corresponds to impedance slightly smaller than that of the protected section (underreach) and is normally instantaneous in operation. Zones with longer reach settings are normally time-delayed to achieve selectivity. As a consequence of the underreach setting, faults near the ends of the line are cleared with a considerable time delay. To accelerate this kind of operation, protective devices at the line ends exchange logic signals (teleprotection).

These signals can be direct trip command, blocking or permissive signals. In some applications even the shortest zone corresponds to impedance larger than that of the protected section (overreach). As a consequence of the overreach setting, faults outside the protected line would also cause an immediate trip command that is not selective. To prevent such unselective tripping, protective devices at the line ends exchange blocking logic signals. The combination of the underreach – overreach settings with direct trip command, permissive of blocking signals facilitates several standard solutions, with the aim of accelerating the trip command while maintaining selectivity.

The teleprotection function block is pre-programmed for some of these modes of operation. The required solution is selected by parameter setting; the user has to assign the appropriate inputs by graphic programming. Similarly, the user has to assign the "send" signal to a relay output and to transmit it to the far end relay. The trip command is directed graphically to the appropriate input of the trip logic, which will energize the trip coil. Depending on the selected mode of operation, the simple binary signal sent and received via a communication channel can have several meanings:

- Direct trip command
- Permissive signal
- Blocking signal.

To increase the reliability of operation, in this implementation of the telecommunication function the sending end generates a signal, which can be transmitted via two different channels.

NOTICE!
The type of the communication channel is not considered here. It can be one of the following: pilot wire, fiber optic channel, high frequency signal over transmission line, radio or microwave, binary communication network, etc.

The function receives the binary signal via optically isolated inputs. It is assumed that the signal received through the communication channel is converted to a DC binary signal matching the binary input requirements.

Principle of operation

For the selection of one of the standard modes of operation, the function offers two enumerated parameters. With the parameter SCH85_Op_EPar_ (Operation) the following options are available:

- PUTT
- POTT
- Dir. Comparison
- Dir. Blocking
- DUTT.

Permissive Underreach Transfer Trip (PUTT)

The IEC standard name of this mode of operation is Permissive Underreach Protection (PUP). The protection system uses telecommunication, with underreach setting at each section end. The signal is transmitted when a fault is detected by the underreach protection. Receipt of the signal at the other end initiates tripping if other local permissive conditions are also fulfilled, depending on parameter setting.

For trip command generation using the parameter SCH85_PUTT_EPar_ (PUTT Trip), the following options are available: with Pickup, and with Overreach.

Permissive Underreach Transfer Trip with Pickup

The protection system uses telecommunication, with underreach setting at each section end. The signal is transmitted when a fault is detected by the underreach protection. The signal is prolonged by a drop-down timer. Receipt of the signal at the other end initiates tripping in the local protection if it is in a started state.

Figure. 6.3.19 - 96. Permissive Underreach Transfer Trip with Pickup: Send signal generation.

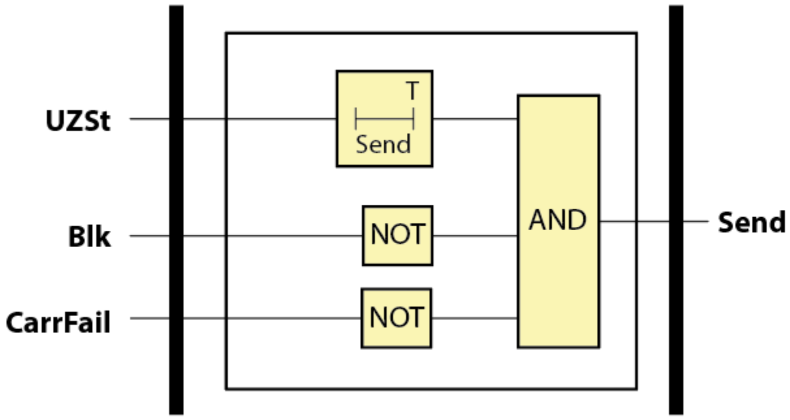
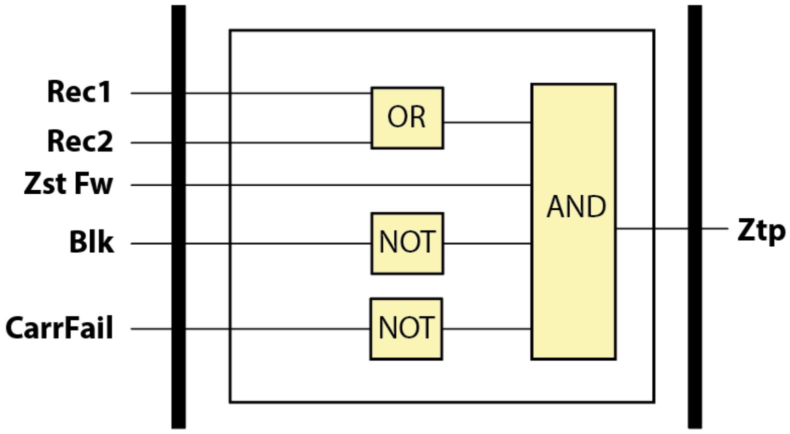


Figure. 6.3.19 - 97. Permissive Underreach Transfer Trip with Pickup: Trip command generation.



Permissive Underreach Transfer Trip with Overreach

The protection system uses telecommunication, with underreach setting at each section end. The signal is transmitted when a fault is detected by the underreach protection. The signal is prolonged by a drop-down timer. Receipt of the signal at the other end initiates tripping if the local overreaching zone detects fault.

Figure. 6.3.19 - 98. Permissive Underreach Transfer Trip with Overreach: Send signal generation.

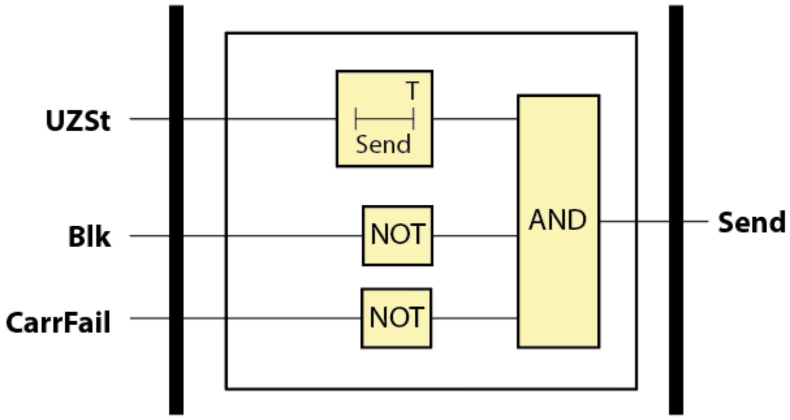
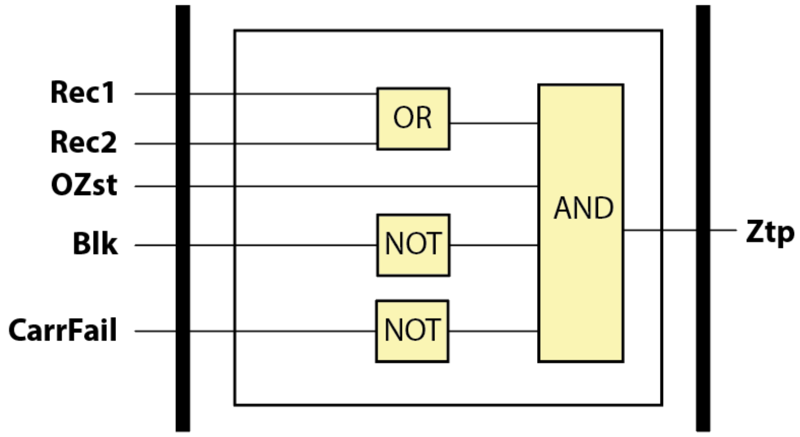


Figure. 6.3.19 - 99. Permissive Underreach Transfer Trip with Overreach: Trip command generation.



Permissive Overreach Transfer Trip (POTT)

The IEC standard name of this mode of operation is Permissive Overreach Protection (POP). The protection system uses telecommunication, with overreach setting at each section end. The signal is transmitted when a fault is detected by the overreach protection. This signal is prolonged if a general trip command is generated. Receipt of the signal at the other end permits the initiation of tripping by the local overreach protection.

Figure. 6.3.19 - 100. Permissive Overreach Transfer Trip: Send signal generation.

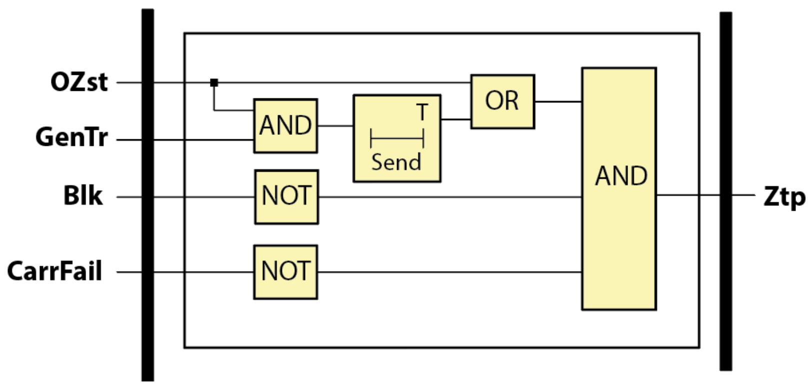
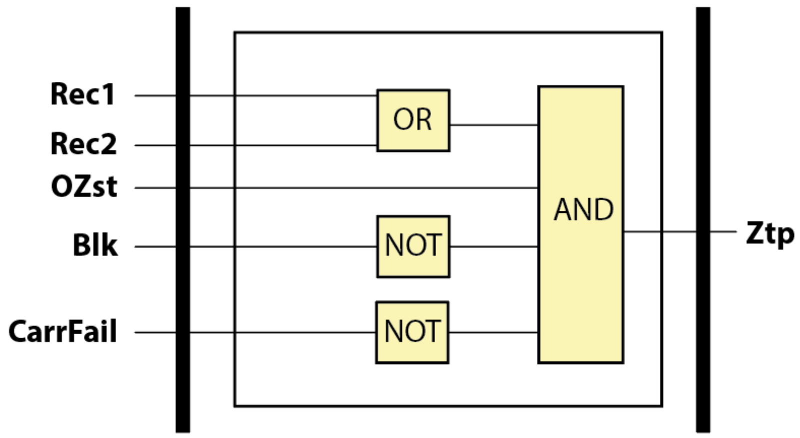


Figure. 6.3.19 - 101. Permissive Overreach Transfer Trip: Trip command generation.



Directional comparison (Dir.Comparison)

The protection system uses telecommunication. The signal is transmitted when a fault is detected in forward direction. This signal is prolonged if a general trip command is generated. Receipt of the signal at the other end permits the initiation of tripping by the local protection if it detected a fault in forward direction.

Figure. 6.3.19 - 102. Directional comparison: Send signal generation.

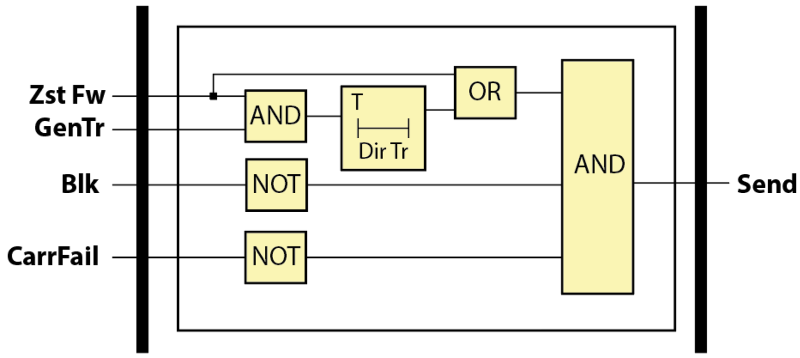
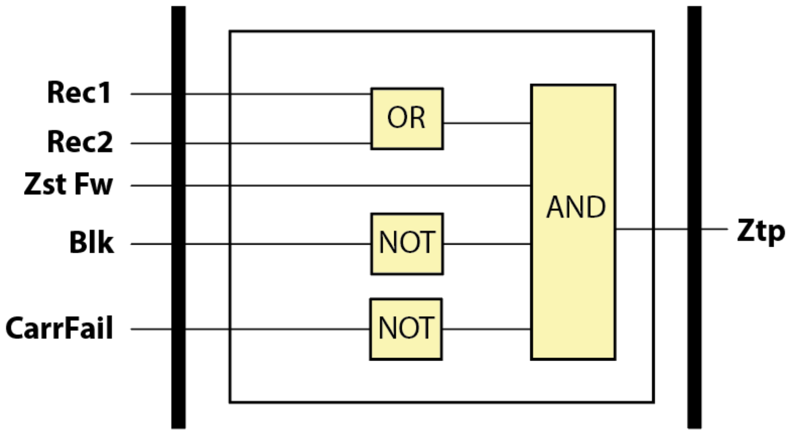


Figure. 6.3.19 - 103. Directional comparison: Trip command generation.



Blocking directional comparison (Dir.Blocking)

The IEC standard name of this mode of operation is Blocking Overreach Protection (BOP). The protection system uses telecommunication, with overreach setting at each section end. The blocking signal is transmitted when a reverse external fault is detected. The signal is prolonged by a drop-down timer. For the trip command, the forward fault detection is delayed to allow time for a blocking signal to be received from the opposite end. Receipt of the signal at the other end blocks the initiation of tripping of the local protection. The blocking signal received is prolonged if the duration of the received signal is longer than a specified minimal duration.

Figure. 6.3.19 - 104. Directional blocking: Send signal generation.

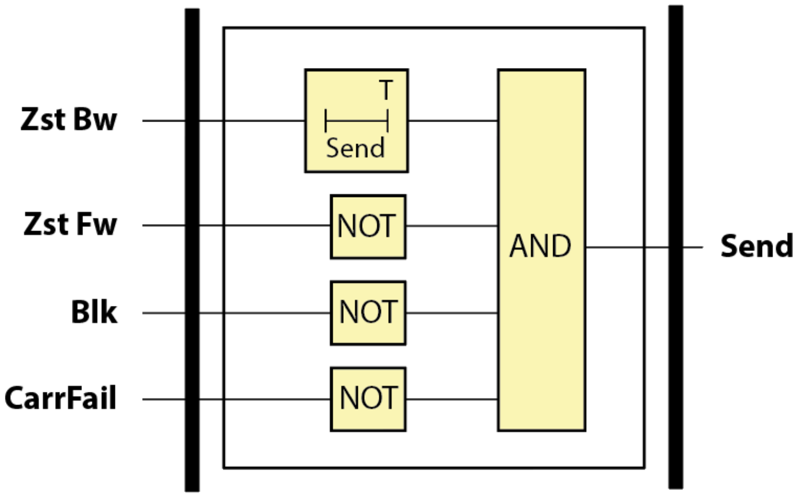
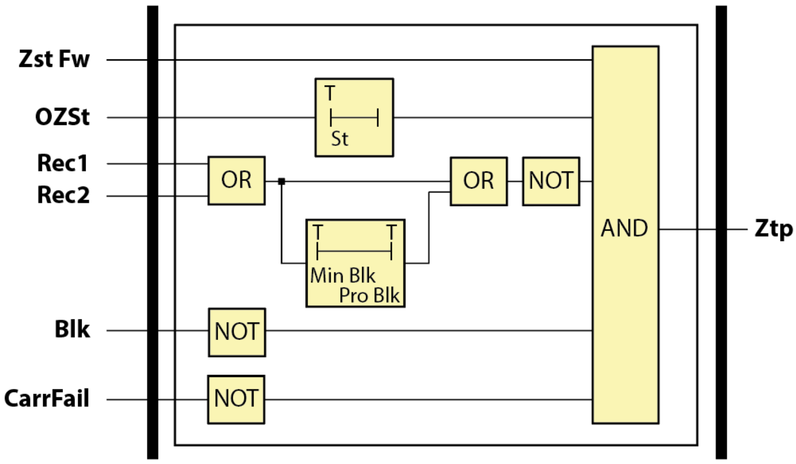


Figure. 6.3.19 - 105. Directional blocking: Trip command generation.



Direct underreaching transfer trip (DUTT)

The IEC standard name of this mode of operation is Intertripping Underreach Protection (IUP). The protection system uses telecommunication, with underreach setting at each section end. The signal is transmitted when a fault is detected by the underreach protection. Receipt of the signal at the other end initiates tripping, independent of the local protection.

Figure. 6.3.19 - 106. Directional Underreaching Transfer Trip: Send signal generation.

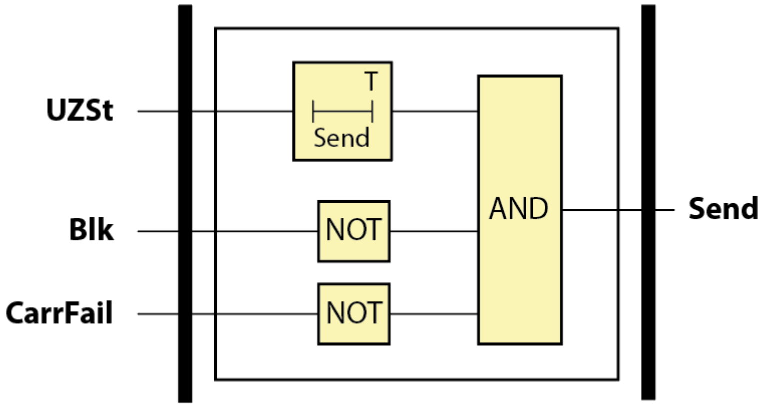
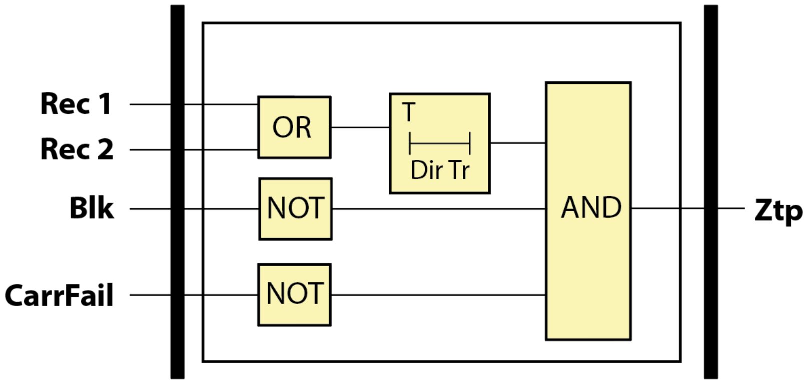


Figure. 6.3.19 - 107. Directional Underreaching Transfer Trip: Trip command generation.



Function block

Figure. 6.3.19 - 108. The function block of the teleprotection protection function.

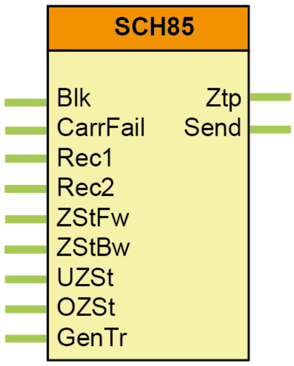


Table. 6.3.19 - 62. The input and output signals of the teleprotection function block.

Signal title	Explanation
Block	Blocking signal
Carrier fall	Signal indicating the failure of the communication channel
Receive opp. 1	Signal1 received from the opposite end

Signal title	Explanation
Receive opp. 2	Signal2 received from the opposite end
Z Gen.start Fw	Protection start in forward direction
Z Underreach Start	Start of the underreaching zone (e.g. Z1)
Z Overreach Start	Start of the overreaching zone (e.g. Z2)
General Trip	General protection trip
Z Gen.start Bw	Protection start in backward direction
Z Teleprot. Trip	Teleprotection trip command
Send signal	Teleprotection signal to be transmitted to the far end

Setting parameters

Table. 6.3.19 - 63. Setting parameters of the teleprotection function.

Parameter	Setting value / range	Step	Default	Description
Operation	Off PUTT POTT Dir.comparison Dir.blocking DUTT	-	Off	Operating mode of the function.
PUTT trip	with Pickup with Overreach	-	with Overreach	Tripping command generation setting
Send prolong time	1…10 000 ms	1 ms	10 ms	Setting for prolonging the teleprotection signal on the sending end.
Direct Trip delay PUTT	1…10 000 ms	1 ms	10 ms	Setting for direct delay for PUTT function.
Z start delay (block)	1…10 000 ms	1 ms	10 ms	Setting for underimpedance start delay.
Min.Block time	1…10 000 ms	1 ms	10 ms	Setting for minimum block time for the teleprotection.
Prolong Block time	1…10 000 ms	1 ms	10 ms	Setting for prolonging the blocked time of teleprotection function.

6.3.20 Inrush current detection (68)

The current can be high during transformer energizing due to the current distortion caused by the transformer iron core asymmetrical saturation. In this case, the second harmonic content of the current is applied to disable the operation of the desired protection function(s).

The inrush current detection function block analyses the second harmonic content of the current, related to the fundamental harmonic. If the content is high, then the assigned status signal is set to "true" value. If the duration of the active status is at least 25 ms, then the resetting of the status signal is delayed by an additional 15 ms. Inrush current detection is applied to residual current measurement also with dedicated separate function.

Table. 6.3.20 - 64. Setting parameters of the inrush current function.

Parameter	Setting value / range	Step	Default	Description
Operation	Off Current Contact Current/ Contact	-	Current	Operating mode selection for the function. Operation can be either disabled "Off" or monitoring either measured current or contact status or both current and contact status.
Start current Ph	20…200 %	1 %	30 %	Pick-up current for the phase current monitoring.
Start current N	10…200 %	1 %	30 %	Pick-up current for the residual current monitoring.
Backup Time Delay	60…1 000 ms	1 ms	200 ms	Time delay for CBFP tripping command for the back-up breakers from the pick-up of the CBFP function monitoring.
Pulse length	0…60 000 ms	1 ms	100 ms	CBFP pulse length setting.

6.3.21 Stub protection

There are short sections of the current path within a substation that are not properly protected by the general protection system. These sections are called stubs and they are usually between the circuit breaker and the current transformer. The general protection system measures the current of the current transformer and if fault is detected, a command is generated to open the circuit breaker.

If, however, the fault is between the circuit breaker and the current transformer, then opening the circuit breaker cannot clear the fault; it is fed via the current transformer from the other side of the protected object. This location is within the back-up zone of the other side protection and, accordingly, it is cleared by a considerable time delay.

The task of the stub protection function is to detect the fault current in the open state of the circuit breaker and to generate a quick trip command to the other side circuit breaker.

Another usual application is in the one-and-a-half circuit breaker arrangement. Here the current transformers are located either before or after the circuit breakers. Additionally, the voltage transformer is either on the bus side or on the line side of the isolator. In the last case the stub is also the section between the circuit breakers and the open line isolator, since if a fault occurs in this section, the detected voltage is independent of the fault; it is unchanged and cannot be applied for the distance protection.

The stub protection function is basically a high-speed overcurrent protection function that is enabled by the open state of a circuit breaker or maybe an isolator.

The inputs of the stub protection function are

- The Fourier components of three phase currents

- Binary inputs for enabling and activating the operation
- Parameters.

The output of the stub protection function is

- A binary output trip command to be directed to the appropriate circuit breaker(s).

If any of the phase currents is above the start current and the binary status signal activates the operation, then after a user-defined time delay the function generates a trip command.

The function can be disabled by programming the blocking signal.

Figure. 6.3.21 - 109. The function block of the stub protection function.

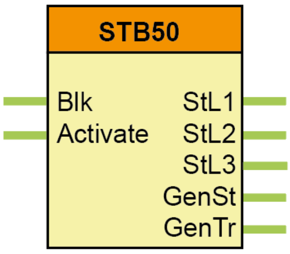


Table. 6.3.21 - 65. The binary output status signals.

Binary output signal	Signal title	Explanation
Indication of starting the function in phase L1		
STB50_StL1_GrI_	Start L1	Indication of starting the function in phase L1
Indication of starting the function in phase L2		
STB50_StL2_GrI_	Start L2	Indication of starting the function in phase L2
Indication of starting the function in phase L3		
STB50_StL3_GrI_	Start L3	Indication of starting the function in phase L3
General indication of starting the function		
STB50_GenSt_GrI_	General Start	OR connection of the phase starting indications
General trip command		
STB50_GenTr_GrI_	General Trip	Trip command generated at time-out of the dedicated timer

Table. 6.3.21 - 66. The binary input status signals.

Binary input signal	Signal title	Explanation
Disabling the function		
STB50_Blk_GrO_	Disable	The programmed True state of this input disables the operation of the function
Activating the function		

Binary input signal	Signal title	Explanation
STB50_Activate_GrO_	Activate	The programmed True state of this signal indicates the open state of the circuit breaker or maybe the isolator.

Table. 6.3.21 - 67. Setting parameters of the function.

Parameter	Setting value/range	Step	Default	Description
Operation	Off On	-	Off	Operating mode selection for the function. Operation can be either disabled "Off" or enabled "On".
Start current	10…400 %	1 %	50 %	Maximum current setting.
Time delay	0…60 000 ms	1 ms	100 ms	Definite time delay of the trip command.

6.3.22 Distance protection

The AQ 300 series distance protection can be configured to function either on polygon characteristics or Mho characteristics. The default configuration is based on polygon characteristics and if the Mho is required the corresponding function block needs to be added into configuration using AQtivate 300 software. This chapter explains the function for both polygon and Mho characteristic.

The distance protection function provides main protection for overhead lines and cables of solidly grounded networks. Its main features are as follows:

- A full-scheme system provides continuous measurement of impedance separately in three independent phase-to-phase measuring loops as well as in three independent phase-to-earth measuring loops.
- Analogue input processing is applied to the zero sequence current of the parallel line.
- Full-scheme faulty phase identification and directional signaling is provided.
- Distance-to-fault evaluation is implemented.
- Five independent distance protection zones are configured.
- The operate decision is based on polygon-shaped or Mho characteristics Mho or on offset circle characteristics (configurable using AQtivate 300 software)
- Load encroachment characteristics can be selected.

The directional decision is dynamically based on:

- Measured loop voltages if they are sufficient for decision
- Healthy phase voltages if they are available for asymmetrical faults
- Voltages stored in the memory if they are available
- Optionally the decision can be non-directional in case of switching to fault or if non-directional operation is selected.

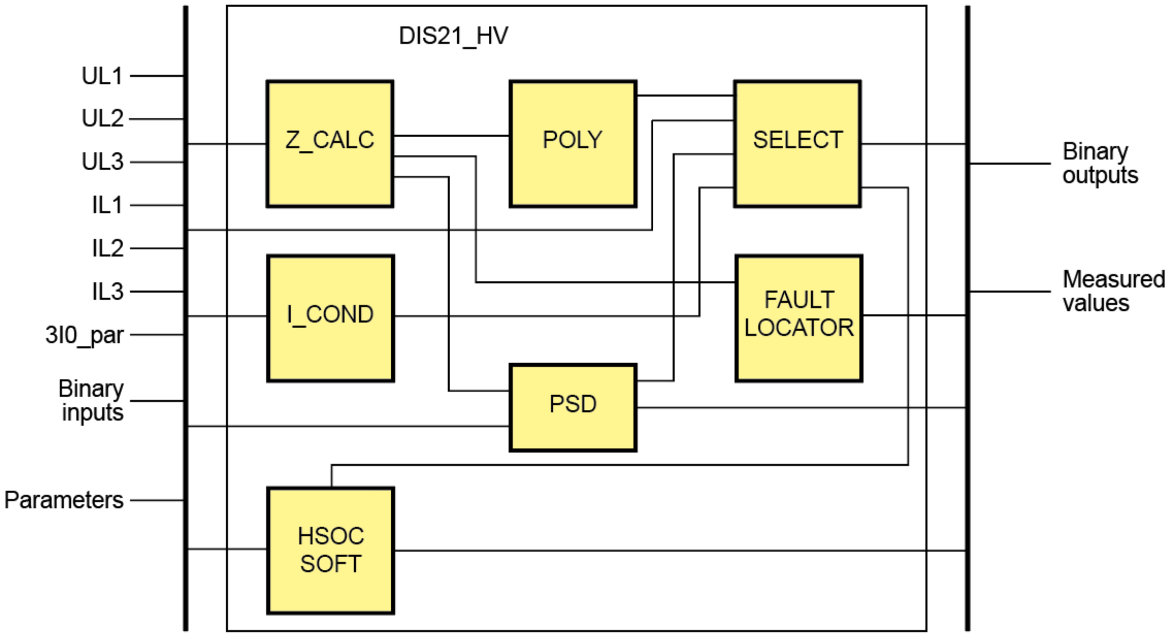
Binary input signals and conditions can influence the operation:

- Blocking/enabling
- VT failure signal.

Detection of power swing condition and out-of-step operation are available.

The structure of the distance protection algorithm is described in figure below.

Figure. 6.3.22 - 110. Structure of the distance protection.



The inputs are:

- Sampled values and Fourier components of three phase voltages
- Sampled values and Fourier components of three phase currents
- Sampled values and Fourier components of (3Iop) the zero sequence current of the parallel line
- Binary inputs
- Setting parameters

The outputs are:

- Binary output status signals
- Measured values for displaying.

The software modules of the distance protection function are as follows:

- Z_CALC calculates the impedances (R+jX) of the six measuring current loops:
  - three phase-phase loops
  - three phase-ground loops.
- POLY compares the calculated impedances with the setting values of the five polygon characteristics. The result is the decision for all six measuring loops and for all five polygons if the impedance is within the polygon.
- SELECT is the phase selection algorithm for all five zones to decide which decision is caused by a faulty loop and to exclude the false decisions in healthy loops.
- I_COND calculates the current conditions necessary for the phase selection logic.
- FAULT LOCATOR calculates the distance to fault after the trip command.The following description explains the details of the individual components.

Principle of the impedance calculation

The distance protection continuously measures the impedances in the six possible fault loops. The calculation is performed in the phase-to-phase loops based on the line-to-line voltages and the difference of the affected phase currents, while in the phase-to-earth loops the phase voltage is divided by the phase current compounded with the zero sequence current. These equations are summarized in following table for different types of faults. The result of this calculation is the positive sequence impedance of the fault loop, including the positive sequence fault resistance at the fault location. For simplicity, the influence of the zero sequence current of the parallel line is not considered in these equations.

Table. 6.3.22 - 68. Impedance calculation formulas.

Fault	Calculation of Z	Other possible calculations
L1L2L3(N)	$Z_{L2L3} = (U_{L2}–U_{L3})/(I_{L2}–I_{L3})$	Z_{L1L2}, Z_{L2L3}, Z_{L3L1} Z_{L1N}, Z_{L2N}, Z_{L3N}
L1L2	$Z_{L1L2} = (U_{L1}–U_{L2})/(I_{L1}–I_{L2})$	
L2L3	$Z_{L2L3} = (U_{L2}–U_{L3})/(I_{L2}–I_{L3})$	
L3L1	$Z_{L3L1} = (U_{L3}–U_{L1})/(I_{L3}–I_{L1})$	
L1L2N	$Z_{L1L2} = (U_{L1}–U_{L2})/(I_{L1}–I_{L2})$	Z_{L1N}, Z_{L2N}
L2L3N	$Z_{L2L3} = (U_{L2}–U_{L3})/(I_{L2}–I_{L3})$	Z_{L2N}, Z_{L3N}
L3L1N	$Z_{L3L1} = (U_{L3}–U_{L1})/(I_{L3}–I_{L1})$	Z_{L3N}, Z_{L1N}
L1N	$Z_{L1N} = U_{L1}/(I_{L1}+3I_0K_N)$	
L2N	$Z_{L2N} = U_{L2}/(I_{L2}+3I_0K_N)$	
L3N	$Z_{L3N} = U_{L3}/(I_{L3}+3I_0K_N)$	

The central column of table contains the formula for calculation. The formulas referred to in the right-hand-side column yield the same impedance value.

$$K_N = \frac{Z_0 - Z_1}{3Z_1} = \frac{1}{3}\left(\frac{Z_0}{Z_1} - 1\right)$$

Equation presents the earth fault compensation factor.

Table above shows that the formula containing the complex earth fault compensation factor yields the correct impedance value in case of phase-to-earth faults only; the other formula can be applied in case of phase-to-phase faults without ground. In case of other kinds of faults (three-phase (-to-earth), phase-to-phase-to-earth) both formulas give the correct impedance value if the appropriate voltages and currents are applied.

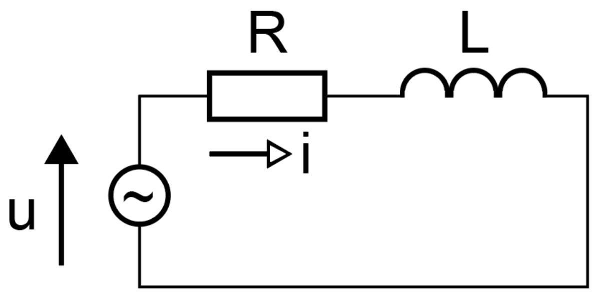
The separation of the two types of equation is based on the presence or absence of the earth (zero sequence) current. In case of a fault involving the earth (on a solidly grounded network), and if the earth current is over a certain level, the formula containing the complex earth fault compensation factor will be applied to calculate the correct impedance, which is proportional to the distance-to-fault.

It can be proven that if the setting value of the complex earth fault compensation factor is correct, the appropriate application of the formulas in the table will always yield the positive sequence impedance between the fault location and the relay location.

General method of calculation of the impedances of the fault loops

If the sampled values are suitable for the calculation (after a zero crossing there are three sampled values above a defined limit (~0.1In), and the sum of the phase currents (3Io) is above Iphase/4), then the numerical processes apply the following equations.

Figure. 6.3.22 - 111. Equivalent circuit of the fault loop.



For the equivalent impedance elements of the fault loop on figure above, the following differential equation can be written:

$$u = Ri + L\frac{di}{dt}$$

If current and voltage values sampled at two separate sampling points in time are substituted in this equation, two equations are derived with the two unknown values R and L, so they can be calculated.

This basic principle is realized in the algorithm by substituting the sampled values of the line-to-line voltages for u and the difference of two phase currents in case of two- or three-phase faults without ground for i. For example, in case of an L2L3 fault:

$$u_{L2} - u_{L3} = R_1(i_{L2} - i_{L3}) + L_1\frac{d(i_{L2} - i_{L3})}{dt}$$

In case of a phase-to-earth fault, the sampled phase voltage and the phase current modified by the zero sequence current have to be substituted:

$$u_{L1} = R_1(i_{L1} + \alpha_R 3i_0 + \beta_R 3i_{op}) + L_1\frac{d}{dt}(i_{L1} + \alpha_L 3i_0 + \beta_L 3i_{op})$$

where:

R_1 = the positive sequence resistance of the line or cable section between the fault location and the relay location
L_1 = the positive sequence inductance of the line or cable section between the fault location and the relay location
L1 = the faulty phase
3io = iL1 + iL2 + iL3 = the sampled value of the zero sequence current of the protected line
$3i_{op}$ = $iL1_p + iL2_p + iL3_p$ = the sampled value of the zero sequence current in parallel line
$\alpha_R = (R_0 - R_1)/3R_1$
$\alpha_L = (L_0 - L_1)/3L_1 = (X_0 - X_1)/3X_1$
$\beta_R = R_m/3R_1$
R_m = the real part of the mutual impedance between the protected and the parallel line
$\beta_L = L_m/3L_1 = X_m/3X_1$
L_m = the mutual inductance between the protected and the parallel line

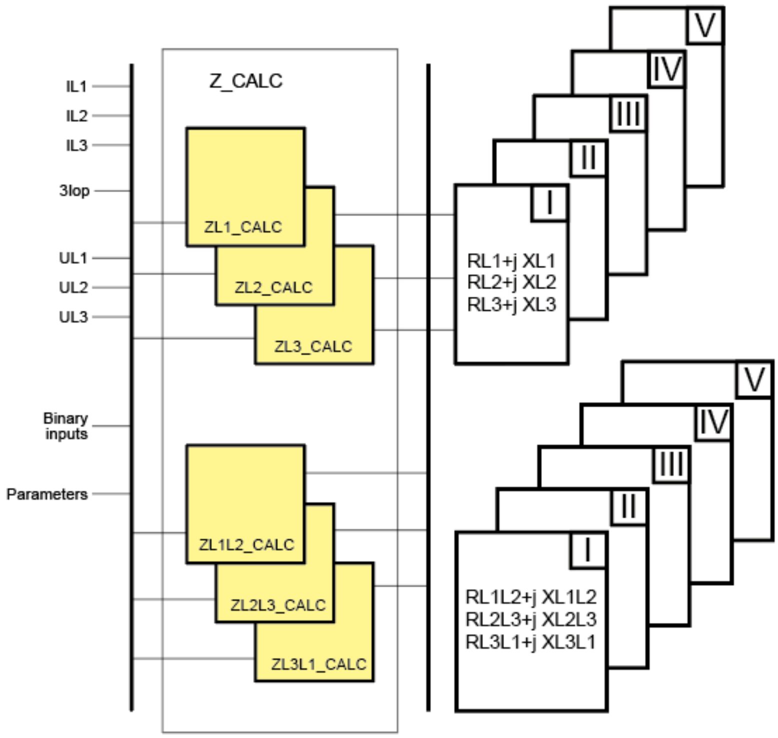
The formula above shows that the factors for multiplying the R and L values contain different "α" and "β" factors but they are real (not complex) numbers.

The applied numerical method is solving the differential equation of the faulty loop, based on three consecutive samples.

The calculation for Zone1 is performed using two different methods in parallel:

- To achieve a better filtering effect, Fourier basic harmonic components are substituted for the components of the differential equations.
- To avoid the influence of current transformer saturation, the differential equation is solved directly with sampled currents and voltages. Under this method, sections of the current wave where the form is not distorted by CT saturation are selected for the calculation. The result of this calculation is matched to a quadrilateral characteristic, which is 85% of the parameter setting value. In case of CVT swing detection; this calculation method has no effect on the operation of the distance protection function.

Figure. 6.3.22 - 112. Impedance calculation principal scheme.



The inputs are the sampled values and Fourier components of:

- Three phase voltages
- Three phase currents
- (3Iop) zero sequence current of the parallel line
- Binary inputs
- Parameters.

The binary inputs influencing the operation of the distance protection function can be selected by the user.

The outputs are the calculated positive-sequence impedances (R+jX) of the six measuring current loops and, as different zero sequence current compensation factors can be set for the individual zones, the impedances are calculated for each zone separately:

- Impedances of the three phase-phase loops
- Impedances of the three phase-ground loops.

Z_CALC includes six practically identical software modules for impedance calculation:

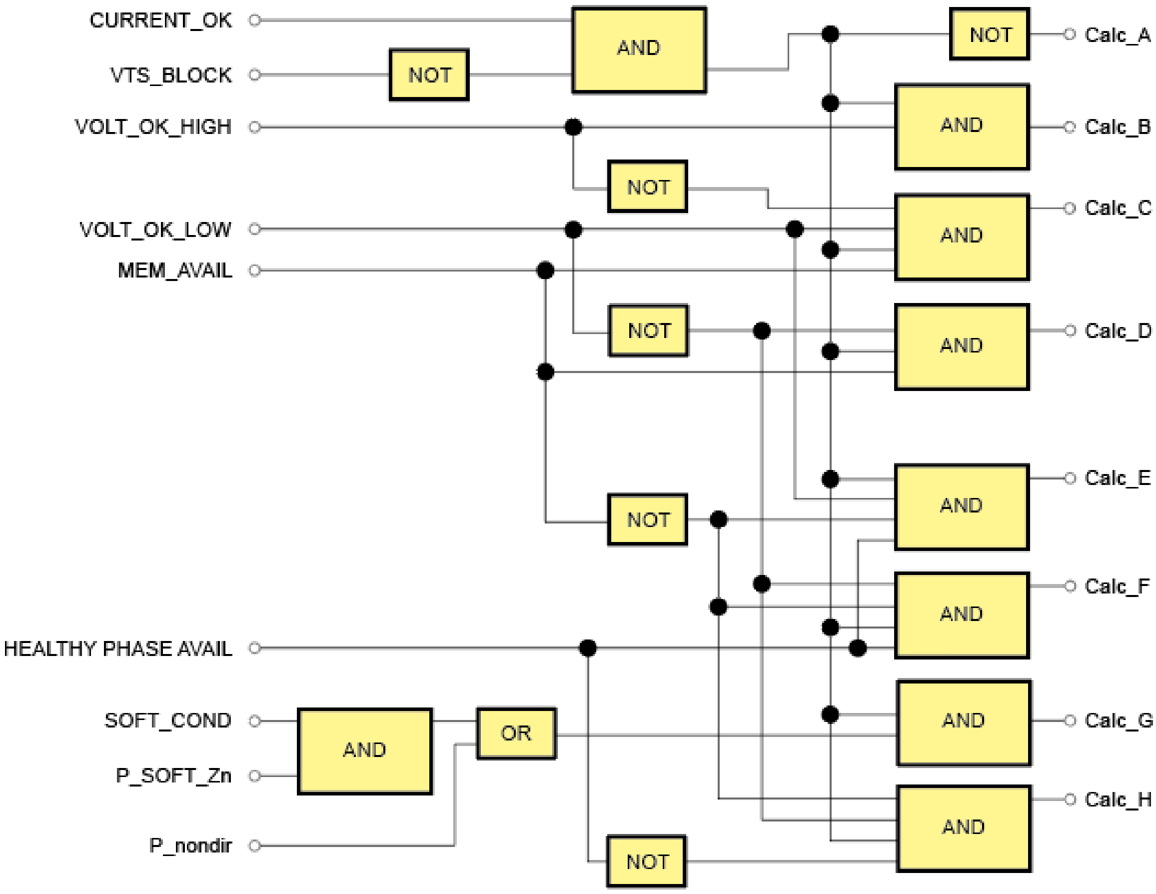
- The three members of the phase group are activated by phase voltages, phase currents and the zero sequence current calculated from the phase current and the zero sequence currents of the parallel line, as measured in a dedicated input.
- The three routines for the phase-to-phase loops get line-to-line voltages calculated from the sampled phase voltages and they get differences of the phase currents. They do not need zero sequence currents for the calculation.

Table. 6.3.22 - 69. Calculated values of the impedance module.

Measured value	Dim.	Explanation
RL1+j XL1	ohm	Measured positive sequence impedance in the L1N loop, using the zero sequence current compensation factor for zone 1
RL2+j XL2	ohm	Measured positive sequence impedance in the L2N loop, using the zero sequence current compensation factor for zone 1
RL3+j XL3	ohm	Measured positive sequence impedance in the L3N loop, using the zero sequence current compensation factor for zone 1
RL1L2+j XL1L2	ohm	Measured positive sequence impedance in the L1L2 loop
RL2L3+j XL2L3	ohm	Measured positive sequence impedance in the L2L3 loop
RL3L1+j XL3XL1	ohm	Measured positive sequence impedance in the L13L1 loop

Internal logic of the impedance calculation

Figure. 6.3.22 - 113. Impedance calculation internal logic.



The decision needs logic parameter settings and, additionally, internal logic signals. The explanation of these signals is as follows:

Table. 6.3.22 - 70. Internal logic parameters of the impedance calculation.

Parameter	Explanation
P_nondir_	This logic variable is true if no directionality is programmed, i.e. the DIS21_Zn_EPar_(Operation Zone1) parameter (where n = 1…5) is set to *"NonDirectional"* for the individual zones.

Table. 6.3.22 - 71. Binary input signals for the impedance calculation.

Input status signal	Explanation
CURRENT_OK_	The current is suitable for impedance calculation in the processed loop if, after a zero crossing, there are three sampled values above a defined limit (~0.1In). For a phase-ground loop calculation, it is also required that the sum of the phase currents (3I0) should be above Iphase/4. This status signal is generated within the *Z_CALC* module based on the parameter DIS21_Imin_IPar_ (I minimum) and in case of phase-ground loops on parameters DIS21_I0Base_IPar_ (I0 Base sens.) and DIS21_I0Bias_IPar_ (I0 Bias).
VTS Block	Binary blocking signal due to error in the voltage measurement.

Input status signal	Explanation
VOLT_OK_HIGH	The voltage is suitable for the calculation if the most recent ten sampled values include a sample above the defined limit (35 % of the nominal loop voltage). This status signal is generated within the *Z_CALC* module.
VOLT_OK_LOW	The voltage can be applied for the calculation of the impedance if the three most recent sampled three values include a sample above the defined lower limit (5 % of the nominal loop voltage), but in this case the direction is to be decided using the voltage samples stored in the memory because the secondary swings of the capacitive voltage divider distort the sampled voltage values. Below this level, the direction is decided based on the sign either of the real part of the impedance or that of the imaginary part of the impedance, whichever is higher. This status signal is generated within the *Z_CALC* module.
MEM_AVAIL	This status signal is true if the voltage memory is filled up with available samples above the defined limit for 80 ms. This status signal is generated within the *Z_CALC* module.
HEALTHY_PHASE_AVAIL	This status signal is true if there are healthy phase voltages (in case of asymmetrical faults) that can be applied to directional decision. This status signal is generated within the *Z_CALC* module.

The outputs of the scheme are calculation methods applied for impedance calculation for the individual zones.

Table. 6.3.22 - 72. Calculation methods applied in the impedance calculation module.

Calculation method	Explanation
Calc(A)	No current is available, the impedances are supposed to be higher than the possible maximum setting values R=1 000 000 mΩ, X=1 000 000 mΩ.
Calc(B)	The currents and voltages are suitable for the correct impedance calculation and directional decision R, X=f(u, i)
Calc(C)	The currents are suitable but the voltages are in the range of the CVT swings, so during the first 35 ms the directional decision is based on pre-fault voltages stored in the memory R, X=f(u, i) direction = f(Umem, i) /in the first 35 ms/ R, X=f(u, i) direction = f(u, i) /after 35 ms/
Calc(D)	The currents are suitable but the voltages are too low. The directional decision is based on pre-fault voltages stored in the memory R, X=f(u, i) direction = f(max{R(Umem, i), X(Umem,i)})
Calc(E)	If no directional decision is required, the decision is based on the absolute value of the impedance R=abs(R), X=abs(X)
Calc(F)	If the decision is not possible (no voltage, no pre-fault voltage), the impedance is set to a value above the possible impedance setting R = 1 000 500 mΩ, X = 1 000 500 mΩ
Calc(G)	If no directional decision is required, then the decision is based on the absolute value of the impedance (forward fault is supposed) R = abs(R), X = abs(X)
Calc(H)	If the decision is not possible (no voltage, no pre-fault voltage, no healthy phase voltage but directional decision is required), then the impedance is set to a value above the possible impedance setting R = 1 000 500 mΩ, X = 1 000 500 mΩ

The impedance calculation methods

The short explanation of the internal logic for the impedance calculation is as follows:

Calculation method Calc(A)

If the CURRENT_OK status signal is false, the current is very small, therefore no fault is possible. In this case, the impedance is set to extreme high values and no further calculation is performed:

R = 1 000 000, X = 1 000 000.

The subsequent decisions are performed if the current is sufficient for the calculation.

Calculation method Calc(B)

If the CURRENT_OK status signal is true and the VOLT_OK_HIGH status signal is true as well, then the current is suitable for calculation and the voltage is sufficient for the directionality decision. In this case, normal impedance calculation is performed based on the sampled currents and voltages. (The calculation method - the function ”f”- is explained later.)

R, X = f(u, i)

Calculation method Calc(C)

If the CURRENT_OK status signal is true but the VOLT_OK_HIGH status signal is false or there are voltage swings, the directionality decision cannot be performed based on the available voltage signals temporarily. In this case, if the voltage is above a minimal level (in the range of possible capacitive voltage transformer swings), then the VOLT_OK_LOW status is “true”, the magnitude of R and X is calculated based on the actual currents and voltages but the direction of the fault (the +/- sign of R and X) must be decided based on the voltage value stored in the memory 80 ms earlier. (The high voltage level setting assures that during the secondary swings of the voltage transformers, no distorted signals are applied for the decision). This procedure is possible only if there are stored values in the memory for 80 ms and these values were sampled during a healthy period.

R, X = f(u, i) direction = f(Umem, i) /in the first 35 ms/

After 35 ms (when the secondary swings of the voltage transformers decayed), the directional decision returns to the measured voltage signal again:

R, X = f(u, i) direction = f(u, i) /after 35 ms/

Calculation method Calc(D)

If the voltage is below the minimal level, then the VOLT_OK_LOW status is “false” but if there are voltage samples stored in the memory for 80 ms, then the direction is decided based on the sign either of the real part of the impedance or that of the imaginary part of the impedance, whichever is higher.

R, X = f(u, i) direction = f(max{R(Umem, i), X(Umem,i)})

Calculation method Calc(E)

If no directional decision is required, the decision is based on the absolute value of the impedance (forward fault is supposed)

R = abs(R), X = abs(X)

Calculation method Calc(F)

If the voltage is not sufficient for a directional decision and no stored voltage samples are available, the impedance is set to a high value:

R = 1 000 500, X = 1 000 500

Calculation method Calc(G)

If no directional decision is required, then the decision is based on the absolute value of the impedance (forward fault is supposed)

R = abs(R), X = abs(X)

Calculation method Calc(H)

If the voltage is not sufficient for a directional decision and no stored voltage samples are available, then the impedance is set to a high value:

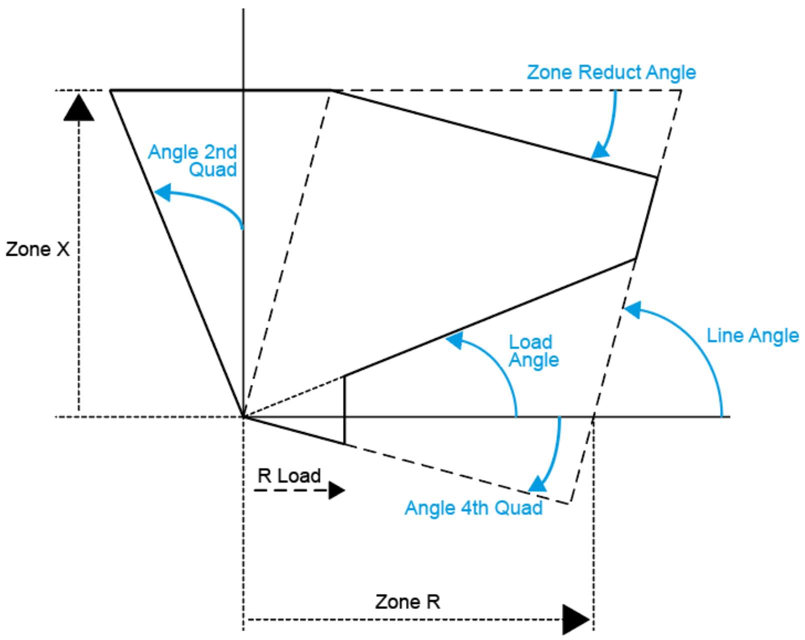
R = 1 000 500, X = 1 000 500

Polygon and Mho characteristics

Polygon

The calculated R_1 and $X_1=L_1$ co-ordinate values define six points on the complex impedance plane for the six possible measuring loops. These impedances are the positive sequence impedances. The protection compares these points with the „polygon" characteristics of the distance protection. The main setting values of R and X refer to the positive sequence impedance of the fault loop, including the positive sequence fault resistance of the possible electric arc and, in case of a ground fault, the positive sequence resistance of the tower grounding as well. (When testing the device using a network simulator, the resistance of the fault location is to be applied to match the positive sequence setting values of the characteristic lines.)

Figure. 6.3.22 - 114. The characteristics of the distance protection in complex plane.

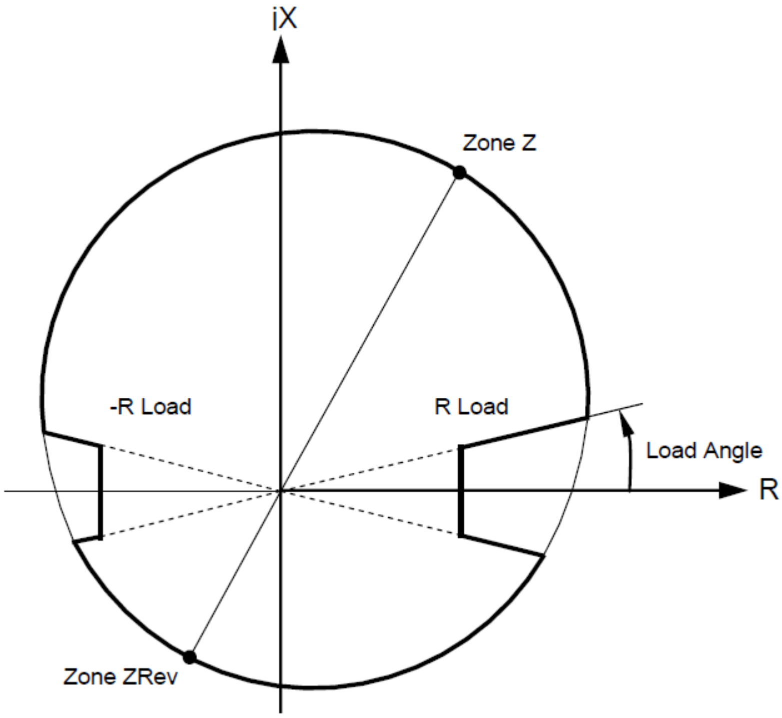


If a measured impedance point is inside the polygon, the algorithm generates the true value of the related output binary signal.

Mho

The calculated R_1 and $X_1=\varpi L_1$ co-ordinate values define six points on the complex impedance plane for the six possible measuring loops. These impedances are the positive sequence impedances. The protection compares these points with the Mho characteristics of the distance protection.

Figure. 6.3.22 - 115. The MHO characteristics of the distance protection function on the complex plane.



If a measured impedance point is inside the Mho circle, the algorithm generates the true valueof the related output binary signal.

The procedure is processed for each line-to-ground loop and for each line-to-line loop. Then this is repeated for all five impedance stages. The result is the setting of 6 x 5 status variables, which indicate that the calculated impedance is within the processed Mho circle, meaning that the impedance stage has started.

Polygon and Mho characteristics logic

The calculated impedance values are compared one by one with the setting values of the corresponding characteristics. This procedure is shown schematically in figures below.

The procedure is processed for each line-to-ground loop and for each line-to-line loop. Then this is repeated for all five impedance stages. The result is the setting of 6 x 5 status variables, which indicate that the calculated impedance is within the processed characteristic, meaning that the impedance stage has started.

Figure. 6.3.22 - 116. Polygon characteristics logic.

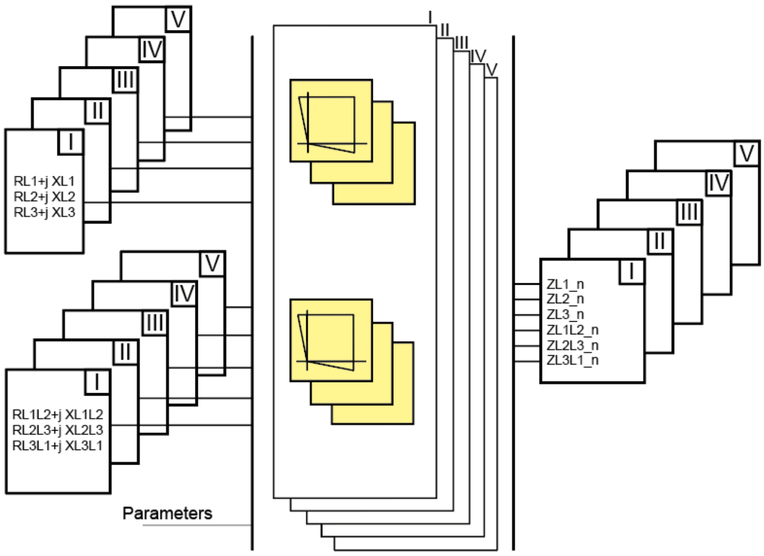


Figure. 6.3.22 - 117. Mho characteristics logic.

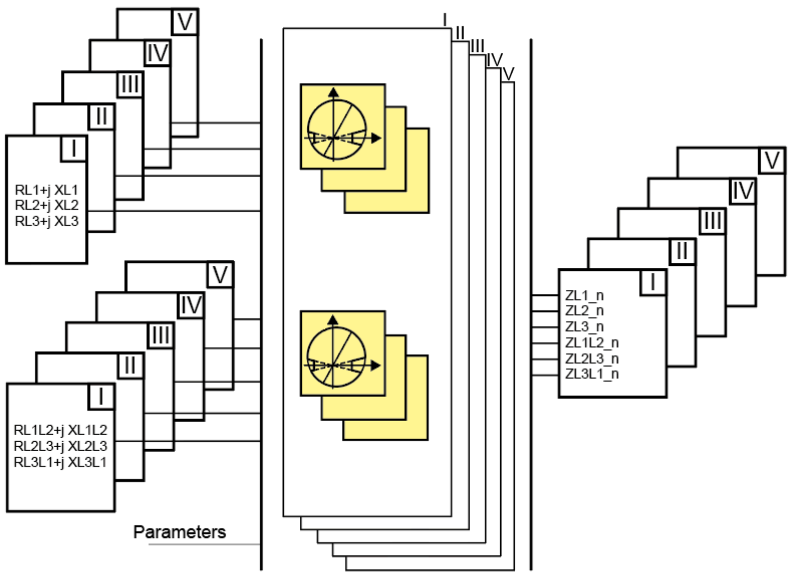


Table. 6.3.22 - 73. Input impedances for the characteristics logic.

Input values	Zones	Explanation
RL1+j XL1	1…5	Calculated impedance in the fault loop L1N using parameters of the zones individually
RL2+j XL2	1…5	Calculated impedance in the fault loop L2N using parameters of the zones individually
RL3+j XL3	1…5	Calculated impedance in the fault loop L3N using parameters of the zones individually
RL1L2+j XL1L2	1…5	Calculated impedance in the fault loop L1L2 using parameters of the zones individually
RL2L3+j XL2L3	1…5	Calculated impedance in the fault loop L2L3 using parameters of the zones individually

Input values	Zones	Explanation
RL3L1+j XL3L1	1…5	Calculated impedance in the fault loop L3L1 using parameters of the zones individually

Table. 6.3.22 - 74. Output signals of the characteristics logic.

Output values	Zones	Explanation
ZL1_n	1…5	The impedance in the fault loop L1N is inside the characteristics
ZL2_n	1…5	The impedance in the fault loop L2N is inside the characteristics
ZL3_n	1…5	The impedance in the fault loop L3N is inside the characteristics
ZL1L2_n	1…5	The impedance in the fault loop L1L2 is inside the characteristics
ZL2L3_n	1…5	The impedance in the fault loop L2L3 is inside the characteristics
ZL3L1_n	1…5	The impedance in the fault loop L3L1 is inside the characteristics

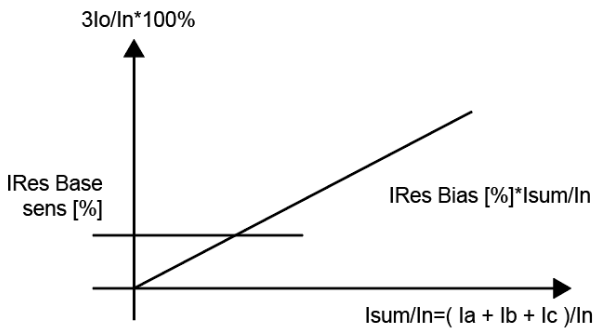
Current conditions of the distance protection function

The distance protection function can operate only if the current is sufficient for impedance calculation. Additionally, a phase-to-ground fault is detected only if there is sufficient zero sequence current. This function performs these preliminary decisions.

The current is considered to be sufficient for impedance calculation if it is above the level set by parameter DIS21_Imin_IPar_ (IPh Base Sens).

To decide the presence or absence of the zero sequence current, biased characteristics are applied. The minimal setting current DIS21_IoBase_IPar_ (Io Base sens.) and a percentage biasing DIS21_IoBias_IPar_ (Io bias) must be set. The biasing is applied for the detection of zero sequence current in the case of increased phase currents.

Figure. 6.3.22 - 118. Percentage characteristic for earth fault detection.



The distance-to-fault calculation

The distance protection function selects the faulty loop impedance (its positive sequence component) and calculates the distance to fault based on the measured positive sequence reactance and the total reactance of the line. This reference value is given as a parameter setting DIS21_LReact_FPar_. The calculated percentage value facilitates displaying the distance in kilometers if the total length of the line is correctly set by the parameter DIS21_Lgth_FPar_.

Table. 6.3.22 - 75. Setting parameters of the distance to fault calculation.

Parameter	Title	Dim.	Min	Max	Default
DIS21_Lgth_FPar_	Line length	km	0.1	1 000	100
DIS21_LReact_FPar_	Line reactance	ohm	0.01	150	10

Online measured values of the distance protection function

Table. 6.3.22 - 76. Measured magnitudes of the distance protection function.

Name	Title	Explanation
DIS21_HTXkm_OLM_	Fault location	Measured distance to fault in kilometers
DIS21_HTXohm_OLM_	Fault reactance	Measured reactance to fault
DIS21_L1N_R_OLM_	L1N loop R	Measured positive sequence resistance in L1N loop
DIS21_L1N_X_OLM_	L1N loop X	Measured positive sequence reactance in L1N loop
DIS21_L2N_R_OLM_	L2N loop R	Measured positive sequence resistance in L2N loop
DIS21_L2N_X_OLM_	L2N loop X	Measured positive sequence reactance in L2N loop
DIS21_L3N_R_OLM_	L3N loop R	Measured positive sequence resistance in L3N loop
DIS21_L3N_X_OLM_	L3N loop X	Measured positive sequence reactance in L3N loop
DIS21_L12N_R_OLM_	L12 loop R	Measured positive sequence resistance in L12 loop
DIS21_L12N_X_OLM_	L12 loop X	Measured positive sequence reactance in L12 loop
DIS21_L23N_R_OLM_	L23 loop R	Measured positive sequence resistance in L23 loop
DIS21_L23N_X_OLM_	L23 loop X	Measured positive sequence reactance in L23 loop
DIS21_L31N_R_OLM_	L31 loop R	Measured positive sequence resistance in L31 loop
DIS21_L31N_X_OLM_	L31 loop X	Measured positive sequence reactance in L31 loop

Table. 6.3.22 - 77. Calculated analogue values of the distance protection function.

Measured value	Dim.	Explanation
ZL1 = RL1+j XL1	ohm	Measured positive sequence impedance in the L1N loop, using the zero sequence current compensation factor for zone 1
ZL2 = RL2+j XL2	ohm	Measured positive sequence impedance in the L2N loop, using the zero sequence current compensation factor for zone 1
ZL3 = RL3+j XL3	ohm	Measured positive sequence impedance in the L3N loop, using the zero sequence current compensation factor for zone 1
ZL1L2 = RL1L2+j XL1L2	ohm	Measured positive sequence impedance in the L1L2 loop

Measured value	Dim.	Explanation
ZL2L3 = RL2L3+j XL2L3	ohm	Measured positive sequence impedance in the L2L3 loop
ZL3L1 = RL3L1+j XL3L1	ohm	Measured positive sequence impedance in the L3L1 loop
Fault location	km	Measured distance to fault
Fault reactance	ohm	Measured impedance in the fault loop

Function block

Figure. 6.3.22 - 119. The function block of the distance protection function with polygon characteristic.

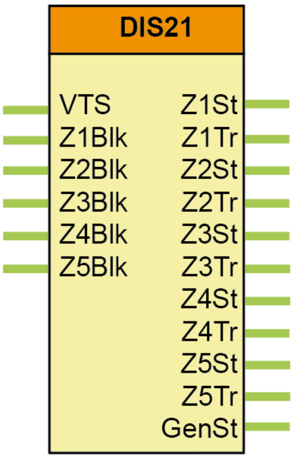
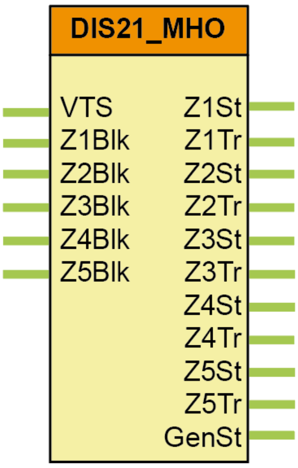


Figure. 6.3.22 - 120. The function block of the distance protection function with MHO characteristic.



The binary input and output status signals of the dead line detection function are listed in tables below.

Table. 6.3.22 - 78. The binary input signals of the distance protection function.

Binary input signal	Signal title	Explanation
DIS21_VTS_GrO_	Block from VTS	Blocking signal due to error in the voltage measurement

Binary input signal	Signal title	Explanation
DIS21_Z1Blk_GrO_	Block Z1	Blocking of Zone 1
DIS21_Z2Blk_GrO_	Block Z2	Blocking of Zone 2
DIS21_Z3Blk_GrO_	Block Z3	Blocking of Zone 3
DIS21_Z4Blk_GrO_	Block Z4	Blocking of Zone 4
DIS21_Z5Blk_GrO_	Block Z5	Blocking of Zone 5

Table. 6.3.22 - 79. The binary output status signals of the distance protection function.

Binary output signal	Signal title	Explanation
Distance Zone 1		
DIS21_Z1St_GrI_	Start Z1	General start of Zone 1
DIS21_Z1Tr_GrI_	Trip Z1	Trip command generated in Zone 1
Distance Zone 2		
DIS21_Z2St_GrI_	Start Z2	General start of Zone 2
DIS21_Z2Tr_GrI_	Trip Z2	Trip command generated in Zone 2
Distance Zone 3		
DIS21_Z3St_GrI_	Start Z3	General start of Zone 3
DIS21_Z3Tr_GrI_	Trip Z3	Trip command generated in Zone 3
Distance Zone 4		
DIS21_Z4St_GrI_	Start Z4	General start of Zone 4
DIS21_Z4Tr_GrI_	Trip Z4	Trip command generated in Zone 4
Distance Zone 5		
DIS21_Z5St_GrI_	Start Z5	General start of Zone 5
DIS21_Z5Tr_GrI_	Trip Z5	Trip command generated in Zone 5
Distance Trip		
DIS21_GenSt	GenStart	General start

6.4 Control, monitoring and measurements

6.4.1 Common function

The AQ300 series devices – independently of the configured protection functions – have some common functionality. The Common function block enables certain kind of extension this common functionality:

1. The WARNING signal of the device

The AQ300 series devices have several LED-s on the front panel. The upper left LED indicates the state of the device:

- Green means normal operation
- Yellow means WARNING state
    - The device is booting while the protection functions are operable
    - No time synchron signal is received
    - There are some setting errors such as the rated frequency setting does not correspond to the measured frequency, mismatch in vector group setting in case of transformer with three voltage levels, etc.
    - Wrong phase-voltage v.s. line-to-line voltage assignment
    - No frequency source is assigned for frequency related functions
    - The device is switched off from normal mode to Blocked or Test or Off mode
    - The device is in simulation mode
    - There is some mismatch in setting the rated values of the analog inputs.
- Red means ERROR state. (This state is indicated also by the dedicated binary output of the power supply module.

The list of the sources of the WARNING state can be extended using the Common function block. This additional signal is programmed by the user with the help of the graphic logic editor.

2. The latched LED signals

The latched LED signals can be reset:

- By the dedicated push button below the LED-s on the front panel of the device
- Using the computer connection and generating a LED reset command
- Via SCADA system, if it is configured
    - The list of the sources of the LED reset commands can be extended using the Common function block. This additional signal is programmed by the user with the help of the graphic logic editor.

The list of the sources of the LED reset commands can be extended using the Common function block. This additional signal is programmed by the user with the help of the graphic logic editor.

3. The Local/Remote state for generating command to or via the device

The Local/Remote state of the device can be toggled:

- From the local front-panel touch-screen of the device

The Local/Remote selection can be extended using the Common function block. There is possibility to apply up to 4 groups, the Local/Remote states of which can be set separately. These additional signals are programmed by the user with the help of the graphic logic editor.

4. AckButton output

AckButton output of the common function block generates a signal whenever the “X” button in the front panel of the relay has been pressed.

5. FixFalse/True

FixFalse/True can be used to write continuous 0 or 1 into an input of a function block or a logic gate.

The Common function block has binary input signals. The conditions are defined by the user applying the graphic logic editor.

Figure. 6.4.1 - 121. The function block of the common function block.

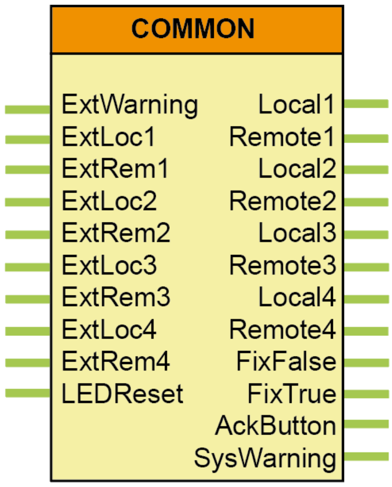


Table. 6.4.1 - 80. The binary output status signals.

Binary output status signal	Title	Explanation
Common_ExtWarning_GrO_	ExtWarning	Input to generate a Warning state of the device.
Common_ExtLoc1_GrO_	ExtLoc1	Input1 to set the state of group 1 to Local
Common_ExtRem1_GrO_	ExtRem1	Input1 to set the state of group 1 to Remote
Common_ExtLoc2_GrO_	ExtLoc2	Input2 to set the state of group 2 to Local
Common_ExtRem2_GrO_	ExtRem2	Input2 to set the state of group 2 to Remote
Common_ExtLoc3_GrO_	ExtLoc3	Input3 to set the state of group 3 to Local
Common_ExtRem3_GrO_	ExtRem3	Input3 to set the state of group 3 to Remote
Common_ExtLoc4_GrO_	ExtLoc4	Input4 to set the state of group 4 to Local
Common_ExtRem4_GrO_	ExtRem4	Input4 to set the state of group 4 to Remote
LEDReset	LED reset	Input to reset the LEDs on the front panel of the device.

Table. 6.4.1 - 81. The binary input status signals.

Binary input status signal	Title	Explanation
Common_Local1_GrI_	Local 1	Output 1 to indicate the state of group 1 as Local
Common_Remote1_GrI_	Remote 1	Output 1 to indicate the state of group 1 as Remote
Common_Local2_GrI_	Local 2	Output 2 to indicate the state of group 2 as Local
Common_Remote2_GrI_	Remote 2	Output 2 to indicate the state of group 2 as Remote
Common_Local3_GrI_	Local 3	Output 3 to indicate the state of group 3 as Local
Common_Remote3_GrI_	Remote 3	Output 3 to indicate the state of group 3 as Remote
Common_Local4_GrI_	Local 4	Output 4 to indicate the state of group 4 as Local

Binary input status signal	Title	Explanation
Common_Remote4_GrI_	Remote 4	Output 4 to indicate the state of group 4 as Remote
Common_FixFalse_GrI_	False	Fix signal FALSE to be applied in the graphic logic editor, if needed
Common_FixTrue_GrI_	True	Fix signal TRUE to be applied in the graphic logic editor, if needed
Common_AckButton_GrI_	AckButton	This is the composed signal which resets the LEDs, for further processing
Common_SysWarning_GrI_	SystemWarning	This is the composed signal with the meaning "WARNING state", for further processing

The Common function block has a single Boolean parameter. The role of this parameter is to enable or disable the external setting of the Local/Remote state.

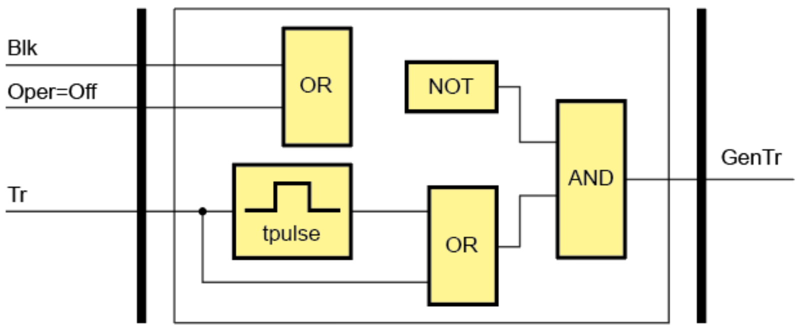
Table. 6.4.1 - 82. Setting parameters.

Parameter	Setting value/ range	Description
Ext LR Source	0	"0" means no external local/remote setting is enabled, the local LCD touch-screen is the only source of toggling.

6.4.2 Trip logic (94)

The simple trip logic function operates according to the functionality required by the IEC 61850 standard for the “Trip logic logical node”. This simplified software module can be applied if only three-phase trip commands are required, that is, phase selectivity is not applied. The function receives the trip requirements of the protective functions implemented in the device and combines the binary signals and parameters to the outputs of the device.

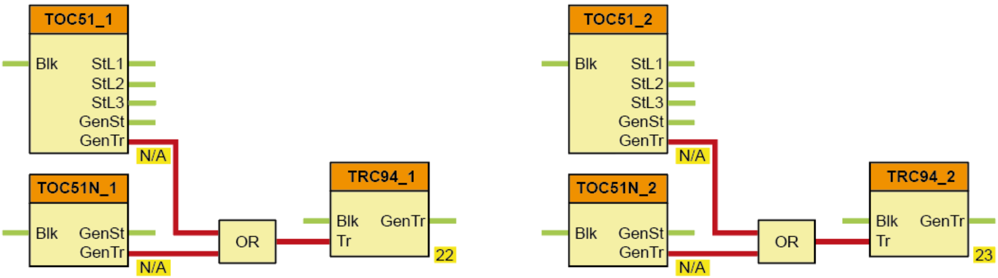
Figure. 6.4.2 - 122. Operation logic of the trip logic function.



The trip requirements can be programmed by the user. The aim of the decision logic is todefine a minimal impulse duration even if the protection functions detect a very short-timefault.

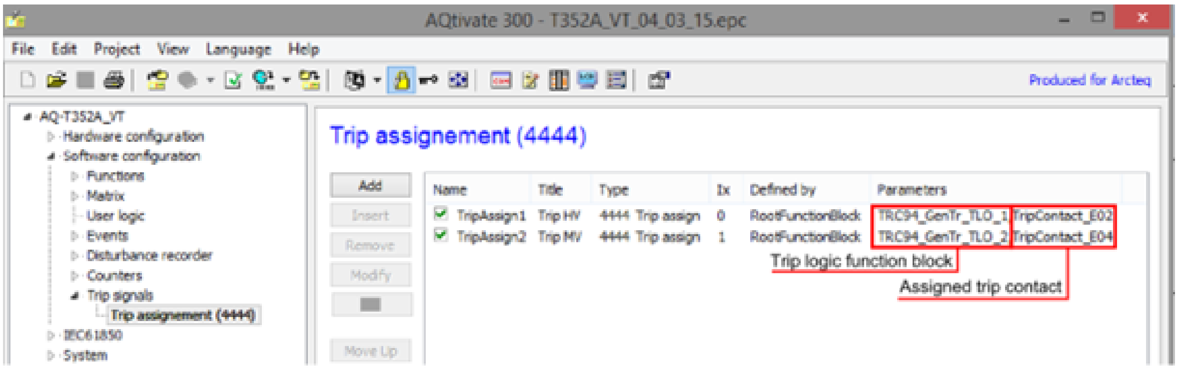
Application example

Figure. 6.4.2 - 123. Example picture where two I> TOC51 and I0> TOC51N trip signals are connected to two trip logic function blocks.



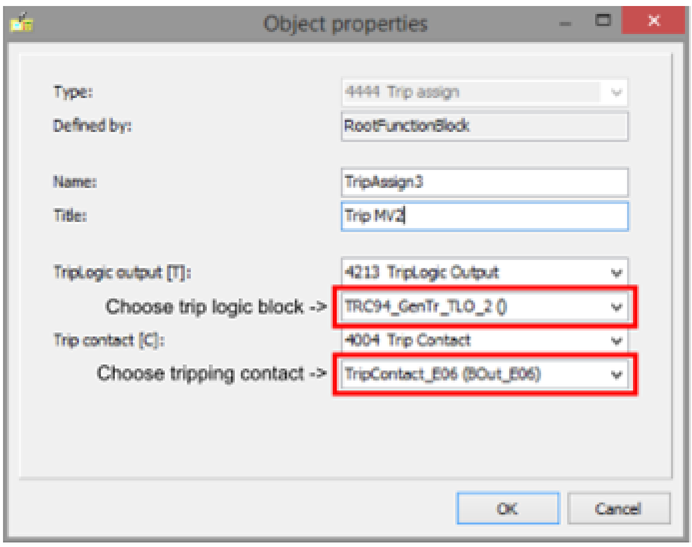
In this example we have a transformer protection supervising phase and residual currentson both sides of the transformer. So in this case the protection function trips have been connected to their individual trip logic blocks (for high voltage side and low voltage side). After connecting the trip signals into trip logic block the activation of trip contacts have to be assigned. The trip assignment is done in Software configuration → Trip signals → Trip assignment.

Figure. 6.4.2 - 124. Trip logic block #1 has been assigned as HV side trip to activate trip contact E02. Trip logic block #2 has been assigned as MV side trip to activate trip contact E04.



The trip contact assignments can be modified or the same trip logic can activate multiple contacts by adding a new trip assignment.

Figure. 6.4.2 - 125. Instructions on adding/modifying trip assignment.



Trip contact connections for wirings can be found in Hardware configuration under Rack designer → Preview or in Connection allocations.

During the parameter setting phase it should be taken care that the trip logic blocks are activated. The parameters are described in the following table.

Setting parameters

Table. 6.4.2 - 83. Setting parameters of the trip logic function.

Parameter	Setting value/range	Step	Default	Description
Operation	On Off	-	On	Operating mode selection for the function. Operation can be either disabled "Off" or enabled "On".
Min pulse length	50…60 000 ms	1 ms	150 ms	Minimum duration of the generated tripping impulse.

6.4.3 Dead line detection (DLD)

The “Dead Line Detection” (DLD) function generates a signal indicating the dead or live state of the line. Additional signals are generated to indicate if the phase voltages and phase currents are above the pre-defined limits.

The task of the “Dead Line Detection” (DLD) function is to decide the Dead line/Live line state.

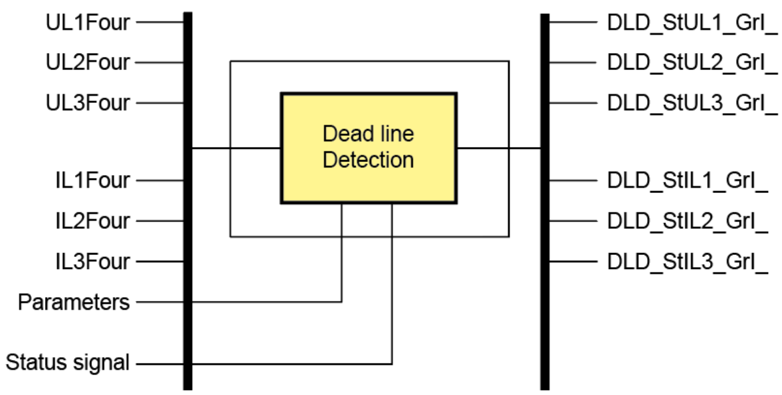
Criteria of “Dead line” state: all three phase voltages are below the voltage setting value AND all three currents are below the current setting value.

Criteria of “Live line” state: all three phase voltages are above the voltage setting value.

Dead line detection function is used in the voltage transformer supervision function also as an additional condition.

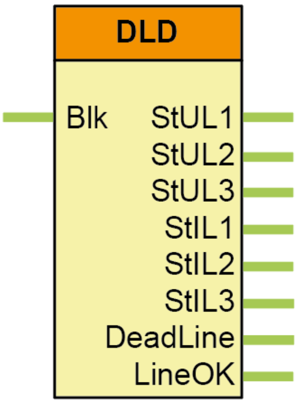
In the figure below is presented the operating logic of the dead line detection function.

Figure. 6.4.3 - 126. Principal scheme of the dead line detection function.



The function block of the dead line detection function is shown in figure bellow. This block shows all binary input and output status signals that are applicable in the AQtivate 300 software.

Figure. 6.4.3 - 127. The function block of the dead line detection function.



The binary input and output status signals of the dead line detection function are listed in tables below.

Table. 6.4.3 - 84. The binary input status signals.

Binary status signal	Explanation
DLD_Blk_GrO_	Output status defined by the user to disable the dead line detection function.

Table. 6.4.3 - 85. The binary output status signals.

Binary output signal	Signal title	Explanation
DLD function		
DLD_StUL1_GrI_	Start UL1	The voltage of phase L1 is above the setting limit
DLD_StUL2_GrI_	Start UL2	The voltage of phase L2 is above the setting limit
DLD_StUL3_GrI_	Start UL3	The voltage of phase L3 is above the setting limit
DLD_StIL1_GrI_	Start IL1	The current of phase L1 is above the setting limit
DLD_StIL2_GrI_	Start IL2	The current of phase L2 is above the setting limit
DLD_StIL3_GrI_	Start IL3	The current of phase L3 is above the setting limit
DLD_DeadLine_GrI_	DeadLine condition	The requirements of "DeadLine condition" are fulfilled
DLD_LineOK_GrI_	LineOK condition	The requirements of "Live line condition" (LineOK) are fulfilled

Table. 6.4.3 - 86. Setting parameters of the dead line detection function.

Parameter	Setting value/ range	Step	Default	Description
Operation	On Off	-	On	Operating mode selection for the function. Operation can be either disabled "Off" or enabled "On".
Min. operate voltage	10…100 %	1 %	60 %	Minimum voltage threshold for detecting the live line status. All measured phase to ground voltages have to be under this setting level.

Parameter	Setting value/ range	Step	Default	Description
Min. operate current	8…100 %	1 %	10 %	Minimum current threshold for detecting the dead line status. If all the phase to ground voltages are under the setting "Min. operate voltage" and also all the phase currents are under the "Min. operate current" setting the line status is considered "Dead".

6.4.4 Voltage transformer supervision (VTS)

The voltage transformer supervision function generates a signal to indicate an error in the voltage transformer secondary circuit. This signal can serve, for example, a warning, indicating disturbances in the measurement, or it can disable the operation of the distance protection function if appropriate measured voltage signals are not available for a distance decision.

The voltage transformer supervision function is designed to detect faulty asymmetrical states of the voltage transformer circuit caused, for example, by a broken conductor in the secondary circuit. The voltage transformer supervision function can be used for either tripping or alarming purposes.

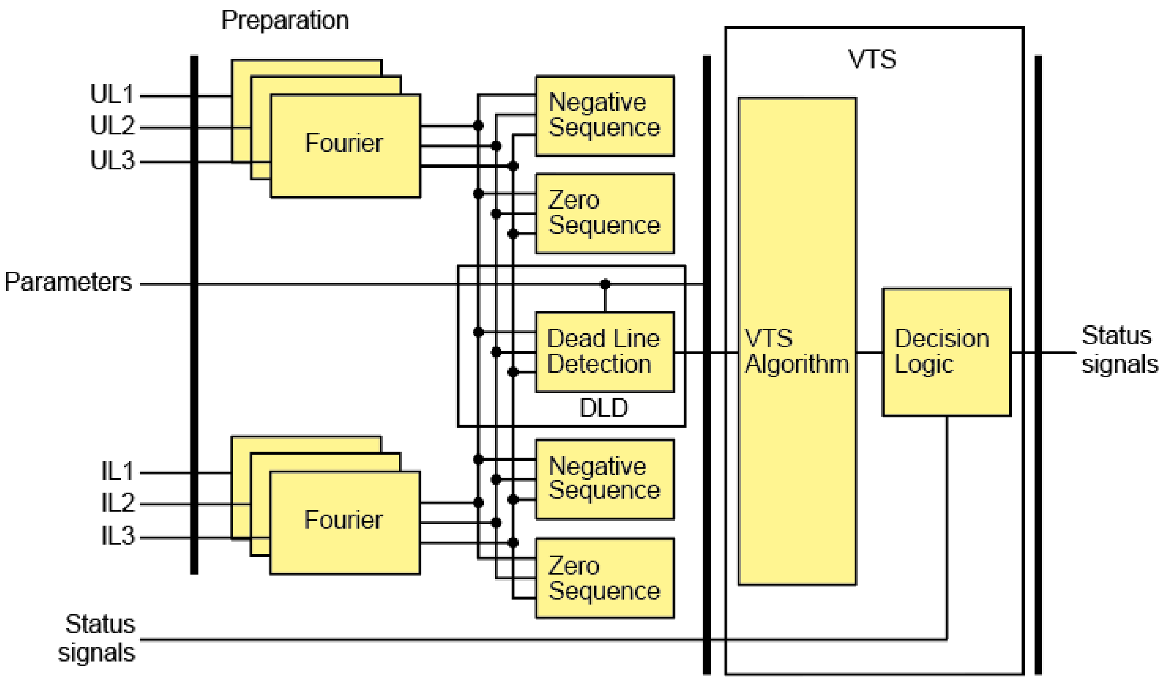
The voltage transformer supervision function can be used in three different modes of application:

- Zero sequence detection (for typical applications in systems with grounded neutral): “VT failure” signal is generated if the residual voltage (3Uo) is above the preset voltage value AND the residual current (3Io) is below the preset current value.
- Negative sequence detection (for typical applications in systems with isolated or resonant grounded (Petersen) neutral): “VT failure” signal is generated if the negative sequence voltage component (U2) is above the preset voltage value AND the negative sequence current component (I2) is below the preset current value.
- Special application: “VT failure” signal is generated if the residual voltage (3Uo) is above the preset voltage value AND the residual current (3Io) AND the negative sequence current component (I2) are below the preset current values.

The voltage transformer supervision function can be triggered if “Live line” status is detected for at least 200 ms. The purpose of this delay is to avoid mal-operation at line energizing if the poles of the circuit breaker make contact with a time delay. The function is set to be inactive if “Dead line” status is detected. If the conditions specified by the selected mode of operation are fulfilled then the voltage transformer supervision function is triggered and the operation signal is generated. When the conditions for operation are no longer fulfilled, the resetting of the function depends on the mode of operation of the primary circuit:

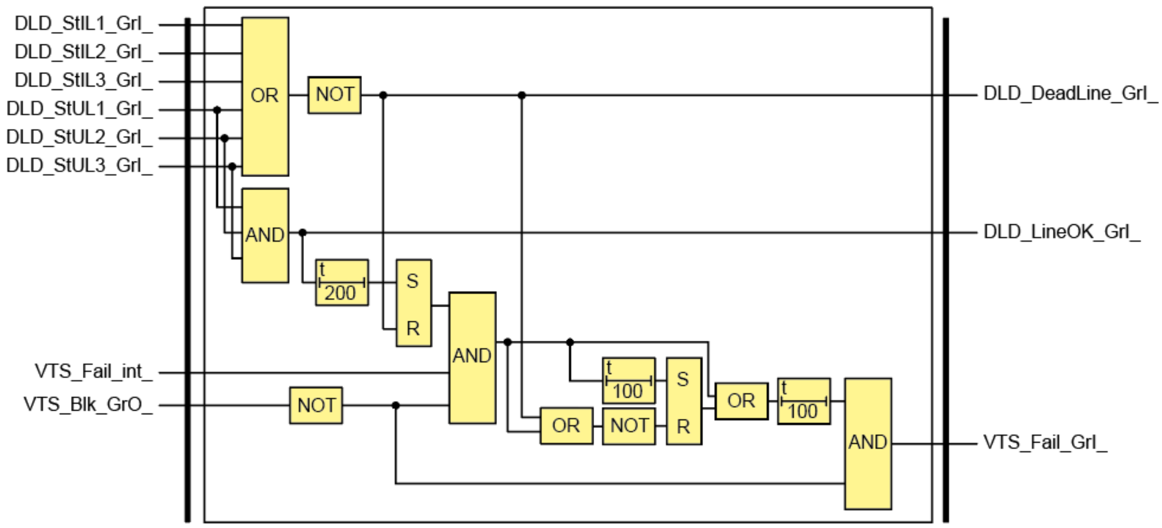
- If the “Live line” state is valid, then the function resets after approx. 200 ms of time delay.
- If the “Dead line” state is started and the “VTS Failure” signal has been continuous for at least 100 ms, then the “VTS failure” signal does not reset; it is generated continuously even when the line is in a disconnected state. Thus, the “VTS Failure” signal remains active at reclosing.
- If the “Dead line” state is started and the “VTS Failure” signal has not been continuous for at least 100 ms, then the “VTS failure” signal resets.

Figure. 6.4.4 - 128. Operation logic of the voltage transformer supervision and dead line detection.



The voltage transformer supervision logic operates through decision logic presented in the following figure.

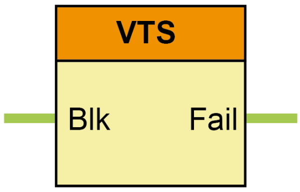
Figure. 6.4.4 - 129. Decision logic of the voltage transformer supervision function.



NOTICE!
For the operation of the voltage transformer supervision function the " Dead line detection function" must be operable as well: it must be enabled by binary parameter.

The function block of voltage transformer supervision function is shown in figure below. This block shows all binary input and output status signals that are applicable in the graphic equation editor.

Figure. 6.4.4 - 130. The function block of the voltage transformer supervision function.



The binary input and output status signals of voltage transformer supervision function are listed in tables below.

Table. 6.4.4 - 87. The binary input and output signals of the VTS function.

Binary status signal	Title	Explanation
VTS_Blk_GrO_	-	Output status defined by the user to disable the voltage transformer supervision function
VTS_Fail_GrI_	VT Failure	Failure status signal of the VTS function

Table. 6.4.4 - 88. Setting parameters of the VTS function.

Parameter	Setting value/ range	Step	Default	Description
Operation	Off Neg. Sequence Zero sequence Special	-	Neg. Sequence	Operating mode selection for the function. Operation can be either disabled "Off" or enabled with criteria "Neg. Sequence", "Zero sequence" or "Special".
Start URes	5…50 %	1 %	30 %	Residual voltage setting limit.
Start IRes	10…50 %	1 %	10 %	Residual current setting limit.
Start UNeg	5…50 %	1 %	10 %	Negative sequence voltage setting limit.
Start INeg	10…50 %	1 %	10 %	Negative sequence current setting limit.

6.4.5 Current transformer supervision (CTS)

The current transformer supervision function can be applied to detect unexpected asymmetry in current measurement.

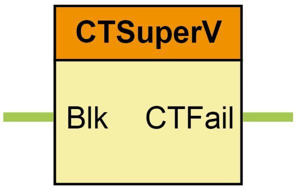
The function block selects maximum and minimum phase currents (fundamental Fourier components). If the difference between them is above the setting limit, the function generates a start signal. For function to be operational the highest measured phase current shall be above 10 % of the rated current and below 150% of the rated current.

The function can be disabled by parameter setting, and by an input signal programmed by the user.

The failure signal is generated after the defined time delay.

The function block of the current transformer supervision function is shown in figure bellow. This block shows all binary input and output status signals that are applicable in the AQtivate300 software.

Figure. 6.4.5 - 131. The function block of the current transformer supervision function.



The binary input and output status signals of the dead line detection function are listed intables below.

Table. 6.4.5 - 89. The binary input and output status signals.

Binary status signal	Title	Explanation
CTSuperV_Blk_GrO_	Block	Blocking of the function
CTSuperV_CtFail_GrI_	CtFail	CT failure signal

Table. 6.4.5 - 90. Setting parameters.

Parameter	Setting value/range	Step	Default	Description
Operation	On Off	-	On	Operating mode selection for the function. Operation can be either disabled "Off" or enabled "On".
IPhase Diff	50…90 %	1 %	80 %	Phase current difference setting.
Time delay	100…60 000 ms	1 ms	1 000 ms	CT supervision time delay.

6.4.6 Synchrocheck (dV/da/df; 25)

Several problems can occur in the power system if the circuit breaker closes and connects two systems operating asynchronously. The high current surge can cause damage in the interconnecting elements, the accelerating forces can overstress the shafts of rotating machines or the actions taken by the protective system can result in the eventual isolation of parts of the power system.

To prevent such problems, this function checks if the systems to be interconnected are operating synchronously. If yes, then the close command is transmitted to the circuit breaker. In case of asynchronous operation, the close command is delayed to wait for the appropriate vector position of the voltage vectors on both sides of the circuit breaker. If the conditions for safe closing cannot be fulfilled within an expected time, then closing is declined.

NOTICE!
For capacitive reference voltage measurement, the voltage measurement card can be ordered with <50 mVA burden special input.

The conditions for safe closing are as follows:

- The difference of the voltage magnitudes is below the set limit.
- The difference of the frequencies is below the set limit.
- The angle difference between the voltages on both sides of the circuit breaker is within the set limit.

The function processes both automatic reclosing and manual close commands.

The limits for automatic reclosing and manual close commands can be set independently of each other.

The function compares the voltage of the line and the voltage of one of the busbar sections (Bus1 or Bus2). The bus selection is made automatically based on a binary input signal defined by the user.

For the reference of the synchrocheck any phase-to-ground or phase-to-phase voltage can be selected.

The function processes the signals of the voltage transformer supervision function and enables the close command only in case of plausible voltages.

The synchrocheck function monitors three modes of conditions:

- Energizing check:
    - Dead bus, live line
    - Live bus, dead line
    - Any Energizing case (including Dead bus, dead line)
- Synchro check (Live line, live bus)
- Synchro switch (Live line, live bus)

If the conditions for “Energizing check” and “Synchro check” are fulfilled, then the function generates the release command, and in case of a manual or automatic close request, the close command is generated.

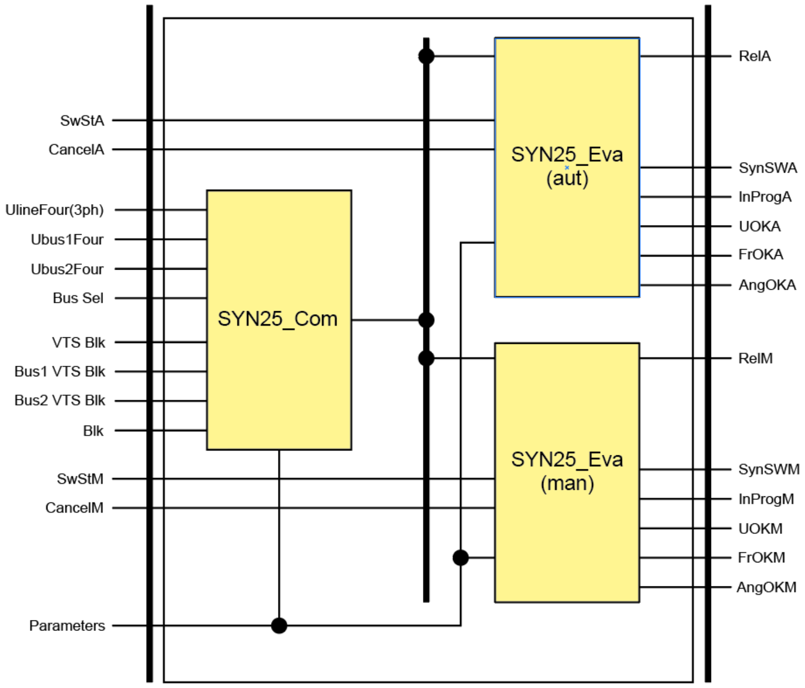
If the conditions for energizing and synchronous operation are not met when the close request is received, then synchronous switching is attempted within the set time-out. In this case, the rotating vectors must fulfill the conditions for safe switching within the set waiting time: at the moment the contacts of the circuit breaker are closed, the voltage vectors must match each other with appropriate accuracy. For this mode of operation, the expected operating time of the circuit breaker must be set as a parameter value, to generate the close command in advance taking the relative vector rotation into consideration.

Started closing procedure can be interrupted by a cancel command defined by the user.

In “bypass” operation mode, the function generates the release signals and simply transmits the close command.

In the following figure is presented the operating logic of the synchrocheck function.

Figure. 6.4.6 - 132. Operation logic of the synchrocheck function.



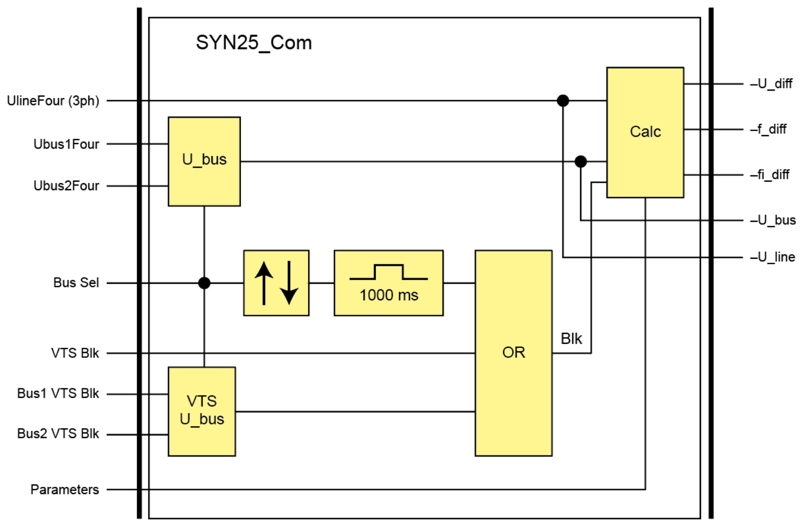
The synchro check/synchro switch function contains two kinds of software blocks:

- SYN25_Com = a common block for manual switching and automatic switching.
- SYN25_EVA = an evaluation block, duplicated for manual switching and for automatic switching.

The SYN25_Com block selects the appropriate voltages for processing and calculates the voltage difference, the frequency difference and the phase angle difference between the selected voltages. The magnitude of the selected voltages is passed for further evaluation.

These values are further processed by the evaluation software blocks. The function is disabled if the binary input (Block) signal is TRUE. The activation of voltage transformer supervision function of the line voltage blocks the operation (VTS Block). The activation of voltage transformer supervision function of the selected bus section blocks the operation (VTS Bus1 Block or VTS Bus2 Block).

Figure. 6.4.6 - 133. Synchrocheck common difference calculation function structure.

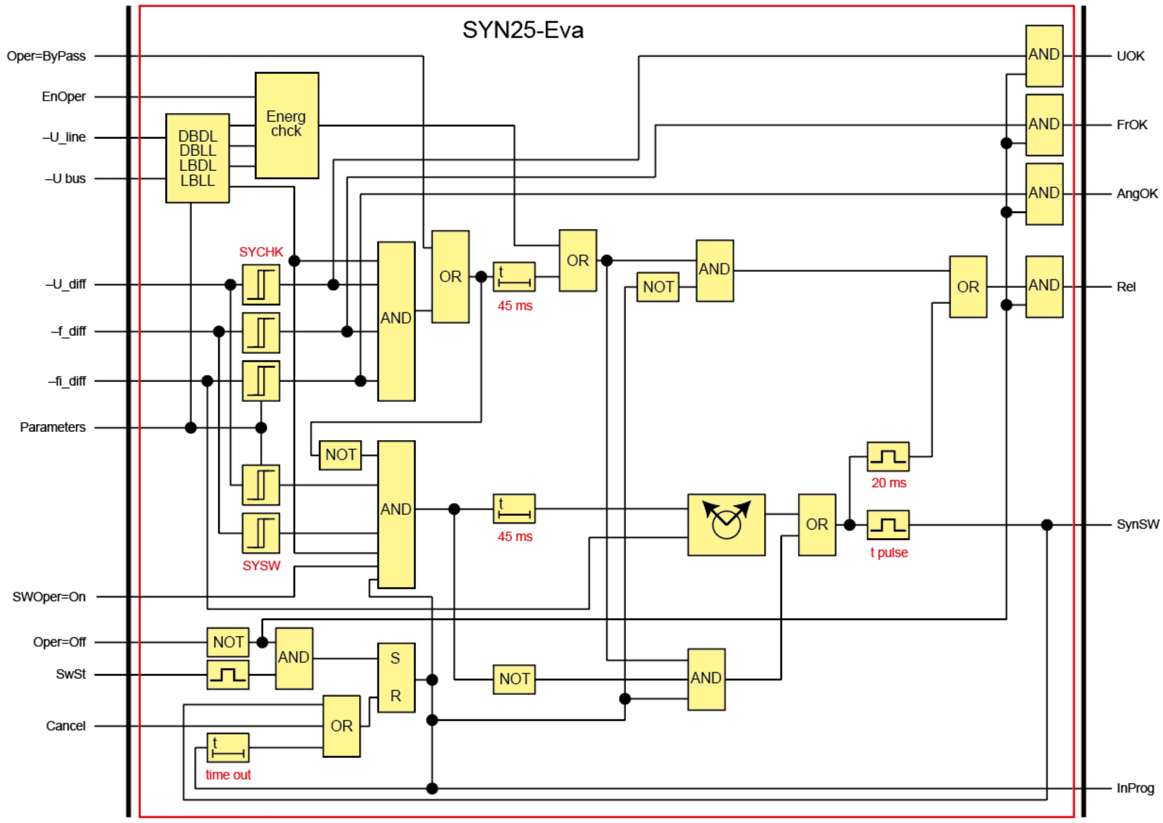


If the active bus section changes the function is dynamically blocked for 1000ms and no release signal or switching command is generated. The processed line voltage is selected based on the preset parameter (Voltage select). The choice is: L1-N, L2-N, L3-N, L1-L2,L2-L3 or L3-L1. The parameter value must match the input voltages received from the bus sections. The active bus section is selected by the input signal (Bus select). If this signal is logic TRUE, then the voltage of Bus2 is selected for evaluation.

The software block SYN25_Eva is applied separately for automatic and manual commands. This separation allows the application to use different parameter values for the two modes of operation.

The structure of the evaluation software block is shown in the following figure.

Figure. 6.4.6 - 134. Synchrocheck evaluation function structure.



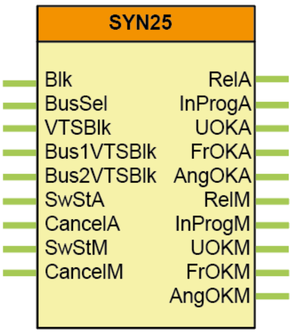
This evaluation software block is used for two purposes: for the automatic reclosing command (the signal names have the suffix "A") and for the manual close request (the signal names have the suffix "M"). As the first step, based on the selected line voltage and bus voltage, the state of the required switching is decided (Dead bus-Dead line, Dead bus-Live line, Live bus-Dead line or Live bus- Live line). The parameters for decision are (U Live) and (U Dead). The parameters (Energizing Auto/Manual) enable the operation individually. The choice is: (Off, DeadBus LiveLine, LiveBus DeadLine, Any energ case). In simple energizing modes, no further checking is needed. This mode selection is bypassed if the parameter (Operation Auto/Manual) is set to "ByPass". In this case the command is transmitted without any further checking.

First, the function tries switching with synchro check. This is possible if: the voltage difference is within the defined limits (Udiff SynChk Auto/Manual)) the frequency difference is within the defined limits (FrDiff SynChk Auto) and the phase angle difference is within the defined limits (MaxPhaseDiff Auto/ Manual)).

If the conditions are fulfilled for at least 45 ms, then the function generates a release output signal (Release Auto/Manual).If the conditions for synchro check operation are not fulfilled and a close request is received as the input signal (SySwitch Auto/Manual), then synchro switching is attempted. This is possible if: the voltage difference is within the defined limits (Udiff SynSW Auto /Manual)) the frequency difference is within the defined limits (FrDiff SynSW Auto).

These parameters are independent of those for the synchro check function. If the conditions for synchro check are not fulfilled and the conditions for synchro switch are OK, then the relative rotation of the voltage vectors is monitored. The command is generated before the synchronous position, taking the breaker closing time into consideration (Breaker Time).The pulse duration is defined by the parameter (Close Pulse). In case of slow rotation and if the vectors are for long time near-opposite vector positions, no switching is possible, therefore the waiting time is limited by the preset parameter (Max.Switch Time).

Figure. 6.4.6 - 135. The function block of the synchrocheck/synchroswitch function.



The progress is indicated by the output status signal (SynInProgr Auto/Manual). The started command can be canceled using the input signal (Cancel Auto/Manual).

The binary input and output status signals of the dead line detection function are listed in tables below.

Table. 6.4.6 - 91. The binary input signals.

Binary status signal	Title	Explanation
SYN25_BusSel_GrO_	Bus Select	If this signal is logic TRUE, then the voltage of Bus2 is selected for evaluation.
SYN25_VTSBlk_GrO_	VTS Block	Blocking signal of the voltage transformer supervision function evaluating the line voltage.
SYN25_Bus1VTSBlk_GrO_	VTS Bus1 Block	Blocking signal of the voltage transformer supervision function evaluating the Bus1 voltage.
SYN25_Bus2VTSBlk_GrO_	VTS Bus2 Block	Blocking signal of the voltage transformer supervision function evaluating the Bus2 voltage.
SYN25_SwStA_GrO_	SySwitch Auto	Switching request signal initiated by the automatic reclosing function.
SYN25_CancelA_GrO_	Cancel Auto	Signal to interrupt (cancel) the automatic switching procedure.
SYN25_Blk_GrO_	Block	Blocking signal of the function.
SYN25_SwStM_GrO_	SySwitch Manual	Switching request signal initiated by manual closing.

Binary status signal	Title	Explanation
SYN25_CancelM_GrO_	Cancel Manual	Signal to interrupt (cancel) the manual switching procedure.

Table. 6.4.6 - 92. The binary output signals.

Binary status signal	Title	Explanation
SYN25_RelA_GrI_	Release Auto	Releasing the close command initiated by the automatic reclosing function.
SYN25_InProgA_GrI_	SynInProgr Auto	Switching procedure is in progress, initiated by the automatic reclosing function.
SYN25_UOKA_GrI_	Udiff OK Auto	The voltage difference is appropriate for automatic closing command.
SYN25_FrOKA_GrI_	FreqDiff OK Auto	The frequency difference is appropriate for automatic closing command, evaluated for synchrocheck.
SYN25_AngOKA_GrI_	Angle OK Auto	The angle difference is appropriate for automatic closing request.
SYN25_RelM_GrI_	Release Man	Releasing the close command initiated by manual closing request.
SYN25_InProgM_GrI_	SynInProgr Man	Switching procedure is in progress, initiated by the manual closing command.
SYN25_UOKM_GrI_	Udiff OK Man	The voltage difference is appropriate for automatic closing command.
SYN25_FrOKM_GrI_	FreqDiff OK Man	The frequency difference is appropriate for manual closing command, evaluated for synchrocheck.
SYN25_AngOKM_GrI_	Angle OK Man	The angle difference is appropriate for manual closing command.

Table. 6.4.6 - 93. Setting parameters.

Parameter	Setting value/ range	Step	Default	Description
Voltage select	L1-N L2-N L3-N L1-L2 L2-L3 L3-L1	-	L1-N	Reference voltage selection. The function will monitor the selected voltage for magnitude, frequency and angle differences.
U Live	60…110 %	1 %	70 %	Voltage setting limit for "Live Line" detection. When measured voltage is above the setting value the line is considered "Live".
U Dead	10…60 %	1 %	30 %	Voltage setting limit for "Dead line" detection. When measured voltage is below the setting value the line is considered "Dead".

Parameter	Setting value/ range	Step	Default	Description
Breaker Time	0…500 ms	1 ms	80 ms	Breaker operating time at closing. This parameter is used for the synchroswitch closing command compensation and it describes the breaker travel time from open position to closed position from the close command.
Close Pulse	10…60 000 ms	1 ms	1 000 ms	Close command pulse length. This setting defines the duration of close command from the IED to the circuit breaker.
Max Switch Time	100…60 000 ms	1 ms	2 000 ms	Maximum allowed switching time. In case synchrocheck conditions are not fulfilled and the rotation of the networks is slow this parameter defines the maximum waiting time after which the close command is failed.
Operation Auto	On Off ByPass	-	On	Operation mode for automatic switching. Selection can be automatic switching off, on or bypassed. If the Operation Auto is set to "Off" automatic switch checking is disabled. If selection is "ByPass" Automatic switching is enabled with bypassing the bus and line energization status checking. When the selection is "On" also the energization status of bus and line are checked before processing the command.
SynSW Auto	On Off	-	On	Automatic synchroswitching selection. Selection may be enabled "On" or disabled "Off".
Energizing Auto	Off DeadBus LiveLine LiveBus DeadLine Any energ case	-	DeadBus LiveLine	Energizing mode of automatic synchroswitching. Selections consist of the monitoring of the energization status of the bus and line. If the operation is wanted to be LiveBus LiveLine or DeadBus DeadLine, the selection is "Any energ case".
Udiff SynChk Auto	5…30 %	1 %	10 %	Voltage difference checking of the automatic synchrocheck mode. If the measured voltage difference is below this setting the condition applies.
Udiff SynSW Auto	5…30 %	1 %	10 %	Voltage difference checking of the automatic synchroswitch mode. If the measured voltage difference is below this setting the condition applies.
MaxPhasediff Auto	5…80 deg	1 deg	20 deg	Phase difference checking of the automatic synchroswitch mode. If the measured phase difference is below this setting the condition applies.
FrDiff SynChk Auto	0.02…0.50 Hz	0.01 Hz	0.02 Hz	Frequency difference checking of the automatic synchrocheck mode. If the measured phase difference is below this setting the condition applies.
FrDiff SynSW Auto	0.10…1.00 Hz	0.01 Hz	0.2 Hz	Frequency difference checking of the automatic synchroswitch mode. If the measured phase difference is below this setting the condition applies.
Operation Man	On Off ByPass	-	On	Operation mode for manual switching. Selection can be manual switching off, on or bypassed. If the Operation Man is set to "Off" manual switch checking is disabled. If selection is "ByPass" manual switching is enabled with bypassing the bus and line energization status checking. When the selection is "On" also the energization status of bus and line are checked before processing the command.

Parameter	Setting value/ range	Step	Default	Description
SynSW Man	On Off	-	On	Manual synchroswitching selection. Selection may be enabled "On" or disabled "Off".
Energizing Man	Off Deadbus LiveLine LiveBus DeadLine Any energ case	-	DeadBus LiveLine	Energizing mode of manual synchroswitching. Selections consist of the monitoring of the energization status of the bus and line. If the operation is wanted to be LiveBus LiveLine or DeadBus DeadLine the selection is "Any energ case".
Udiff SynChk Man	5…30 %	1 %	10 %	Voltage difference checking of the manual synchrocheck mode. If the measured voltage difference is below this setting the condition applies.
Udiff SynSW Man	5…30 %	1 %	10 %	Voltage difference checking of the manual synchroswitch mode. If the measured voltage difference is below this setting the condition applies.
MaxPhaseDiff Man	5…80 deg	1 deg	20 deg	Phase difference checking of the manual synchroswitch mode. If the measured phase difference is below this setting the condition applies.
FrDiff SynChk Man	0.02…0.50 Hz	0.01 Hz	0.02 Hz	Frequency difference checking of the manual synchroswitch mode. If the measured phase difference is below this setting the condition applies.
FrDiff SynSW Man	0.10…1.00 Hz	0.01 Hz	0.2 Hz	Frequency difference checking of the manual synchroswitch mode. If the measured phase difference is below this setting the condition applies.

6.4.7 Auto-reclosing (MV) (79)

Operation

The automatic reclosing function for medium-voltage networks can perform up to four shots of reclosing. The dead time can be set individually for each reclosing and separately for earth faults and for multi-phase faults.

The starting signal of the cycles can be generated by any combination of the protection functions or external signals of the binary inputs defined by user.

The automatic reclosing function is triggered if as a consequence of a fault a protection function generates a trip command to the circuit breaker and the protection function resets because the fault current drops to zero and/or the circuit breakers auxiliary contact signals open state. According to the preset parameter values, either of these two conditions starts counting the dead time, at the end of which the automatic reclosing function generates a close command. If the fault still exist or reappears, then within the "Reclaim time" (according to parameter setting, started at the close command) the auto-reclose function picks up again and the subsequent cycle is started. If no pickup is detected within this time, then the automatic reclosing function resets and a new fault will start the procedure with the first cycle again.

Following additional requirements apply to performing automatic reclosing:

- The automatic reclosing function can be blocked with any available signal or combination of signals defined by user.

- After a pickup of the protection function, a timer starts to measure the "Action time" (the duration depends on parameter setting (Action time)). The trip command must be generated within this time to start reclosing cycles, or else the automatic function enters blocked state.
- At the moment of generating the close command, the circuit breaker must be ready for operation, which is signaled via binary input (CB Ready). The preset parameter value (CB Supervision time) decides how long the automatic reclosing function is allowed to wait at the end of the dead time for this signal. If the signal is not received during this dead time extension, then the automatic reclosing function terminates and after a "dynamic blocking time" (depending on the preset parameter value (Dynamic Blocking time)) the function resets.

In case of a manual close command (which is assigned to the logic variable (Manual Close) using equation programming), a preset parameter value decides how long the MV autorecloser function should be disabled after the manual close command.

The duration of the close command depends on preset parameter value (Close command time), but the close command terminates if any of the protection functions issues a trip command.

Cycles

The automatic reclosing function can control up to four reclosing cycles, separately for earth faults and for multi-phase faults. Depending on the preset parameter values (EarthFaults Rec,Cycle) and (PhaseFaults Rec,Cycle), there are different modes of operation, both for earth faults and for multi-phase faults:

- Disabled = no automatic reclosing is selected
- 1. Enabled = only one automatic reclosing cycle is selected
- 1.2. Enabled = two automatic reclosing cycles are activated
- 1.2.3. Enabled = three automatic reclosing cycles are activated
- 1.2.3.4. Enabled = all automatic reclosing cycles are activated.

The MV automatic reclosing function enters into the dynamic blocking state:

- If the parameter selection for (Reclosing started by) is "Trip reset" and the trip impulse is too long.
- If the parameter selected for (Reclosing started by) is "CB open", then during the runtime of the timer CB open signal is received).

The start of dead time counter of any reclosing cycle can be delayed. The delay is activated if the value of the (Dead Time St.Delay) status signal is TRUE. This delay is defined by the timer parameter (DeadTime Max.Delay).

For all four reclosing cycles, separate dead times can be defined for line-to-line faults and for earth faults.The timer parameters for line-to-line faults are:

1. Dead Time Ph
2. Dead Time Ph
3. Dead Time Ph
4. Dead Time Ph

The timer parameters for earth faults are:

1. Dead Time EF
2. Dead Time EF
3. Dead Time EF
4. Dead Time EF

In case of evolving faults, the dead times depend on the first fault detection.

The automatic reclosing function is prepared to generate three-phase trip commands only. The applied dead time setting depends on the first detected fault type indicated by the input signal (EarthFaultTrip NoPhF). (This signal is TRUE in case of an earth fault.) The subsequent cycles do not change this decision.

If the circuit breaker is not ready, the controller function waits for a pre-programmed time for this state. The waiting time is defined by the user as parameter value (CB Supervision time). If circuit breaker ready signal does not activate during the waiting time, then the automatic reclosing function enters into “Dynamic blocked” state.

Synchro-check conditions

Reclosing is possible only if the conditions required by the “synchro-check” function are fulfilled. This state is signaled by the binary variable (SYNC Release). The automatic reclosing function waits for a pre-programmed time for this signal. This time is defined by the user as parameter value (Sync-check Max.Tim). If the “SYNC Release” signal is not received during the running time of this timer, then the “synchronous switch” operation is started and the signal (CloseRequ.SynSwitch) is generated.

If the conditions of the synchronous state are not fulfilled, another timer starts. The waiting time is defined by the user as parameter value (Sync-switch Max.Tim). This separate function controls the generation of the close command in case of relatively rotating voltage vectors for the circuit breaker to make contact at the synchronous state of the rotating vectors. For this calculation, the closing time of the circuit breaker must be defined. This mode of operation is indicated by the output variable (CloseRequ. SynSwitch).

If no switching is possible during the running time of this timer, then the automatic reclosing function enters “Dynamic blocked” state and resets.When the close command is generated, a timer is started to measure the “Reclaim time”. The duration is defined by the parameter value (Reclaim time), but it is prolonged up to the reset of the close command (if the close command duration is longer than the reclaim time set). If the fault is detected again during this time, then the sequence of the automatic reclosing cycles continues. If no fault is detected, then at the expiry of the reclaim time the reclosing is considered successful and the function resets. If fault is detected after the expiry of this timer, then the cycles restart with the first reclosing cycle.

If the user programmed the status variable (Protection Start) and it gets TRUE during the Reclaim time, then the automatic reclosing function continues even if the trip command is received after the expiry of the Reclaim time.

After a manual close command, the automatic reclosing function enters “Not Ready” state for the time period defined by parameter (Block after Man.Close). If the manual close command is received during the running time of any of the cycles, then the automatic reclosing function enters into “Dynamic blocked” state and resets.

If the fault still exists at the end of the last cycle, the automatic reclosing function trips and generates the signal for final trip: (Final Trip). The same final trip signal is generated in case of an evolving fault if “Block Reclosing” is selected. After final trip, the automatic reclosing function enters “Dynamic blocked” state. A final trip command is also generated if, after a multi-phase fault, a fault is detected again during the dead time.

There are several conditions to cause dynamic blocked state of the automatic reclosing function. This state becomes valid if any of the conditions of the dynamic blocking changes to active during the running time of any of the reclosing cycles. At the time of the change a timer is started. Timer duration is defined by the time parameter (Dynamic Blocking time). During this time, no reclosing command is generated.

The conditions to start the dynamic blocked state are:

- There is no trip command during the “Action time”.
- The duration of the starting impulse for the MV automatic reclosing function is too long.

- If no “CB ready” signal is received at the intended time of reclosing command.
- The dead time is prolonged further then the preset parameter value (DeadTime Max.Delay).
- The waiting time for the “SYNC Release” signal is too long.
- After the final trip command.
- In case of a manual close command or a manual open command (if the status variable (CB OPEN single-pole) gets TRUE without (AutoReclosing Start)).
- In case of a general block (the device is blocked).

In a dynamic blocked state, the (Blocked) status signal is TRUE (similar to “Not ready” conditions).

There are several conditions that must be satisfied before the automatic reclosing function enters “Not Ready” state. This state becomes valid if any of the conditions of the blocking get TRUE outside the running time of the reclosing cycles.

- Reclosing is disabled by the parameter if it is selected to “Off”.
- The circuit breaker is not ready for operation.
- After a manual close command.
- If the parameter (CB State Monitoring) is set to TRUE and the circuit breaker is in Open state, i.e., the value of the (CB OPEN position) status variable gets TRUE.
- The starting signal for automatic reclosing is selected by parameter (Reclosing started by) to be “CB open” and the circuit breaker is in Open state.
- In case of a general block (the device is blocked).

Setting parameters

Table. 6.4.7 - 94. Setting parameters.

Parameter	Setting value/ range	Step	Default	Description
Operation	On Off	-	On	Enabling / Disabling of the autorecloser function.
EarthFault RecCycle	Disabled 1. Enabled 1.2. Enabled 1.2.3. Enabled 1.2.3.4. Enabled	-	1. Enabled	Selection of the number of reclosing sequences for earth faults.
PhaseFault RecCycle	Disabled 1. Enabled 1.2. Enabled 1.2.3. Enabled 1.2.3.4. Enabled	-	1. Enabled	Selection of the number of reclosing sequences for line-to-line faults.
Reclosing started by	Trip reset CB Open	-	Trip reset	Selection of triggering the dead time counter (trip signal reset or circuit breaker open position).
Evolving fault	Block Reclosing, Start 3Ph Rec.	-	Block Reclosing	Selection of behavior in case of evolving fault (block reclosing or perform three-phase automatic reclosing cycle).
CB State monitoring	Enabled Disabled	-	Disabled	Enable CB state monitoring for "Not Ready" state.
Reclaim time	100…100 000 ms	10 ms	2 000 ms	Reclaim time setting.

Parameter	Setting value/ range	Step	Default	Description
Close Command time	10…10 000 ms	10 ms	100 ms	Pulse duration setting for the CLOSE command from the IED to circuit breaker.
Dynamic Blocking time	0…100 000 ms	10 ms	1 500 ms	Setting of the dynamic blocking time.
Block after Man.Close	0…100 000 ms	10 ms	1 000 ms	Setting of the blocking time after manual close command.
Action time	0…20 000 ms	10 ms	1 000 ms	Setting of the action time.
Start-signal Max.Tim	0…10 000 ms	10 ms	1 000 ms	Time limitation of the starting signal.
DeadTime Max.Delay	0…1 000 000 ms	10 ms	3 000 ms	Delaying the start of the dead-time counter.
CB Supervision Time	10…1 000 000 ms	10 ms	1 000 ms	Waiting time for circuit breaker ready signal.
Sync-check Max.Tim	500…100 000 ms	10 ms	10 000 ms	Waiting time for synchronous state signal.
Sync-switch Max.Tim	500…100 000 ms	10 ms	10 000 ms	Waiting time for synchronous switching.
1.Dead Time 3Ph	0…100 000 ms	10 ms	500 ms	Dead time setting for the first reclosing cycle for multi-phase fault.
2.Dead Time 3Ph	10…100 000 ms	10 ms	600 ms	Dead time setting for the second reclosing cycle for multi-phase fault.
3.Dead Time 3Ph	10…100 000 ms	10 ms	700 ms	Dead time setting for the third reclosing cycle for multi-phase fault.
4.Dead Time 3Ph	10…100 000 ms	10 ms	800 ms	Dead time setting for the fourth reclosing cycle for multi-phase fault.
1.Dead Time 1 PH	0…100 000 ms	10 ms	1 000 ms	Dead time setting for the first reclosing cycle for single-phase fault.
2.Dead Time 1 PH	10…100 000 ms	10 ms	2 000 ms	Dead time setting for the second reclosing cycle for single-phase fault.
3.Dead Time 1 PH	10…100 000 ms	10 ms	3 000 ms	Dead time setting for the third reclosing cycle for single-phase fault.
4.Dead Time 1 PH	10…100 000 ms	10 ms	4 000 ms	Dead time setting for the fourth reclosing cycle for single-phase fault.
Accelerate 1. Trip	Enabled Disabled	-	Disabled	Acceleration of the 1st reclosing cycle trip command.
Accelerate 2. Trip	Enabled Disabled	-	Disabled	Acceleration of the 2nd reclosing cycle trip command.

Parameter	Setting value/ range	Step	Default	Description
Accelerate 3. Trip	Enabled Disabled	-	Disabled	Acceleration of the 3rd reclosing cycle trip command.
Accelerate 4. Trip	Enabled Disabled	-	Disabled	Acceleration of the 4th reclosing cycle trip command.
Accelerate final Trip	Enabled Disabled	-	Disabled	Acceleration of the final trip command.

6.4.8 Auto-reclosing (HV) (79)

Operation

The HV automatic reclosing function for high voltage networks can realize up to four shots of reclosing. The dead time can be set individually for each reclosing and separately for singlephase faults and for multi-phase faults.

The starting signal of the cycles can be generated by any combination of the protection functions or external signals of the binary inputs. The selection is made by graphic equation programming.

The automatic reclosing function is triggered if as a consequence of a fault a protection function generates a trip command to the circuit breaker and the protection function resets because the fault current drops to zero or the circuit breaker's auxiliary contact signals open state. According to the preset parameter values, either of these two conditions starts counting the dead time, at the end of which the HV automatic reclosing function generates a close command automatically. If the fault still exists or reappears, then within the "Reclaim time" (according to parameter setting REC79_Rec_TPar_), started at the close command, the protection functions picks up again and the subsequent cycle is started. If no pickup is detected within this time, then the HV automatic reclosing cycle resets and a new fault will start the procedure with the first cycle again.

There are some additional requirements to perform automatic reclosing:

- The HV automatic reclosing function can be blocked by the variable REC79_Blk_GrO_, for which the user has to compose a graphic logical equation.
- After a pickup of the protection function, a timer starts to measure the "Action time" (the duration of which depends on parameter setting REC79_Act_TPar_ (Action time)). The trip command must be generated within this time to start reclosing cycles, or else the HV automatic function enters dynamic blocked state.
- At the moment of generating the close command, the circuit breaker must be ready for operation, which is signaled via binary input REC79_CBRdy_GrO_ (CB Ready). The preset parameter value REC79_CBTO_TPar_ (CB Supervision time) decides how long the HV automatic reclosing function is allowed to wait when the function is in "In Progress" state. If the signal is not received during this time, then the HV automatic reclosing function terminates and after a "dynamic blocking time" (depending on the preset parameter value REC79_DynBlk_TPar_ (Dynamic Blocking time)) the function resets.

Depending on the preset parameter value, the HV automatic reclosing function can influence the operation of the protection functions as well. The binary outputs of the HV automatic reclosing function, including the "In progress" (Run) state, can be applied for this purpose in the graphic equation editor.

In case of a manual close command which is assigned to the logic variable REC79_ManCl_GrO_ (Manual Close) using graphic equation programming, a preset parameter value decides how long the HV automatic reclosing function should be disabled after the manual close command.

Cycles

The HV automatic reclosing function can control up to four reclosing cycles. Depending on the preset parameter value REC79_CycEn_EPar_ (Reclosing cycles), there are different modes of operation:

- Disabled = no automatic reclosing is selected
- 1. Enabled = only one automatic reclosing cycle is selected
- 1.2. Enabled = two automatic reclosing cycles are activated
- 1.2.3. = three automatic reclosing cycles are activated
- 1.2.3.4. = all four automatic reclosing cycles are activated.

The function can be switched Off /On using the parameter REC79_Op_EPar_ (Operation).

The user can also block the HV automatic reclosing function applying the graphic equation editor. The binary status variable to be programmed is REC79_Blk_GrO_ (Block).

If the device is generally blocked, then the HV automatic reclosing function is also blocked.

Depending on the present parameter value REC79_St_EPar_ (Reclosing started by), the HV automatic reclosing function can be started either by resetting of the TRIP command (setting: Trip reset) or by the binary signal indicating the open state of the circuit breaker (setting: CB open).

If the reset state of the TRIP command is selected to start the HV automatic reclosing function, then the conditions are defined by the user applying the graphic equation editor. The binary status variable to be programmed is: REC79_Tr_GrO_ (AutoReclosing Start).

If the open state of the circuit breaker is selected to start the HV automatic reclosing function, then additionally to programming the REC79_Tr_GrO_ (AutoReclosing Start) signal, the conditions for detecting the open state of the CB are defined by the user applying the graphic equation editor. The binary status variable to be programmed is: REC79_CBOpen_GrO_ (CB OPEN single-pole). This signal is TRUE if at least one of the poles is open.

The HV automatic reclosing function gets the trip commands of the protection functions intended to trigger the reclosing function. The conditions for detecting the triggered state of the protection functions are defined by the user applying the graphic equation editor. The binary status variable to be programmed is: REC79_Tr_GrO_ (AutoReclosing Start). This signal starts a dedicated timer, the elapsed time of which is compared to the preset parameter value REC79_MaxSt_TPar_ (Start-signal Max.Tim).

The HV automatic reclosing function enters the dynamic blocking state:

- If the parameter selected for REC79_St_EPar_ (Reclosing started by) is “Trip reset”, and the trip impulse is too long.
- If the parameter selected for REC79_St_EPar_ (Reclosing started by) is “CB open”, then during the runtime of the timer CB open signal is not received.

In the base case, the dead time counter of any reclosing cycle is started by the starting signal but starting can be delayed. The delay is activated if the value of the REC79_DtDel_GrO_ (Dead Time St.Delay) status signal is TRUE. The conditions are defined by the user applying the graphic equation editor. This delay is limited by the timer parameter REC79_DtDel_TPar_ (DeadTime Max.Delay).

For all four reclosing cycles, separate dead times can be defined for single-phase trip commands (as a consequence of single-phase faults) and for three-phase trip commands (as a consequence of multi-phase faults).

The timer parameters for single-phase trip commands are:

- REC79_1PhDT1_TPar_ 1. Dead Time 1Ph
- REC79_1PhDT2_TPar_ 2. Dead Time 1Ph

- REC79_1PhDT3_TPar_ 3. Dead Time 1Ph
- REC79_1PhDT4_TPar_ 4. Dead Time 1Ph

The timer parameters for three-phase trip commands are:

- REC79_3PhDT1_TPar_ 1. Dead Time 3Ph
- REC79_3PhDT2_TPar_ 2. Dead Time 3Ph
- REC79_3PhDT3_TPar_ 3. Dead Time 3Ph
- REC79_3PhDT4_TPar_ 4. Dead Time 3Ph

The different dead time settings can be justified as follows: in case of a single-phase fault, only the circuit breakers of the faulty phase open. In this case, due to the capacitive coupling of the healthy phases, the extinction of the secondary electric arc at the fault location can be delayed. Consequently, a longer dead time is needed for the fault current to die out than in the case of a three-phase open state, when no coupled voltage can sustain the fault current.

From other point of view, in case of a transmission line connecting two power systems, only a shorter dead time is allowed for the three-phase open state because, due to the possible power unbalance between the interconnected systems, a large angle difference can be reached if the dead time is too long. If only a single phase is open, then the two connected healthy phases and the ground can sustain the synchronous operation of both power systems.

Special dead time for the first cycle

This special dead time can be necessary for the following reason:

Assume a line between substations A and B, and a protection system without tele-protection. In the event of a three-phase fault near substation B, the protection at A generates a trip command according to the second zone's time setting only, and starts measuring the dead time with considerable delay as compared to the protection at B, which generates a trip command immediately due to the close-in fault.

If the three-phase dead time is too short, the HV automatic reclosing at B may attempt to close the circuit breaker during the running time of the second zone trip at A, which means that the fault is not cleared yet. Consequently, a prolonged dead time is needed if the fault was detected in the first zone.

The preset timer parameter value is REC79_3PhDT1_TPar_2 (1. special DT 3Ph). The special dead time is valid if the REC79_1cyc3PhFlt_GrO_ (3PhFault for Spec.DT1) status signal is TRUE. The conditions are defined by the user applying the graphic equation editor.

Reduced dead time

Dead time reduction may be applicable under the following circumstances:

If healthy voltage is measured in all three phases during the dead time, this means that no fault exists on the line. In this case, the expiry of the normal dead time need not be waited for, a reclosing attempt can be initiated immediately.

The dead time is terminated immediately if the REC79_RDT_GrO_ (Reduced DeadTime) status signal is TRUE. The conditions are defined by the user applying the graphic equation editor.

Three-phase trip

The HV automatic reclosing function is prepared to get the general trip command as programmed to the binary input status variable REC79_Tr_GrO_ (AutoReclosing Start) and the three-phase trip signal REC79_3PhTr_GrO_ (3Ph Trip). If no three-phase trip signal is received, then it performs automatic reclosing cycles with the dead times according to the setting for single phase cycles. The three-phase cycles are controlled by the status variable REC79_3PhTr_GrO_ (3Ph Trip). If this is TRUE, three-phase cycles are performed. The conditions are defined by the user applying the graphic equation editor.

If, during the cycles, the three-phase dead time is applied once, then all subsequent cycles will consider the three-phase dead time settings, too.

Three-phase reclosing can be disabled by the preset parameter value REC79_3PhRecBlk_BPar_ (Disable 3Ph Rec.). If the value of this parameter is TRUE, then if a three-phase trip command is received, the HV automatic reclosing function enters “Dynamic blocked” state.

Checking the ready state of the circuit breaker

At the end of the dead time, reclosing is possible only if the circuit breaker can perform the command. The binary variable REC79_CBRdy_GrO_ (CB Ready) indicates this state. The conditions are defined by the user applying the graphic equation editor. If the circuit breaker is not ready, the controller functions wait for a pre-programmed time for this state. The waiting time is defined by the user as parameter value REC79_CBTO_TPar_ (CB Supervision time). If this condition is not fulfilled during the waiting time, then the HV automatic reclosing function enters “Dynamic blocked” state.

Reclosing with synchronous state supervision

Reclosing is possible only if the conditions required by the “synchro-check” function are fulfilled. This state is signaled by the binary variable REC79_SynRel_GrO_ (SYNC Release). The conditions are defined by the user applying the graphic equation editor. The HV automatic reclosing function waits for a pre-programmed time for this signal. This time is defined by the user as parameter value REC79_SYN1_TPar_ (SynCheck Max Time). If the “SYNC Release” signal is not received during the running time of this timer, then the “synchronous switch” operation is started and the signal REC79_ClReq_GrI_ (CloseRequ.SynSwitch) is generated.

Reclosing with synchronous switching

If the conditions of the synchronous state are not fulfilled, another timer starts. This waiting time is defined by the user as parameter value REC79_SYN2_TPar_ (SynSW Max Time).

This separate function controls the generation of the close command in case of relatively rotating voltage vectors on both sides of the circuit breaker to make contact at the synchronous state of the rotating vectors. For this calculation, the closing time of the circuit breaker must be defined.

This mode of operation is indicated by the output variable REC79_ClReq_GrI_ (CloseRequ. SynSwitch).

If no switching is possible during the running time of this timer, then the HV automatic reclosing function enters “Dynamic blocked” state and resets.

Impulse duration of the CLOSE command

The “Close” impulse is generated as one of the output status signals of the HV automatic reclosing function REC79_Close_GrI_ (Close command). This signal is common to all three phases. The impulse duration is defined by the user setting the timer parameter REC79_Close_TPar_ (Close command time).

Behavior after reclosing

When the close command is generated, a timer is started to measure the “Reclaim time”. The duration is defined by the parameter value REC79_Rec_TPar_ (Reclaim time), but it is prolonged up to the reset of the close command (if the close command duration is longer then the reclaim time set). If the fault is detected again during this time, then the sequence of the HV automatic reclosing cycles continues. If no fault is detected, then at the expiry of the reclaim time the reclosing is evaluated as successful and the function resets. If fault is detected after the expiry of this timer, then the cycles restart with the first reclosing cycle.

If the user programmed the status variable REC79_St_GrO_ (Protection Start) and it gets TRUE during the Reclaim time, then the HV automatic reclosing function continues even if the trip command is received after the expiry of the Reclaim time.

Behavior after manual CLOSE command

This state of manual close command is signaled by the binary variable REC79_ManCl_GrO_ (Manual Close). The conditions are defined by the user applying the graphic equation editor.

After a manual close command, the HV automatic reclosing function enters "Not Ready" state for the time period defined by parameter REC79_MC_TPar_ (Block after Man.Close).

If the manual close command is received during the running time of any of the cycles, then the HV automatic reclosing function enters "Dynamic blocked" state and resets.

Behavior in case of evolving fault

In case of evolving faults (when a single-phase fault detected changes to multi-phase fault), the behavior of the automatic reclosing function is controlled by the preset parameter value REC79_EvoFlt_EPar_ (Evolving fault).

The options are:

- "Block Reclosing"
- "Start 3Ph Rec"

If "Block Reclosing" is selected, the HV automatic reclosing function enters dynamic blocked state and the subsequent reclosing command is not generated.

If "Start 3Ph Rec." is selected, the HV automatic reclosing function goes on performing the subsequent cycle according to the three-phase parameters.

The final trip

If the fault still exists at the end of the last cycle, the HV automatic reclosing function trips and generates the signal for final trip: REC79_FinTr_GrI_ (Final Trip). The same final trip signal is generated in case of an evolving fault if "Block Reclosing" is selected. After final trip, the HV automatic reclosing function enters "Dynamic blocked" state.

A final trip command is also generated if, after a multi-phase fault, a fault is detected again during the dead time.

Action time

The user can compose a binary status variable to indicate the start of the protection functions, the operation of which is related to the HV automatic reclosing function. This status variable is REC79_St_GrO_ (Protection Start). This signal starts the "Action time", the duration of which is defined by the preset parameter value REC79_Act_TPar_ (Action time). During the running time, the HV automatic reclosing function waits for the trip command. If no trip command is received, then the HV automatic reclosing function enters "Dynamic blocked" state.

Accelerating trip commands

Depending on binary parameter settings, the automatic reclosing function block can accelerate trip commands of the individual reclosing cycles. This means that the output "TrAcc" of the function block gets active for the first starting state of the protection function or at the end of the dead time of the running cycle, if the dedicated parameter enables acceleration. This signal needs user-programmed graphic equations to generate the accelerated trip command.

Dynamic blocking conditions

There are several conditions to result dynamic blocked state of the HV automatic reclosing function. This state becomes valid if any of the conditions of the dynamic blocking get TRUE during the running time of any of the reclosing cycles.

At the time of the change to start the dynamic blocked state a timer is started, the running duration of which is defined by the time parameter REC79_DynBlk_TPar_ (Dynamic Blocking time). During its running time the function is blocked, no reclosing command is generated.

The conditions to start the dynamic blocked state are:

- There is no trip command during the “Action time”.
- The duration of the starting impulse for the HV automatic reclosing function is too long.
- If no “CB ready” signal is received at the intended time of reclosing command.
- The dead time is prolonged further then the preset parameter value REC79_DtDel_TPar_ (DeadTime Max.Delay).
- The waiting time for the “SYNC Release” signal is too long.
- After the final trip command.
- AR is started during the blocking time after a manual close command.
- While CB State Monitoring is on, a manual open command (the status variable REC79_CBOpen_GrO_ (CB OPEN single-pole) gets TRUE without REC79_Tr_GrO_ (AutoReclosing Start)).
- In case of a three-phase trip command if the preset parameter REC79_3PhRecBlk_BPar_ (Disable 3Ph Rec.) is set to TRUE.
- In case of evolving faults, if the parameter setting for REC79_EvoFlt_EPar_ (Evolving fault) is “Block Reclosing”.
- AR is started during a general block.

In a dynamic blocked state, the REC79_Blocked_GrI_ (Blocked) status signal is TRUE (similar to “Not ready” conditions).

"Not ready" conditions

There are several conditions to result “Not Ready” state of the HV automatic reclosing function. This state becomes valid if any of the conditions of the blocking get TRUE outside the running time of the reclosing cycles.

- Reclosing is disabled by the parameter REC79_Op_EPar_ (Operation) if it is selected to “Off”.
- No reclosing cycles are selected by the parameter REC79_CycEn_EPar_ (Reclosing cycles) if it is set to “Disabled”.
- The circuit breaker is not ready for operation: the result of the graphic programming of the binary variable REC79_CBRdy_GrO_ (CB Ready) is FALSE.
- After a manual close command.
- If the parameter REC79_CBState_BPar_ (CB State Monitoring) is set to TRUE and the circuit breaker is in Open state, i.e., the value of the REC79_CBOpen_GrO_ (CB OPEN single-pole) status variable gets TRUE.
- The starting signal for automatic reclosing is selected by parameter REC79_St_EPar_ (Reclosing started by) to be “CB open” and the circuit breaker is in Open state.
- In case of a general block.

In a “Not ready” state, the REC79_Blocked_GrI_ (Blocked) status signal is TRUE (similar to “Dynamic blocking” conditions).

Setting parameters

Table. 6.4.8 - 95. Setting parameters.

Parameter	Setting value/ range	Step	Default	Description
Operation	On Off	-	On	Enabling / Disabling of the autorecloser function.
EarthFault RecCycle	Disabled 1. Enabled 1.2. Enabled 1.2.3. Enabled 1.2.3.4. Enabled	-	1. Enabled	Selection of the number of reclosing sequences for earth faults.
PhaseFault RecCycle	Disabled 1. Enabled 1.2. Enabled 1.2.3. Enabled 1.2.3.4. Enabled	-	1. Enabled	Selection of the number of reclosing sequences for line-to-line faults.
Reclosing started by	Trip reset CB Open	-	Trip reset	Selection of triggering the dead time counter (trip signal reset or circuit breaker open position).
Evolving fault	Block Reclosing, Start 3Ph Rec.	-	Block Reclosing	Selection of behavior in case of evolving fault (block reclosing or perform three-phase automatic reclosing cycle).
CB State monitoring	Enabled Disabled	-	Disabled	Enable CB state monitoring for "Not Ready" state.
Reclaim time	100…100 000 ms	10 ms	2 000 ms	Reclaim time setting.
Close Command time	10…10 000 ms	10 ms	100 ms	Pulse duration setting for the CLOSE command from the IED to circuit breaker.
Dynamic Blocking time	0…100 000 ms	10 ms	1 500 ms	Setting of the dynamic blocking time.
Block after Man.Close	0…100 000 ms	10 ms	1 000 ms	Setting of the blocking time after manual close command.
Action time	0…20 000 ms	10 ms	1 000 ms	Setting of the action time.
Start-signal Max.Tim	0…10 000 ms	10 ms	1 000 ms	Time limitation of the starting signal.
DeadTime Max.Delay	0…1 000 000 ms	10 ms	3 000 ms	Delaying the start of the dead-time counter.
CB Supervision Time	10…1 000 000 ms	10 ms	1 000 ms	Waiting time for circuit breaker ready signal.

Parameter	Setting value/ range	Step	Default	Description
Sync-check Max.Tim	500…100 000 ms	10 ms	10 000 ms	Waiting time for synchronous state signal.
Sync-switch Max.Tim	500…100 000 ms	10 ms	10 000 ms	Waiting time for synchronous switching.
1.Dead Time 3Ph	0…100 000 ms	10 ms	500 ms	Dead time setting for the first reclosing cycle for multi-phase fault.
2.Dead Time 3Ph	10…100 000 ms	10 ms	600 ms	Dead time setting for the second reclosing cycle for multi-phase fault.
3.Dead Time 3Ph	10…100 000 ms	10 ms	700 ms	Dead time setting for the third reclosing cycle for multi-phase fault.
4.Dead Time 3Ph	10…100 000 ms	10 ms	800 ms	Dead time setting for the fourth reclosing cycle for multi-phase fault.
1.Dead Time 1 PH	0…100 000 ms	10 ms	1 000 ms	Dead time setting for the first reclosing cycle for single-phase fault.
2.Dead Time 1 PH	10…100 000 ms	10 ms	2 000 ms	Dead time setting for the second reclosing cycle for single-phase fault.
3.Dead Time 1 PH	10…100 000 ms	10 ms	3 000 ms	Dead time setting for the third reclosing cycle for single-phase fault.
4.Dead Time 1 PH	10…100 000 ms	10 ms	4 000 ms	Dead time setting for the fourth reclosing cycle for single-phase fault.
Accelerate 1. Trip	Enabled Disabled	-	Disabled	Acceleration of the 1st reclosing cycle trip command.
Accelerate 2. Trip	Enabled Disabled	-	Disabled	Acceleration of the 2nd reclosing cycle trip command.
Accelerate 3. Trip	Enabled Disabled	-	Disabled	Acceleration of the 3rd reclosing cycle trip command.
Accelerate 4. Trip	Enabled Disabled	-	Disabled	Acceleration of the 4th reclosing cycle trip command.
Accelerate final Trip	Enabled Disabled	-	Disabled	Acceleration of the final trip command.

6.4.9 Switch-on-to-fault

Some protection functions, e.g. distance protection, directional overcurrent protection, etc. need to decide the direction of the fault. This decision is based on the angle between the voltage and the current. In case of close-in faults, however, the voltage of the faulty loop is near zero: it is not sufficient for a directional decision. If there are no healthy phases, then the voltage samples stored in the memory are applied to decide if the fault is forward or reverse.

If the protected object is energized, the close command for the circuit breaker is received in “dead” condition. This means that the voltage samples stored in the memory have zero values. In this case the decision on the trip command is based on the programming of the protection function for the “switch-onto-fault” condition.

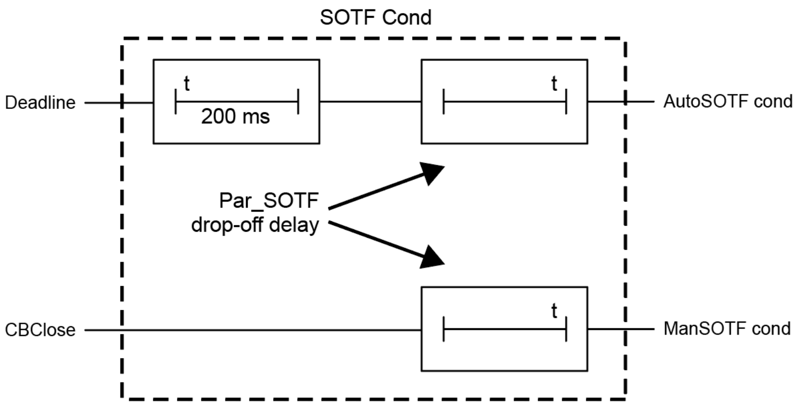
This “switch-onto-fault” (SOTF) detection function prepares the conditions for the subsequent decision. The function can handle both automatic and manual close commands.

The function receives the “Dead line” status signal from the DLD (dead line detection) function block. After dead line detection, the binary output signal AutoSOTF is delayed by a timer with a constant 200 ms time delay. After voltage detection (resetting of the dead line detection input signal), the drop-off of this output signal is delayed by a timer (SOTF Drop Delay) set by the user. The automatic close command is not used it is not an input for this function.

The manual close command is a binary input signal. The drop-off of the binary output signal ManSOTF is delayed by a timer (SOTF Drop Delay) set by the user. The timer parameter is common for both the automatic and manual close command.

The operation of the “switch-onto-fault” detection function is shown in Figure below.

Figure. 6.4.9 - 136. The scheme of the switch-on-to-fault preparation.



The binary input signals of the “switch-onto-fault” detection function are:

- CBClose Manual close command to the circuit breaker.
- DeadLine Dead line condition detected; this is usually the output signal of the DLD (dead line detection) function block.

The binary output signals of the “switch-onto-fault” detection function are:

- AutoSOTF cond Signal enabling switch-onto-fault detection as a consequence of an automatic close command.
- ManSOTF cond Signal enabling switch-onto-fault detection as a consequence of a manual close command.

Figure. 6.4.9 - 137. The function block of the switch-on-to-fault function.

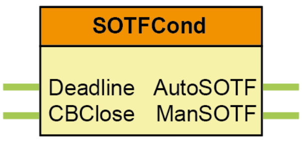


Table. 6.4.9 - 96. The timer parameter of the function.

Parameter	Title	Unit	Min	Max	Step	Default
Drop-off time delay for the output signals.						

Parameter	Title	Unit	Min	Max	Step	Default
SOTF_SOTFDel_TPar_	SOTF Drop Delay	ms	100	10 000	1	1000

Table. 6.4.9 - 97. The binary input and output status signals of the function.

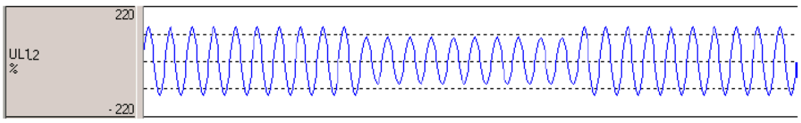
Binary status signal	Signal title	Explanation
SOTF_AutoSOTF_GrI_	AutoSOTF cond	Signal enabling switch-on-to-fault detection as a consequence of automatic close command.
SOTF_Man_SOTF_GrI_	ManSOTF cond	Signal enabling switch-on-to-fault detection as a consequence of manual close command.
SOTF_CBClose_GrO_	CBClose	Manual close command to the circuit breaker.
SOTF_DeadLine_GrO_	DeadLine	Dead line condition detected.

6.4.10 Voltage variation (voltage sag and swell)

Short duration voltage variations have an important role in the evaluation of power quality. Short duration voltage variations can be:

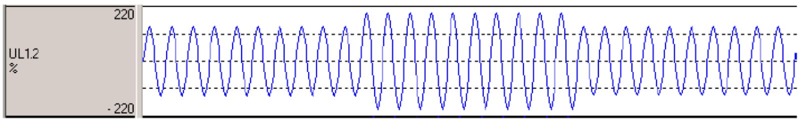
- Voltage sag, when the RMS value of the measured voltage is below a level defined by a dedicated parameter and at the same time above a minimum level specified by another parameter setting. For the evaluation, the duration of the voltage sag should be between a minimum and a maximum time value defined by parameters.

Figure. 6.4.10 - 138. Voltage sag.



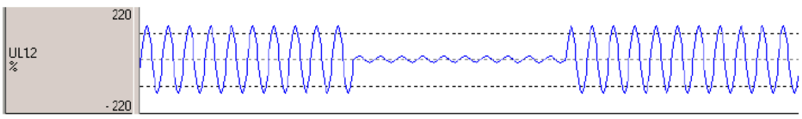
- Voltage swell, when the RMS value of the measured voltage is above a level defined by a dedicated parameter. For the evaluation, the duration of the voltage swell should be between a minimum and a maximum time value defined by parameters.

Figure. 6.4.10 - 139. Voltage swell.



- Voltage interruption, when the RMS value of the measured voltage is below a minimum level specified by a parameter. For the evaluation, the duration of the voltage interruption should be between a minimum and a maximum time value defined by parameters.

Figure. 6.4.10 - 140. Voltage interruption.



Voltage sag is detected if any of the three phase-to-phase voltages falls to a value between the "Sag limit" setting and the "Interruption Limit" setting. In this state, the binary output "Sag" signal is activated. The signal resets if all of the three phase-to-phase voltages rise above the "Sag limit", or if the set time "Maximum duration" elapses. If the voltage returns to normal state after the set "Minimum duration" and before the time "Maximum duration" elapses, then the "Sag Counter" increments by 1, indicating a short-time voltage variation.

The report generated includes the duration and the minimum value. A voltage swell is detected if any of the three phase-to-phase voltages increases to a value above the "Swell limit" setting. In this state, the binary output "Swell" signal is activated. The signal resets if all of the three phase-to-phase voltages fall below the "Swell limit", or if the set time "Maximum duration" elapses. If the voltage returns to normal state after the "Minimum duration" and before the time "Maximum duration" elapses, then the "Swell Counter" increments by 1, indicating a short-time voltage variation.

The report generated includes the duration and the maximum value. A voltage interruption is detected if all three phase-to-phase voltages fall to a value below the "Interruption Limit" setting. In this state, the binary output "Interruption" is activated. The signal resets if any of the three phase-to-phase voltages rises above the "Interruption limit", or if the time "Maximum duration" elapses. No counter is assigned to this state.

The inputs of the sag and swell detection function are:

- RMS values of the of three phase-to-phase voltages
- Binary input
- Setting parameters.

The outputs of the sag and swell detection function are:

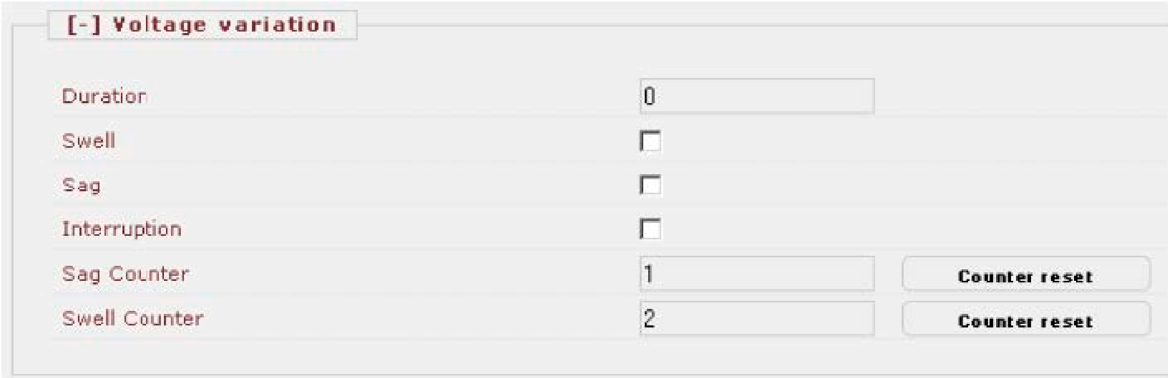
- Sag detection
- Swell detection
- Interruption detection
- Counters.

NOTICE!
if all three phase-to-phase voltages do not fall below the specified "Interruption Limit" value, then the event is classified as "sag" but the reported minimum value is set to zero. The sag and swell detection algorithm measures the duration of the short-time voltage variation. The last variation is displayed.

The sag and swell detection algorithm offers measured values, status signals and counter values for displaying:

- The duration of the latest detected short-time voltage variation
- Binary signals:
    - Swell
    - Sag
    - Interruption
- Timer values:
    - Sag counter
    - Swell counter

Figure. 6.4.10 - 141. Sag and swell monitoring window in the AQtivate 300 setting tool.



The sag and swell detection algorithm offers event recording, which can be displayed in the “Event list” window of the user interface software.

Figure. 6.4.10 - 142. Example sag and swell.

6.4.11 Disturbance recorder

The disturbance recorder function can record analog signals and binary status signals. These signals are user configurable. The disturbance recorder function has a binary input signal, which serves the purpose of starting the function. The conditions of starting are defined by the user. The disturbance recorder function keeps on recording during the active state of this signal but the total recording time is limited by the timer parameter setting. The pre-fault time, max-fault time and post-fault time can be defined by parameters.

If the conditions defined by the user - using the graphic equation editor – are satisfied, then the disturbance recorder starts recording the sampled values of configured analog signals and binary signals. The analog signals can be sampled values (voltages and currents) received via input modules or they can be calculated analog values (such as negative sequence components, etc.) The number of the configured binary signals for recording is limited to 64. During the operation of the function, the pre-fault signals are preserved for the time duration as defined by the parameter “PreFault”. The fault duration is limited by the parameter “MaxFault” but if the triggering signal resets earlier, this section is shorter. The post-fault signals are preserved for the time duration as defined by the parameter “PostFault”. During or after the running of the recording, the triggering condition must be reset for a new recording procedure to start.

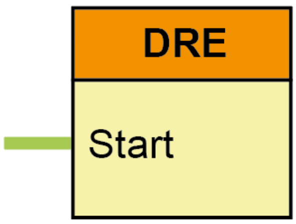
The records are stored in standard COMTRADE format:

- The configuration is defined by the file .cfg
- The data are stored in the file .dat
- Plain text comments can be written in the file .inf.

The procedure for downloading the records includes a downloading of a single compressed. zip-file. Downloading can be initiated from a web browser tool or from the software tools.This procedure assures that the three component files (.cfg, .dat and .inf) are stored in the same location. The evaluation can be performed using any COMTRADE evaluator software, e.g. Arcteq’s AQview software. Consult your nearest Arcteq representative for availability.

The function block of the disturbance recorder function is shown in figure bellow. This block shows all binary input and output status signals that are applicable in the AQtivate 300 software.

Figure. 6.4.11 - 143. The function block of the disturbance recorder function.



The binary input and output status signals of the dead line detection function are listed intables below.

Table. 6.4.11 - 98. The binary input signal of the function.

Binary status signal	Explanation
DRE_Start_GrO_	Output status of a graphic equation defined by the user to start the disturbance recorder function.

Table. 6.4.11 - 99. Setting parameters.

Parameter	Setting value/range	Step	Default	Description
Operation	On Off	-	On	Function enbaling / disabling.
PreFault	100…500 ms	1 ms	200 ms	Pre triggering time included in the recording.
PostFault	100…1 000 ms	1 ms	200 ms	Post fault time included in the recording.

Parameter	Setting value/range	Step	Default	Description
MaxFault	500…10 000 ms	1 ms	1 000 ms	Overall maximum time limit in the recording.

6.4.12 Event recorder

The events of the device and those of the protection functions are recorded with a time stamp of 1 ms time resolution. This information with indication of the generating function can be checked on the touch-screen of the device in the "Events" page, or using an Internet browser of a connected computer.

Table. 6.4.12 - 100. List of events.

Event	Explanation
Voltage transformer supervision function (VTS)	
VT Failure	Error signal of the voltage transformer supervision function
Common	
Mode of device	Mode of device
Health of device	Health of device
Three-phase instantaneous overcurrent protection function (IOC50)	
Trip L1	Trip command in phase L1
Trip L2	Trip command in phase L2
Trip L3	Trip command in phase L3
General Trip	General trip command
Residual instantaneous overcurrent protection function (IOC50N)	
General Trip	General trip command
Directional overcurrent protection function (TOC67) low setting stage	
Start L1	Start signal in phase L1
Start L2	Start signal in phase L2
Start L3	Start signal in phase L3
Start	Start signal
Trip	Trip command
Directional overcurrent protection function (TOC67) high setting stage	
Start L1	Start signal in phase L1
Start L2	Start signal in phase L2
Start L3	Start signal in phase L3
Start	Start signal

Trip	Trip command
Residual directional overcurrent protection function (TOC67N) low setting stage	
Start	Start signal
Trip	Trip command
Residual directional overcurrent protection function (TOC67N) high setting stage	
Start	Start signal
Trip	Trip command
Line thermal protection function (TTR49L)	
Alarm	Line thermal protection alarm signal
General Trip	Line thermal protection trip command
Current unbalance protection function	
General Start	General Start
General Trip	General Trip
Current unbalance protection function	
2.Harm Restraint	Second harmonic restraint
Definite time overvoltage protection function (TOV59)	
Low Start L1	Low setting stage start signal in phase L1
Low Start L2	Low setting stage start signal in phase L2
Low Start L3	Low setting stage start signal in phase L3
Low General Start	Low setting stage general start signal
Low General Trip	Low setting stage general trip command
High Start L1	High setting stage start signal in phase L1
High Start L2	High setting stage start signal in phase L2
High Start L3	High setting stage start signal in phase L3
High General Start	High setting stage general start signal
High General Trip	High setting stage general trip command
Definite time undervoltage protection function (TUV27)	
Low Start L1	Low setting stage start signal in phase L1
Low Start L2	Low setting stage start signal in phase L2
Low Start L3	Low setting stage start signal in phase L3
Low General Start	Low setting stage general start signal
Low General Trip	Low setting stage general trip command

High Start L1	High setting stage start signal in phase L1
High Start L2	High setting stage start signal in phase L2
High Start L3	High setting stage start signal in phase L3
High General Start	High setting stage general start signal
High General Trip	High setting stage general trip command
Overfrequency protection function (TOF81)	
Low General Start	Low setting stage general start signal
Low General Trip	Low setting stage general trip command
High General Start	High setting stage general start signal
High General Trip	High setting stage general trip command
Underfrequency protection function (TUF81)	
Low General Start	Low setting stage general start signal
Low General Trip	Low setting stage general trip command
High General Start	High setting stage general start signal
High General Trip	High setting stage general trip command
Rate-of-change of frequency protection function (FRC81)	
Low General Start	Low setting stage general start signal
Low General Trip	Low setting stage general trip command
High General Start	High setting stage general start signal
High General Trip	High setting stage general trip command
Breaker failure protection function (BRF50)	
Backup Trip	Repeated trip command
Trip logic function (TRC94)	
General Trip	General Trip
Synchrocheck function (SYN25)	
Released Auto	The function releases automatic close command
In progress Auto	The automatic close command is in progress
Close_Auto	Close command in automatic mode of operation
Released Man	The function releases manual close command
In progress Man	The manual close command is in progress
Close_Man	Close command in manual mode of operation
Automatic reclosing function (REC79)	

Blocked	Blocked state of the automatic reclosing function
Close Command	Close command of the automatic reclosing function
Status	State of the automatic reclosing function
Actual cycle	Running cycle of the automatic reclosing function
Final Trip	Definite trip command at the end of the automatic reclosing cycles
Measurement function (MXU)	
Current L1	Current violation in phase L1
Current L2	Current violation in phase L2
Current L3	Current violation in phase L3
Voltage L12	Voltage violation in phase L12
Voltage L23	Voltage violation in phase L23
Voltage L31	Voltage violation in phase L31
Active Power – P	Active Power – P violation
Reactive Power – Q	Reactive Power – Q violation
Apparent Power – S	Apparent Power – S violation
Frequency	Frequency violation
CB1Pol	
Status value	Status of the circuit breaker
Enable Close	Close command is enabled
Enable Open	Open command is enabled
Local	Local mode of operation
Operation counter	Operation counter
CB OPCap	
Disconnector Line	
Status value	Status of the circuit breaker
Enable Close	Close command is enabled
Enable Open	Open command is enabled
Local	Local mode of operation
Operation counter	Operation counter
DC OPCap	
Disconnector Earth	
Status value	Status of the earthing switch

Enable Close	Close command is enabled
Enable Open	Open command is enabled
Local	Local mode of operation
Operation counter	Operation counter
DC OPCap	
Disconnector Bus	
Status value	Status of the bus disconnector
Enable Close	Close command is enabled
Enable Open	Open command is enabled
Local	Local mode of operation
Operation counter	Operation counter
DC OPCap	

6.4.13 Measured values

The measured values can be checked on the touch-screen of the device in the "On-line functions" page, or using an Internet browser of a connected computer. The displayed values are secondary voltages and currents, except the block "Line measurement". This specific block displays the measured values in primary units, using the VT and CT primary value settings.

Table. 6.4.13 - 101. Analogue value measurements.

Analog value	Explanation
VT4 module	
Voltage Ch – U1	RMS value of the Fourier fundamental harmonic voltage component in phase L1
Angle Ch – U1	Phase angle of the Fourier fundamental harmonic voltage component in phase L1*
Voltage Ch – U2	RMS value of the Fourier fundamental harmonic voltage component in phase L2
Angle Ch – U2	Phase angle of the Fourier fundamental harmonic voltage component in phase L2*
Voltage Ch – U3	RMS value of the Fourier fundamental harmonic voltage component in phase L3
Angle Ch – U3	Phase angle of the Fourier fundamental harmonic voltage component in phase L3*
Voltage Ch – U4	RMS value of the Fourier fundamental harmonic voltage component in Channel U4
Angle Ch – U4	Phase angle of the Fourier fundamental harmonic voltage component in Channel U4*
CT4 module	
Current Ch – I1	RMS value of the Fourier fundamental harmonic current component in phase L1
Angle Ch – I1	Phase angle of the Fourier fundamental harmonic current component in phase L1*
Current Ch – I2	RMS value of the Fourier fundamental harmonic current component in phase L2

Analog value	Explanation
Angle Ch – I2	Phase angle of the Fourier fundamental harmonic current component in phase L2*
Current Ch – I3	RMS value of the Fourier fundamental harmonic current component in phase L3
Angle Ch – I3	Phase angle of the Fourier fundamental harmonic current component in phase L3*
Current Ch – I4	RMS value of the Fourier fundamental harmonic current component in Channel I4
Angle Ch – I4	Phase angle of the Fourier fundamental harmonic current component in Channel I4*
Values for the directional measurement	
L12 loop R	Resistance of loop L1L2
L12 loop X	Reactance of loop L1L2
L23 loop R	Resistance of loop L2L3
L23 loop X	Reactance of loop L2L3
L31 loop R	Resistance of loop L3L1
L31 loop X	Reactance of loop L3L1
Line thermal protection	
Calc. Temperature	Calculated line temperature
Synchrocheck	
Voltage Diff	Voltage magnitude difference
Frequency Diff	Frequency difference
Angle Diff	Angle difference
Line measurement (here the displayed information means primary value)	
Active Power – P	Three-phase active power
Reactive Power – Q	Three-phase reactive power
Apparent Power – S	Three-phase power based on true RMS voltage and current measurement
Current L1	True RMS value of the current in phase L1
Current L2	True RMS value of the current in phase L2
Current L3	True RMS value of the current in phase L3
Voltage L1	True RMS value of the voltage in phase L1
Voltage L2	True RMS value of the voltage in phase L2
Voltage L3	True RMS value of the voltage in phase L3
Voltage L12	True RMS value of the voltage in phase L1L2
Voltage L23	True RMS value of the voltage in phase L2L3
Voltage L31	True RMS value of the voltage in phase L3L1

Analog value	Explanation
Frequency	Frequency

6.4.14 Status monitoring for switching devices

The status of circuit breakers and the disconnectors (line disconnector, bus disconnector, earthing switch) are monitored continuously. This function also enables operation of these devices using the screen of the local LCD. To do this the user can define the user screen and the active scheme.

6.4.15 Trip circuit supervision

All four fast acting trip contacts contain build-in trip circuit supervision function. The output voltage of the circuit is 5V (+-1V). The pickup resistance is 2.5kohm (+-1kohm).

> CAUTION!
> Pay attention to the polarity of the auxiliary voltage supply as outputs are polarity dependent.

7 Line differential communication applications

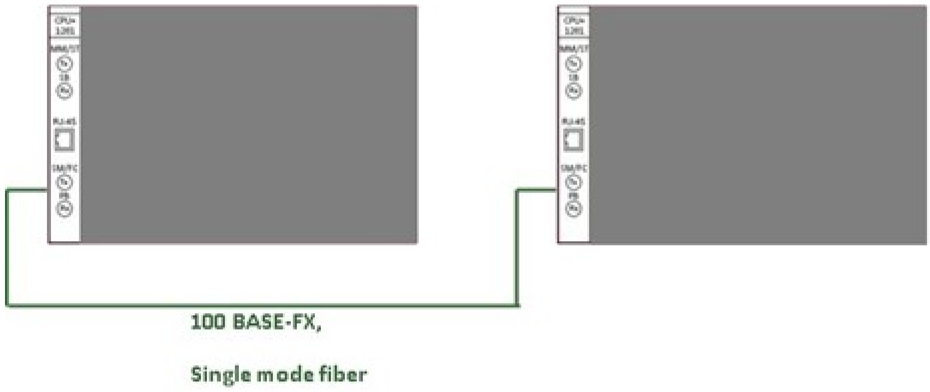
This chapter is intended to explain different line differential protection communication methods with AQ 300 devices.

7.1 Peer-to-peer communication

Direct link

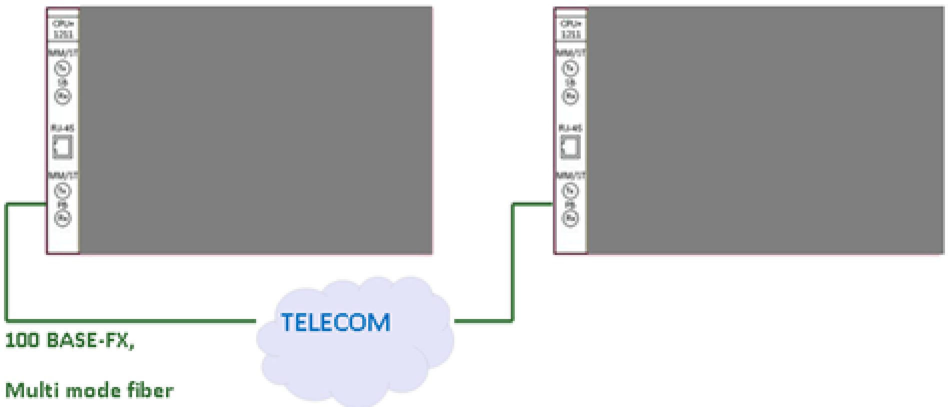
If dark fiber is available between two substations the peer-to-peer communication mode is recommended. For short-haul applications that are limited to 2 km the multi-mode fiber can be used. Long-haul applications up to 35 dB line attenuation, that is 100...120 km in practice, the single mode 1550 nm fiber can be used.

Figure. 7.1 - 144. Direct link communication scheme.



Via LAN/Telecom network

Figure. 7.1 - 145. LAN/Telecom network communication scheme.



7.2 Pilot wire application

Pilot wire application allows protection devices to communicate with each other via traditional copper wire. The xDSL technology supports high speed and reliable communication channel establishment via 2-8 wire copper lines. The AQ 300 is connected to an industrial grade Ethernet/SHDSL MODEM via an Ethernet 100Base-Fx interface.

Figure. 7.2 - 146. Pilot wire communication scheme.

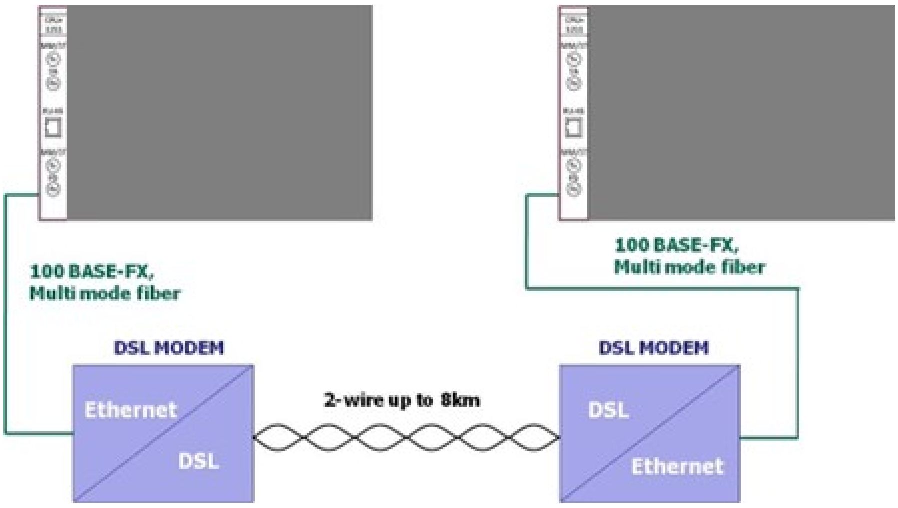


Table. 7.2 - 102. SHDSL interface specification.

Specification	ITU-T G.991.2-G.shdsl, ITU-T G.991.2-G.shdsl.bis
Line Code	TC-PAM16/32, Extended: TC-PAM4/8/64/128
Impedance	135 Ω
Transmit Power	13.5 (Annex A) or 14.5 (Annex B) dBm @ 135 Ω
Number of Pairs	1.2 or 4
Bit Rate	192 to 5704 kbit/s, Extended: 128 to 15,232 kbit/s
Distance	Max. 8 km @ 0.8 mm (AWG 20) wire Max. 6 km @ 0.6 mm (AWG 23) wire Max. 4 km @ 0.4 mm (AWG 26) wire
Connector Type	RJ-45, 8 pin
Overvoltage Protection	ITU-T Rec. K.20/K.21
Wetting Current	2...4 mA @ 47 V DC

Table. 7.2 - 103. Ethernet interface specification.

Standard	IEEE 802.3, VLAN IIEEE 802.1Q, QoS IEEE 802.1P
Data Rate	100Base-TX, Full/Half Duplex
Interface/connector Type @ Europrot+ side	Multi-mode 1310 nm, ST connector

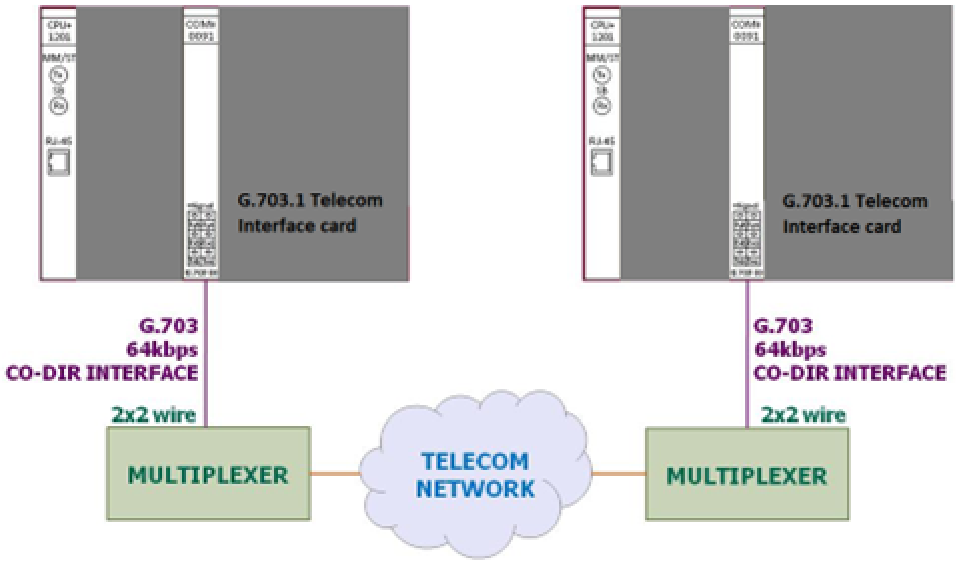
Interface/connector Type @ MODEM side	SFP multi-mode 1310 nm, LC connector

7.3 Line differential communication via telecom networks

Communication via G.703 64 kbit/s co-directional interface (E0)

The AQ 300 device also supports line differential communication via telecom networksusing G.703.1 64kbit/s co-directional interface type. This type of communication isperformed via 2*2 wire isolated galvanic type interface. The protection device is connectedto a multiplexer or gateway which is responsible for protocol/speed conversion.

Figure. 7.3 - 147. G.703 co-directional communication scheme.

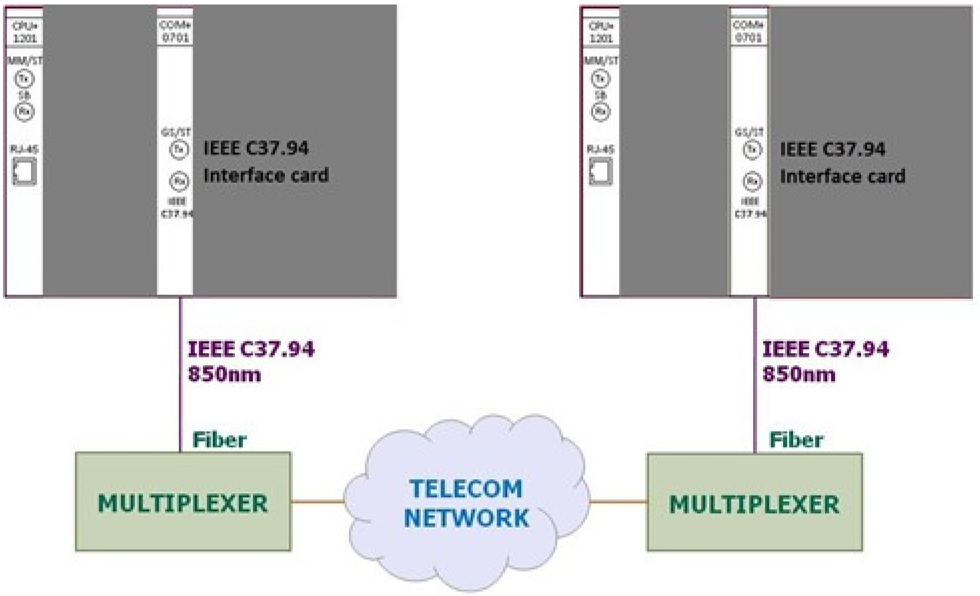


Connector type: Weidmüller
Impedance: 120 Ω
Cable length: 50 m
Interface type: G.703.1 64 kbit/s (E0) co-directional, selectable grounding

Communication via C37.94 N×64 kbit/s interface

The IEEE C37.94 standard describes the N time 64 kbit/s optical fiber interface between teleprotection and multiplexer equipment. The data rate can be 1...12×64 kbit/s with 64 kbit/s steps.

Figure. 7.3 - 148. IEEE C37.94 communication scheme.

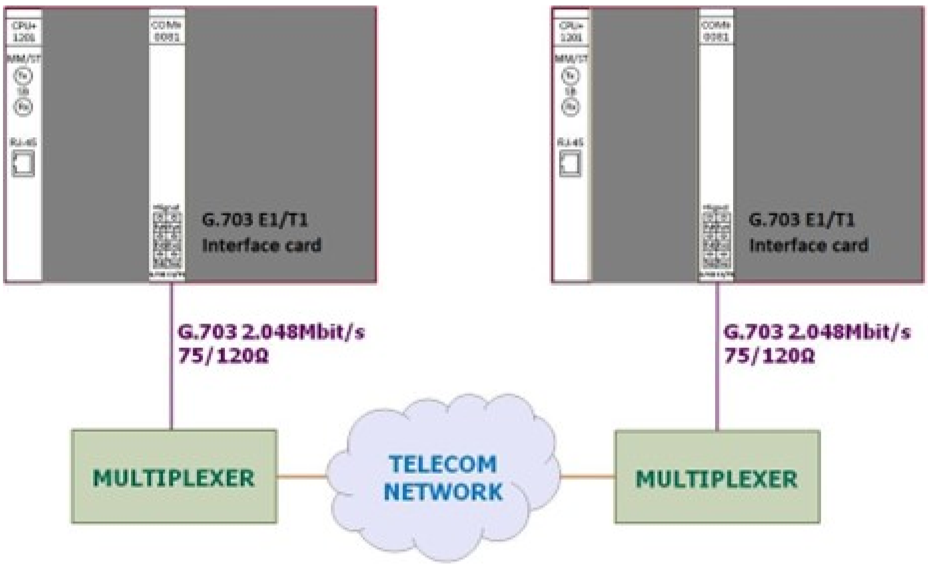


Connector type: ST
Wavelength: 850 nm
Optical output power: -15 dBm
Optical input sensitivity: -34 dBm
Data rate: 64...768 kbit/s

Communication via 2.048 Mbit/s (E1/T1) N×64 kbit/s interface

AQ 300 device supports line differential communication via telecom networks with G.703/704 2.048 Mbit/s interface (E1). Besides E1 in European networks, the T1 interface (1.54 Mbit/s) in America is also available.

Figure. 7.3 - 149. G.703/704 communication scheme.



Connector type: Weidmüller
Impedance: 75/120 Ω
Cable length: 50 m
Interface type: G.703 1.544 Mbit/s (T1) or 2.048 Mbit/s (E1), selectable grounding

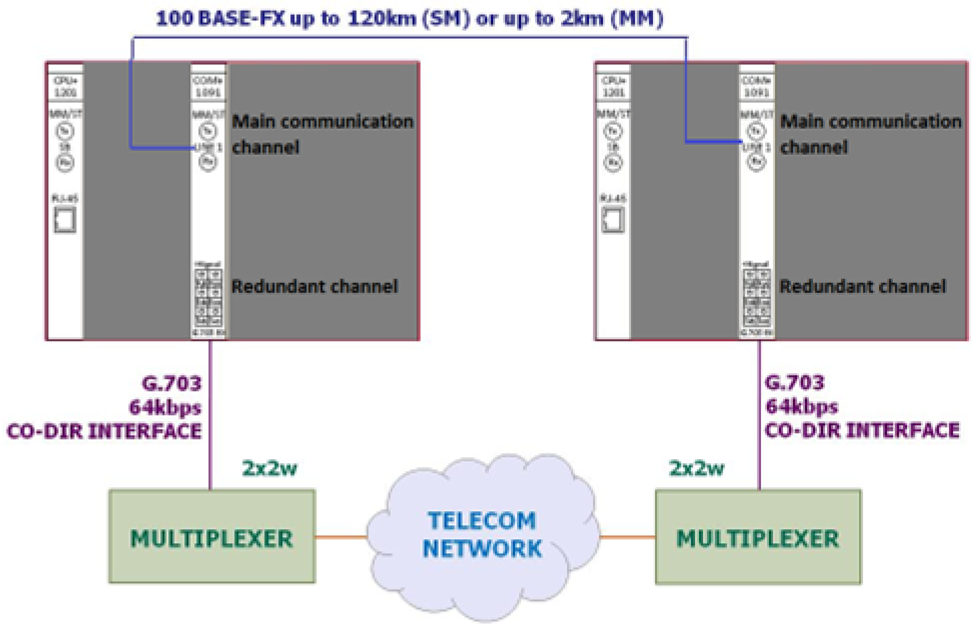
7.4 Redundant line differential comunication

The data interchange over the two communication channels is carried out in parallel way which enables hot standby operation. In case of single point of failure in one of the links the algorithm processes the data from the other link without switchover time.

G.703 and 100Base-FX redundancy

Redundant communication also supported by AQ 300 devices. The high speed 100Base-FX link is used as main channel and G.703.1 leased or dedicated line as backup link. An extra communication card needs to be added to the AQ 300 IED for this kind of redundancy, consult your nearest Arcteq representative for availability.

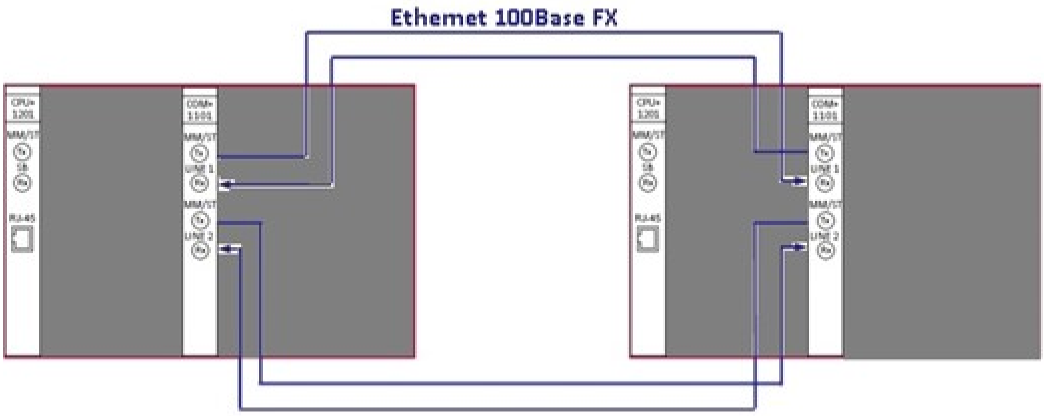
Figure. 7.4 - 150. G.703 and 100Base redundant communication scheme.



100Base-FX redundancy

Both communication links are Ethernet 100Base-FX type and the connection type can be direct link (dark fiber) and/or a service from a telecom operator. An extra communication card needs to be added to the configuration for this kind of redundancy, consult your nearest Arcteq representative for availability.

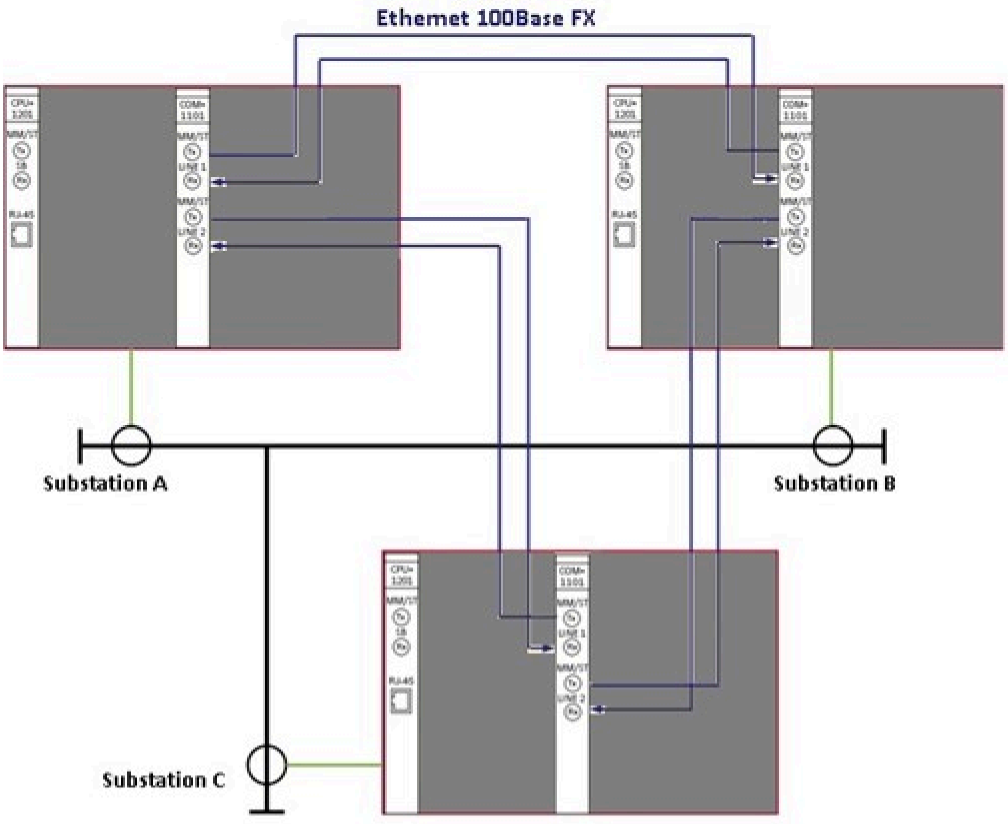
Figure. 7.4 - 151. 100Base redundant communication scheme.



7.5 Three terminal line differential communication

With an additional communication card added to AQ 300 device a three terminal line differential communication between IEDs can be implemented. Communication channel in this case is Ethernet 100Base-Fx. The three terminal line differential protection scheme can tolerate the link failure of one of the three communication channels between the devices.

Figure. 7.5 - 152. Three terminal line differential communication scheme.



8 System integration

The AQ L3x9 contains two ports for communicating to upper level supervisory system and one for process bus communication. The physical media or the ports can be either serial fiber optic or RJ 45 or Ethernet fiber optic. Communication ports are always in the CPU module of the device.

The AQ L3x9 line protection IED communicates using IEC 61850, IEC 101, IEC 103, IEC 104, Modbus RTU, DNP3.0 and SPA protocols. For details of each protocol refer to respective interoperability lists.

For IRIG-B time synchronization binary input module O12 channel 1 can be used.

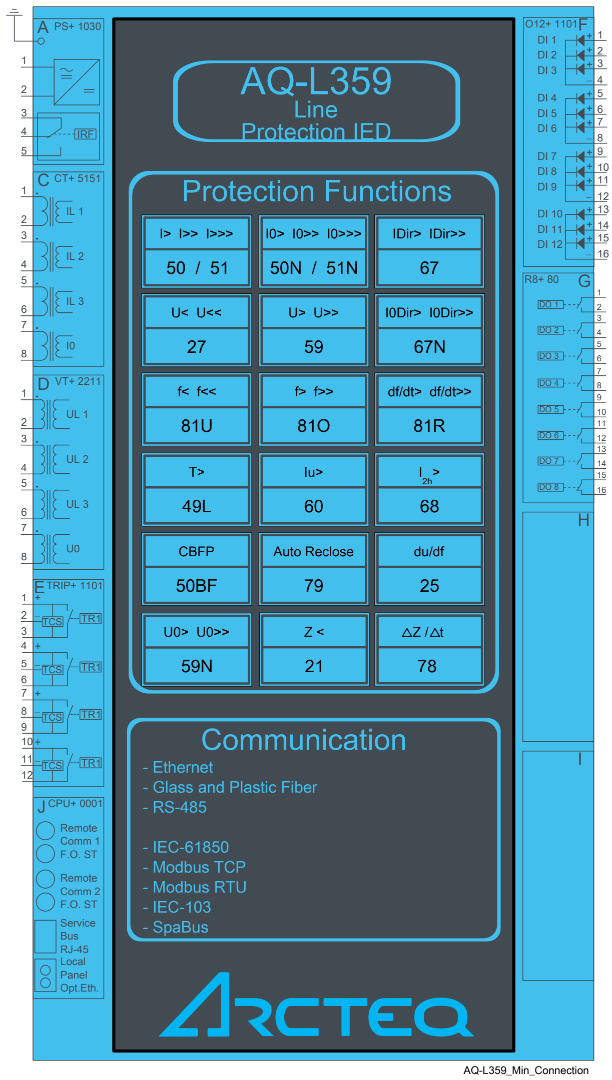
9 Connections

9.1 Block diagrams

NOTICE!
The structure of both AQ-L359 (the half-rack version) and AQ-L399 (the full rack version) is the same, except AQ-L399 has more option card slots available.

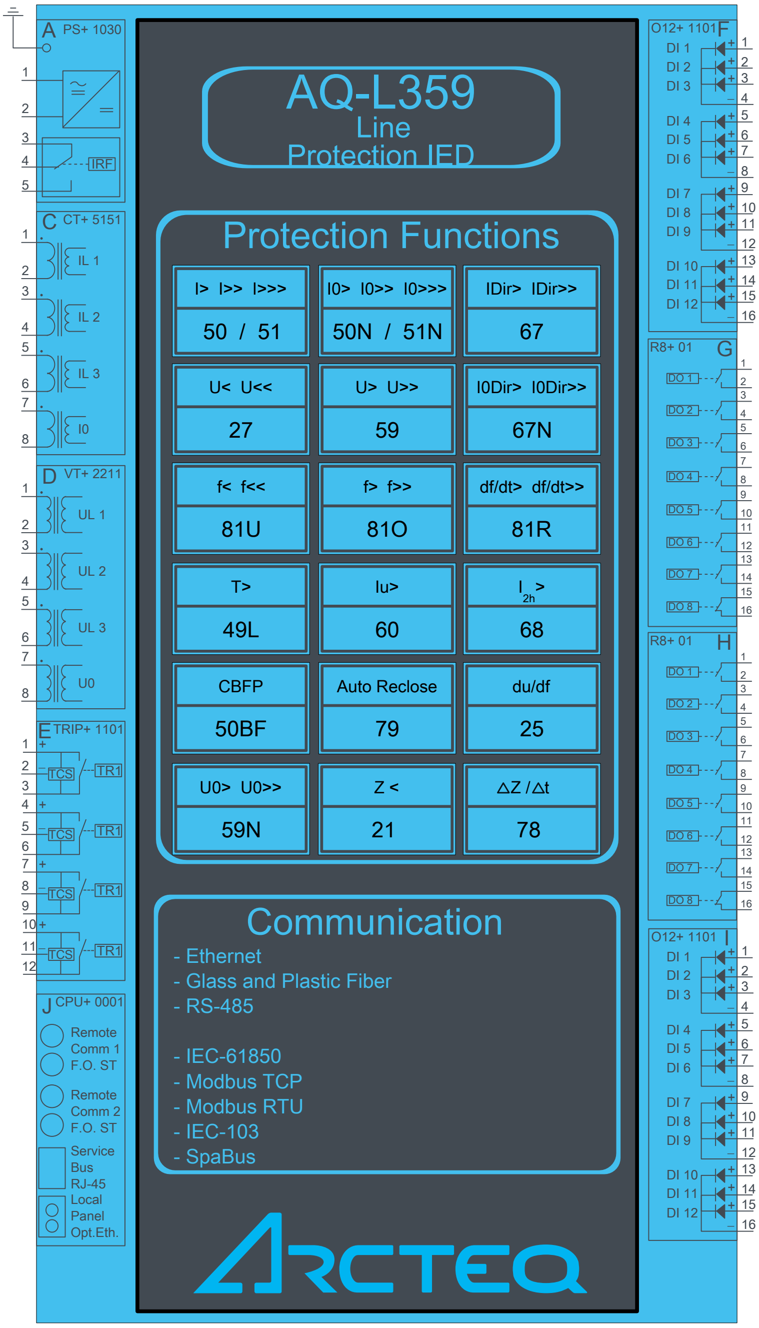
Block diagram of AQ-L359 with minimum options

Figure. 9.1 - 153. Block diagram of AQ-L359 with minimum options installed.



Block diagram of AQ-L359 with all options

Figure. 9.1 - 154. Block diagram of AQ-L359 with all options installed.

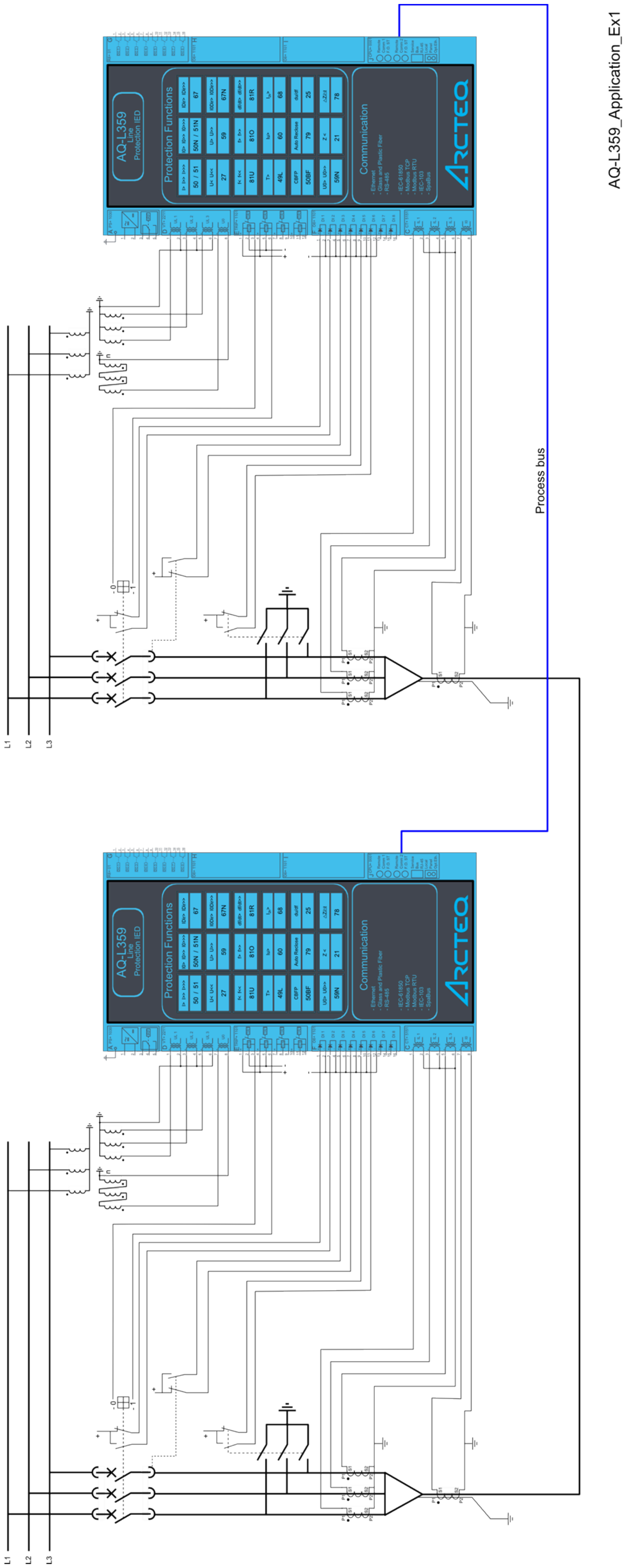


AQ-L359_Full_Connection

9.2 Connection example

NOTICE!
While the connection example below is for AQ-L359, AQ-L399 is connected in the same way.

Figure. 9.2 - 155. Connection example of AQ-L359 line protection IED.



10 Construction and installation

10.1 Construction

The Arcteq AQ-L3x9 line protection IED consists of hardware modules. Due to its modular structure the optional positions for the slots can be user defined in the ordering of the IED to include I/O modules and other types of additional modules. An example module arrangement configuration of AQ-L359 and AQ-L399 are shown in the figures below. Visit https://configurator.arcteq.fi/ to see all of the available options.

Figure. 10.1 - 156. An example module arrangement configuration for the AQ-L359 IED.

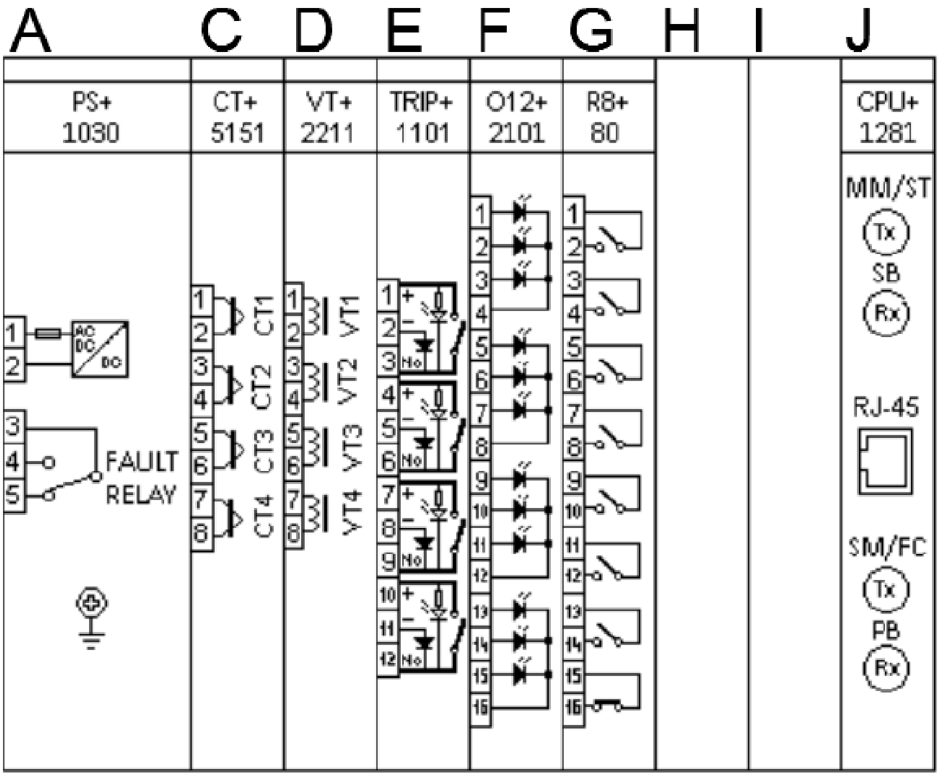


Table. 10.1 - 104. Descriptions of the hardware modules for AQ-L359.

Position	Module identifier	Explanation
A–B	PS+ 1030	Power supply unit, 85…265 V AC, 88…300 V DC
C	CT+ 5151	Analog current input module
D	VT+ 2211	Analog voltage input module
E	TRIP+ 1101	Trip relay output module, 4 tripping contacts
F	O12+ 2101	Binary input module, 12 inputs, threshold 110 V DC
G	R8+ 80	Signaling output module, 8 output contacts (7 NO + 1 NC)

Position	Module identifier	Explanation
J	CPU+ 1201	Processor and communication module
H, I	Spare	—

Figure. 10.1 - 157. An example module arrangement configuration for the AQ-L399 IED.

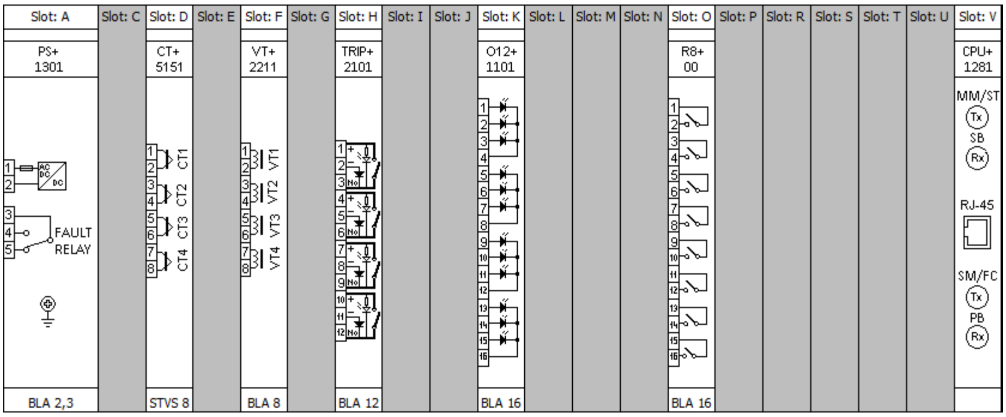


Table. 10.1 - 105. Descriptions of the hardware modules for AQ-L399.

Position	Module identifier	Explanation
A–B	PS+ 1301	Power supply unit, 85…265 V AC, 88…300 V DC
D	CT+ 5151	Analog current input module
F	VT+ 2211	Analog voltage input module
H	TRIP+ 2101	Trip relay output module, 4 tripping contacts
K	O12+ 1101	Binary input module, 12 inputs, threshold 110 V DC
O	R8+ 00	Signaling output module, 8 output contacts (7 NO + 1 NC)
V	CPU+ 1201	Processor and communication module
Others	Spare	Empty slots which can be used for additional DI or DO slots.

10.2 CPU module

The CPU module contains all the protection, control and communication functions of the AQ-x3xx device. Dual 500 MHz high-performance Analog Devices Blackfin processors separates relay functions (RDSP) from communication and HMI functions (CDSP). Reliable communication between processors is performed via high-speed synchronous serial internal bus (SPORT).

Each processor has its own operative memory such as SDRAM and flash memories for configuration, parameter and firmware storage. CDSP's operating system (uClinux) utilizes a robust JFFS flash file system, which enables fail-safe operation and the storage of disturbance record files, configuration and parameters.

After power-up the RDSP processor starts up with the previously saved configuration and parameters. Generally, the power-up procedure for the RDSP and relay functions takes approx. 1 sec. That is to say, it is ready to trip within this time. CDSP's start-up procedure is longer, because its operating system needs time to build its file system, initializing user applications such as HMI functions and the IEC 61850 software stack.

The built-in 5- port Ethernet switch allows the AQ-x3xx device to connect to IP/Ethernet- based networks. The following Ethernet ports are available:

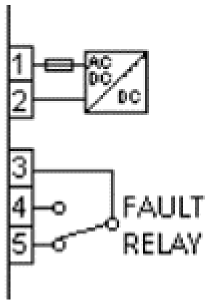
- Station bus (100Base-FX Ethernet).
- Redundant Station bus (100Base-FX Ethernet).
- Process bus (100Base-FX Ethernet).
- EOB (Ethernet over Board) user interface.
- Optional 100Base-TX port via RJ-45 connector.

Other communication:

- R422/RS485/RS232 interfaces.
- Plastic or glass fiber interfaces to support legacy protocols.
- Process-bus communication controller on COM+ card.

10.3 Power supply module

Figure. 10.3 - 158. Connector allocation of the 30 W power supply unit.



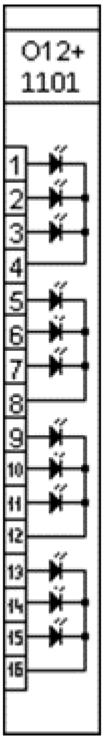
The power supply module converts primary AC and/or DC voltage to required system voltages. Redundant power supply cards extend system availability in case of the outage of any power source and can be ordered separately if required.

Main features of the power supply module:

- 30 W input.
- Maximum 100 ms power interruption time: measured at nominal input voltage with nominal power consumption.
- IED system fault contacts (NC and NO): device fault contact and also assignable to user functions. All the three relay contact points (NO, NC, COM) are accessible to users 80…300 V DC input range, AC power is also supported.
- Redundant applications which require two independent power supply modules can be ordered optionally.
- On-board self-supervisory circuits: temperature and voltage monitors.
- Short-circuit-protected outputs.
- Efficiency: >70 %.
- Passive heat sink cooling.
- Early power failure indication signals to the CPU the possibility of power outage, thus the CPU has enough time to save the necessary data to non-volatile memory.

10.4 Binary input module(s)

Figure. 10.4 - 159. The binary input module O12+ 1101.



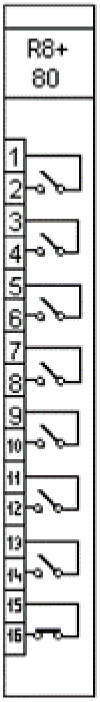
The inputs are galvanic isolated and the module converts high-voltage signals to the voltagelevel and format of the internal circuits. This module is also used as an external IRIG-B synchronization input. Dedicated synchronization input (input channel 1) is used for this purpose.

The binary input modules are:

- Rated input voltage: 110/220 V DC.
- Clamp voltage: falling 0.75 Un, rising 0.78 Un.
- Digitally filtered per channel.
- Current drain approx.: 2 mA per channel.
- 12 inputs.
- IRIG-B timing and synchronization input.

10.5 Binary output module(s)

Figure. 10.5 - 160. The binary output module R8+ 80.



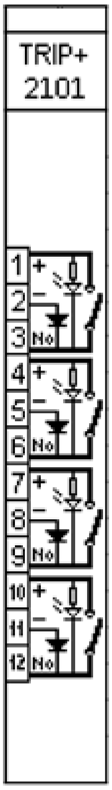
The signaling output modules can be ordered as 8 relay outputs with dry contacts.

The binary output modules are:

- Rated voltage: 250 V AC/DC.
- Continuous carry: 8 A.
- Breaking capacity, (L/R = 40 ms)at 220 V DC: 0.2 A
- 8 contacts: 7 NO and 1 NC

10.6 Tripping module

Figure. 10.6 - 161. The tripping module TRIP+ 2101.



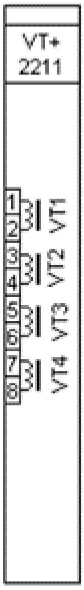
The tripping module applies direct control of a circuit breaker. The module provides fast operation and is rated for heavy duty controlling.

The main characteristics of the trip module:

- 4 independent tripping circuits.
- High-speed operation.
- Rated voltage: 110 V, 220 V DC.
- Continuous carry: 8 A.
- Making capacity: 0.5 s, 30 A.
- Breaking capacity (L/R = 40 ms) at 220 V DC: 4A.
- Trip circuit supervision for each trip contact.

10.7 Voltage measurement module

Figure. 10.7 - 162. The voltage measurement module VT+ 2211.



For voltage related functions (over- /under -voltage, directional functions, distance function,power functions) or disturbance recorder functionality this module is needed. This module also has capability for frequency measurement.

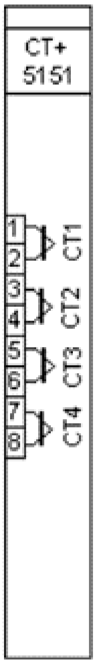
For capacitive voltage measurement of the synchrocheck reference, the voltage measurement module can be ordered with reduced burden in channel VT4. In this module the burden is < 50 mVA.

The main characteristics of the voltage measurement module:

- Number of channels: 4.
- Rated frequency: 50 Hz, 60 Hz.
- Selectable rated voltage (Un): 100/√3, 100 V, 200/√3, 200 V by parameter.
- Voltage measuring range: 0.05 Un – 1.2 Un.
- Continuous voltage withstand: 250 V.
- Power consumption of voltage input: ≤1 VA at 200 V (with special CVT module the burden is < 50 mVA for VT4 channel).
- Relative accuracy: ±0.5 %.
- Frequency measurement range: ±0.01 % at Ux 25 % of rated voltage.
- Measurement of phase angle: 0.5º Ux 25 % of rated voltage.

10.8 Current measurement module

Figure. 10.8 - 163. Connector allocation of the current measurement module.



Current measurement module is used for measuring current transformer output current. Module includes three phase current inputs and one zero sequence current input. The nominal rated current of the input can be selected with a software parameter either 1 A or 5 A.

The main chracteristics of the current measurement module:

- Number of channels: 4.
- Rated frequency: 50 Hz, 60 Hz.
- Electronic iron-core flux compensation.
- Low consumption: ≤0.1 VA at rated current.
- Current measuring range: 35 x In.
- Selectable rated current 1 A/5 A by parameter.
- Thermal withstand:
  - 20 A (continuously)
  - 500 A (for 1 s)
  - 1200 A (for 10 ms)
- Relative accuracy: ±0.5 %.
- Measurement of phase angle: 0.5º, Ix 10 % rated current.

10.9 Installation and dimensions

Figure. 10.9 - 164. Dimensions of AQ-x35x IED.

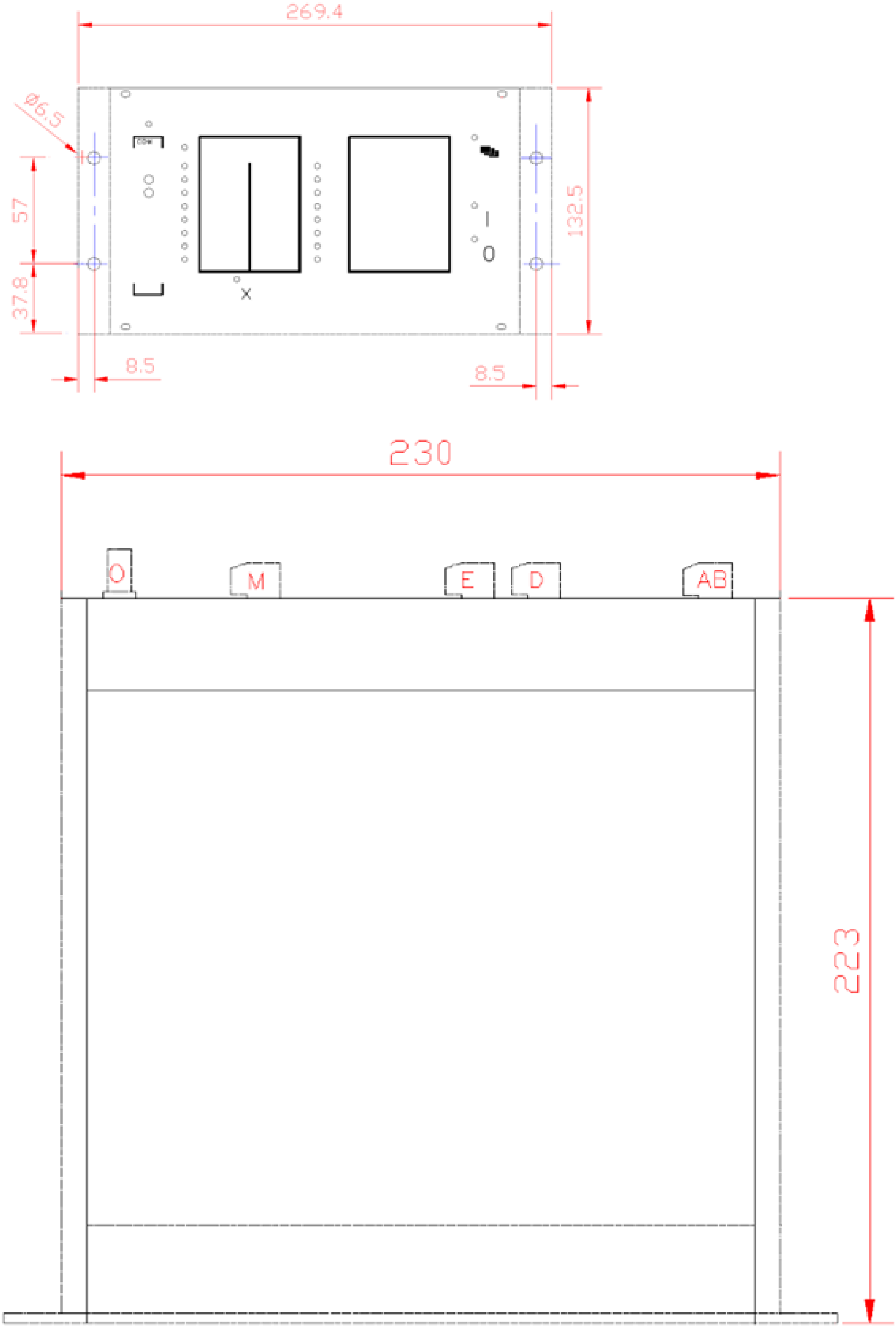


Figure. 10.9 - 165. Panel cut-out and spacing of AQ-x35x IED.

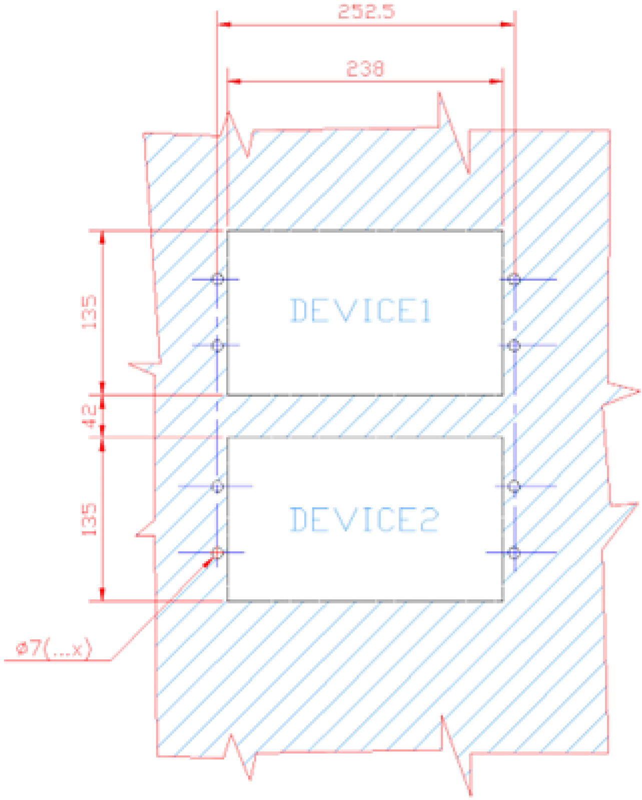


Figure. 10.9 - 166. Dimensions of AQ-x39x IED.

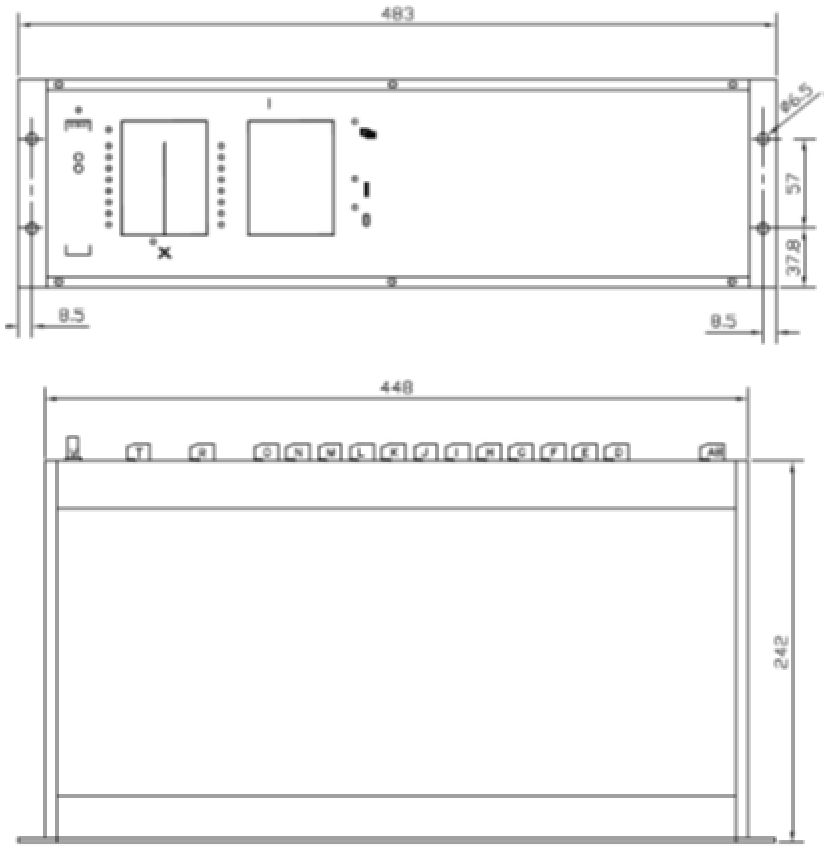
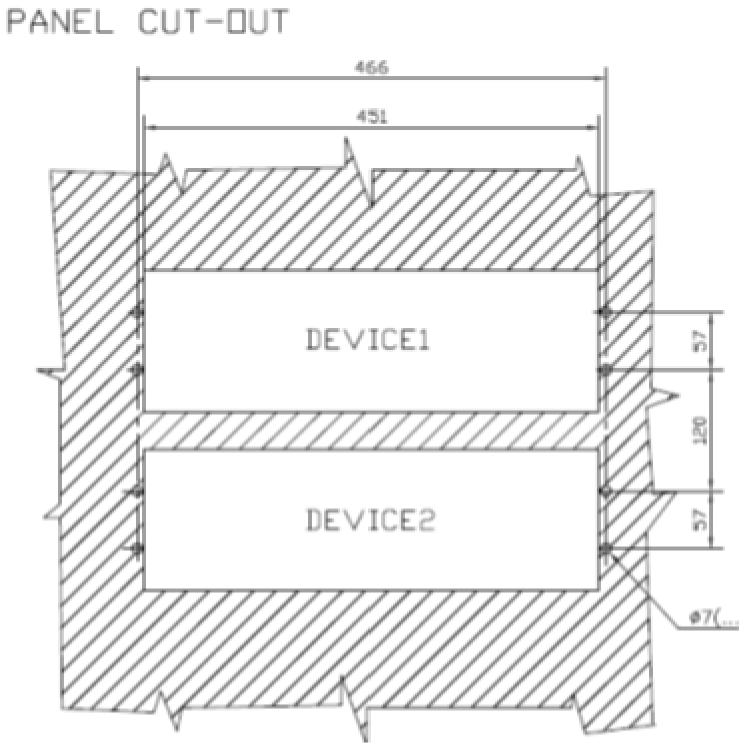


Figure. 10.9 - 167. Panel cut-out and spacing of AQ-x39x IED.



11 Technical data

11.1 Protection functions

Breaker failure protection function CBFP, (50BF)

Current inaccuracy	<2 %
Re-trip time	Approx. 15ms
Operation time inaccuracy	± 5ms
Current reset time	20ms

Current unbalance protection function (60)

Pick-up starting inaccuracy at In	< 2 %
Reset ratio	0,95
Operate time	70 ms

Three-phase instantaneous overcurrent protection I> (50)

Operating characteristic	Instantaneous
Pick-up current inaccuracy	<2%
Reset ratio	0.95
Operate time at 2*In Peak value calculation Fourier calculation	<15 ms <25 ms
Reset time	16 – 25 ms
Transient overreach Peak value calculation Fourier calculation	80 % 2 %

Three-phase time overcurrent protection I> (50/51)

Pick-up current inaccuracy	< 2%
Operation time inaccuracy	±5% or ±15ms
Reset ratio	0.95
Minimum operating time with IDMT	35ms
Reset time	Approx 35ms
Transient overreach	2 %

Pickup time	25 – 30ms

Residual instantaneous overcurrent protection I0> (50N)

Operating characteristic	Instantaneous
Picku-up current inaccuracy	<2%
Reset ratio	0.95
Operate time at 2*In Peak value calculation Fourier calculation	<15 ms <25 ms
Reset time	16 – 25 ms
Transient overreach Peak value calculation Fourier calculation	80 % 2 %

Residual time overcurrent protection I0> (51N)

Pick-up current inaccuracy	< 2%
Operation time inaccuracy	±5% or ±15ms
Reset ratio	0.95
Minimum operating time with IDMT	35ms
Reset time	Approx 35ms
Transient overreach	2 %
Pickup time	25 – 30ms

Three-phase directional overcurrent protection function I0Dir> (67)

Pick-up current inaccuracy	< 2%
Operation time inaccuracy	±5% or ±15ms
Reset ratio	0.95
Minimum operating time with IDMT	35ms
Reset time	Approx 35ms
Transient overreach	2 %
Pickup time	25 – 30ms
Angular inaccuracy	<3°

Residual directional overcurrent protection function I0Dir> (67N)

Pick-up current inaccuracy	< 2%

Operation time inaccuracy	±5% or ±15ms
Reset ratio	0.95
Minimum operating time with IDMT	35ms
Reset time	Approx 35ms
Transient overreach	2 %
Pickup time	25 – 30ms
Angular inaccuracy	<3°

Overvoltage protection function U> (59)

Pick-up starting inaccuracy	< 0,5 %
Reset time U> → Un U> → 0	50 ms 40 ms
Operation time inaccuracy	± 15 ms

Undervoltage protection function U< (27)

Pick-up starting inaccuracy	< 0.5 %
Reset time: • U> → Un • U> → 0	50 ms 40 ms
Operate time inaccuracy	+15 ms

Residual overvoltage protection function U0> (59N)

Pick-up starting inaccuracy	< 0,5 %
Reset time U> → Un U> → 0	50 ms 40 ms
Operate time inaccuracy	± 15 ms

Overfrequency protection function f> (81O)

Operating range	40 - 60 Hz
Operating range inaccuracy	30mHz
Effective range inaccuracy	2mHz
Minimum operating time	100ms
Operation time inaccuracy	± 10ms
Reset ratio	0,99

Underfrequency protection function f< (81U)

Operating range	40 - 70 Hz
Operating range inaccuracy	30 mHz
Effective range inaccuracy	2 mHz
Minimum operating time	140 ms
Operation time inaccuracy	+10 ms
Reset ratio	0.99

Rate-of-change of frequency protection function df/dt> (81R)

Effective operating range	-5...+5 Hz/s
Pick-up inaccuracy	0.01 Hz/s
Minimum operating time	140 ms
Operation time inaccuracy	+15 ms

Thermal overload protection function T> (49)

Operation time inaccuracy at I> 1.2*Itrip	3 % or +20 ms

Line differential protection IdL> (87L)

Operating characteristic	Biased 2 breakpoints and unrestrained decision
Reset ratio	0.95
Characteristic inaccuracy	<2% (Ibias > 2xIn)
Operate time	Typically 35ms (Ibias > 0.3xIn)
Reset time	Typically 60ms

Distance protection Z> (21)

Number of zones	5
Current effective range	20…2000% of In
Voltage effective range	2…110% of Un
Operation inaccuracy (current & voltage)	±1%
Impedance effective range	0.1 – 200 Ohm (In =1A) 0.1 – 40 Ohm (In = 5A)
Impedance operation inaccuracy	±5%
Zone static range	48…52Hz 49.5…50.5Hz

Zone static inaccuracy	±5% (48..52Hz) ±2% (49.5…50.5Hz)
Zone angular inaccuracy	±3 °
Minimum operate time	<20ms
Typical operate time	25ms
Operate time inaccuracy	±3ms
Reset time	16-25ms
Reset ratio	1.1

Teleprotection (85)

Operate time accuracy	±5% or ±15 ms, whichever is greater

Inrush current detection function INR2, (68)

Current inaccuracy	<2 %
Reset ratio	0,95
Operating time	Approx. 20 ms

11.2 Control functions

Switch on to fault logic

Timer accuracy	±5% or ±15ms, whichever is greater

Synchroncheck function du/df (25)

Rated Voltage Un	100/200V, setting parameter
Voltage effective range	10-110 % of Un
Voltage inaccuracy	±1% of Un
Frequency effective range	47.5 – 52.5 Hz
Frequency inaccuracy	±10mHz
Phase angle inaccuracy	±3 °
Operate time inaccuracy	±3ms
Reset time	<50ms
Reset ratio	0.95

11.3 Monitoring functions

Current transformer supervision function CTS

Pick-up starting inaccuracy at In	<2%
Minimum operation time	70ms
Reset ratio	0.95

Voltage transformer supervision function VTS

Pick-up voltage inaccuracy	1 %
Operation time inaccuracy	<20 ms
Reset ratio	0.95

Voltage variation (sag and swell)

Voltage measurement inaccuracy	±1 % of Un
Timer inaccuracy	±2 % of setting value or ± 20 ms

Dead line detectioin (DLD)

Pick-up voltage inaccuracy	1%
Operation time inaccuracy	<20ms
Reset ratio	0.95

Trip logic (94)

Impulse time duration accuracy	<3ms

11.4 Hardware

Power supply module

Input voltage	80-255VAC 90-300VDC
Nominal voltage	110VDC/220VDC
Maximum interruption	100ms
Maximum power consumption	30W

Current measurement module

Nominal current	1/5A (parameter settable) 0.2A (ordering option)
Number of channels per module	4
Rated frequency	50Hz 60Hz (ordering option)
Burden	<0.1VA at rated current
Thermal withstand	20A (continuous) 500A (for 1s) 1200A (for 10ms)
Current measurement range	0-50xIn
Power consumption at rated current	0.01 VA with 1A rated current 0.25 VA with 5A rated current
Phase angle accuracy at Ix ≥ 10% ± 1 digit	≤ 0.5 º
Relative accuracy [%] ± 1 digit	± 1 (> 0.5In) with 1A rated current ± 1 (> 0.4In) with 5A rated current

Voltage measurement module

Rated voltage Un	100/√3, 100V, 200/√3, 200V (parameter settable)
Number of channels per module	4
Rated frequency	50Hz 60Hz (ordering option)
Burden	<1VA at 200V
Voltage withstand	250V (continuous) 275VAC/350VDC (1s)
Voltage measurement range	0.05-1.2xUn
Power consumption	0.61VA at 200V 0.2 VA at 100V
Relative accuracy	±0.5 % (>0.6Un)
Frequency measurement range	±0.01 % at Ux ≥ 25% of rated voltage
Phase angle accuracy	≤ 0.5 º at Ux ≥ 25% of rated voltage

Binary input module

Rated voltage Un	110 or 220Vdc (ordering option)
Number of inputs per module	12 (in groups of 3)
Current drain	approx. 2mA per channel

Breaking capacity	0.2A (L/R=40ms, 220Vdc)

Binary output module

Rated voltage Un	250Vac/dc
Number of outputs per module	7 (NO) + 1(NC)
Continuous carry	8A
Breaking capacity	0.2A (L/R=40ms, 220Vdc)

High speed trip module

Rated voltage Un	110/220VDC
Max. withstand voltage	242V DC
Number of outputs per module	4
Continuous carry	8A
Making capacity	30A (0.5s)
Breaking capacity	4A (L/R=40ms, 220Vdc)

11.5 Tests and environmental conditions

Disturbance tests

EMC test	CE approved and tested according to EN 50081-2, EN 50082-2
Emission - Conducted (EN 55011 class A) - Emitted (EN 55011 class A)	0.15 - 30MHz 30 - 1 000MHz
Immunity	
- Static discharge (ESD) (According to IEC244-22-2 and EN61000-4-2, class III)	Air discharge 8kV Contact discharge 6kV
- Fast transients (EFT) (According to EN61000-4-4, class III and IEC801-4, level 4)	Power supply input 4kV, 5/50ns other inputs and outputs 4kV, 5/50ns
- Surge (According to EN61000-4-5 [09/96], level 4)	Between wires 2 kV / 1.2/50µs Between wire and earth 4 kV / 1.2/50µs
- RF electromagnetic field test (According. to EN 61000-4-3, class III)	f = 80….1000 MHz 10V /m
- Conducted RF field (According. to EN 61000-4-6, class III)	f = 150 kHz….80 MHz 10V

Voltage tests

Insulation test voltage acc- to IEC 60255-5	2 kV, 50Hz, 1min

Impulse test voltage acc- to IEC 60255-5	5 kV, 1.2/50us, 0.5J

Mechanical tests

Vibration test	2 ... 13.2 Hz ±3.5mm 13.2 ... 100Hz, ±1.0g
Shock/Bump test acc. to IEC 60255-21-2	20g, 1000 bumps/dir.

Casing and package

Protection degree (front)	IP 54 (with optional cover)
Weight	5kg net (AQ-x35x devices) 6kg net (AQ-x39x devices) 6kg with package (AQ-x35x devices) 7kg with package (AQ-x39x devices)

Environmental conditions

Specified ambient service temp. range	-10…+55°C
Transport and storage temp. range	-40…+70°C

12 Ordering information

Visit https://configurator.arcteq.fi/ to build a hardware configuration, define an ordering code and get a module layout image.

13 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.fi
Technical support:	support.arcteq.fi +358 10 3221 388 (EET 9:00 – 17.00)
E-mail (sales):	sales@arcteq.fi