PART OF ENSTO GROUP

AQ-G3x7

Generator protection device

Instruction manual

Table of contents

Disclaimer

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

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

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

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

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

Copyright

1 Document information

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	July 2012
Changes	• Synchrocheck function revised. • Technical data revised. • Order code updated.
Revision	**1.04**
Date	January 2014
Changes	• Measurement connection examples added.
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	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 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-G3x7 generator 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-G3x7 generator protection IED.

AQ G357 and AQ G397 contain the same software functionality. Difference is in physical size, AQ G357 is a half 19 inch rack version with limited I/O capability whereas AQ G397 is a full 19 inch rack version offering enhanced I/O capabilities.

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.

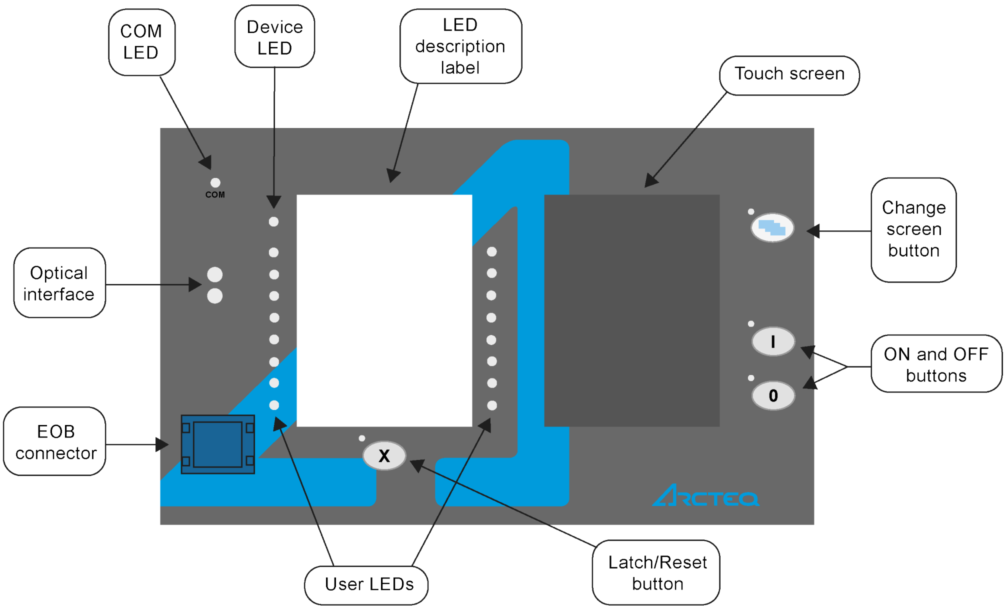


Table. 5.1 - 3. Elements of the front panel.

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-G3x7 factory configuration.

Table. 5.2 - 4. The LED assignment of AQ-G3x7.

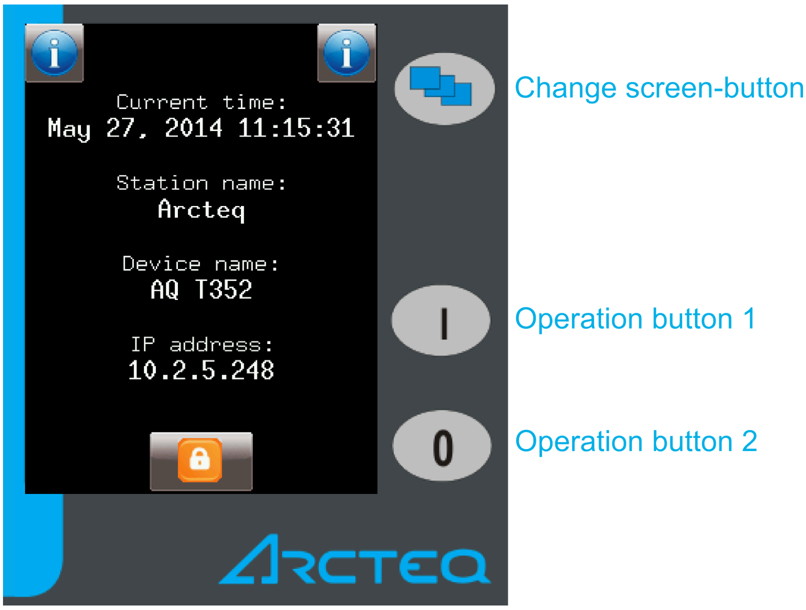
LED	Explanation
General Trip	Trip command generated by the TRC94 function
I> Trip	Trip command generated by the phase overcurrent protection functions
Io> Trip	Trip command generated by the residual overcurrent protection functions
Frequ Trip	Trip command generated by the frequency-related functions
Voltage Trip	Trip command generated by the voltage-related functions
I2> Trip	Trip command generated by the current unbalance protection function
Therm Trip	Trip command of the thermal overload protection
Impedance Trip	Trip command of the impedance trip stage
Diff Trip	Trip command generated by differential protection
P< Trip	Trip command generated by underpower protection
P> Trip	Trip command generated by overpower protection
Loss of exc.	Trip command generated by loss of excitation protection
VOC Trip	Trip command generated by voltage dependent overcurrent protection
Overexcitation	Trip command generated by overexcitation protection
Poleslip Trip	Trip command generated by poleslip protection
Locale	Local/Remote control signal

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

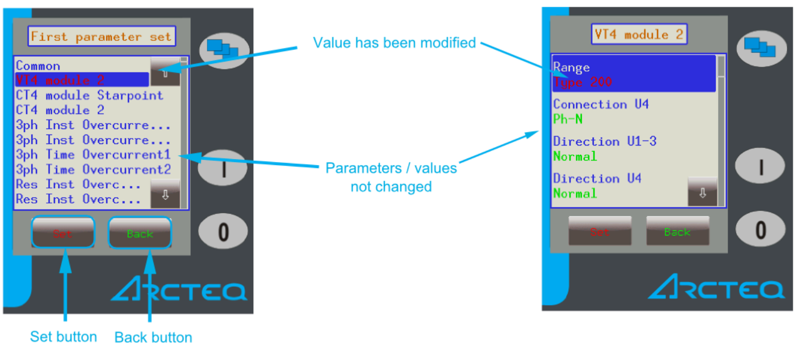
In the parameters menu (below) you can view, set and edit certain parameters within the device. You can also choose which of the parameter sets the device uses.

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.

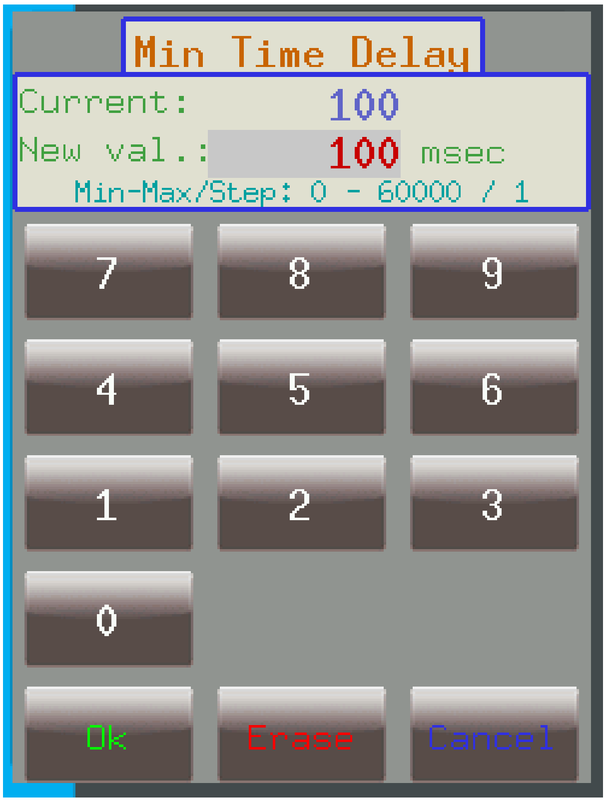
The Set button brings up a screen where you can modify a value. If there is a lock icon instead of the "Set" button, the device must first be unlocked. The Back button returns you to the previous screen.

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.

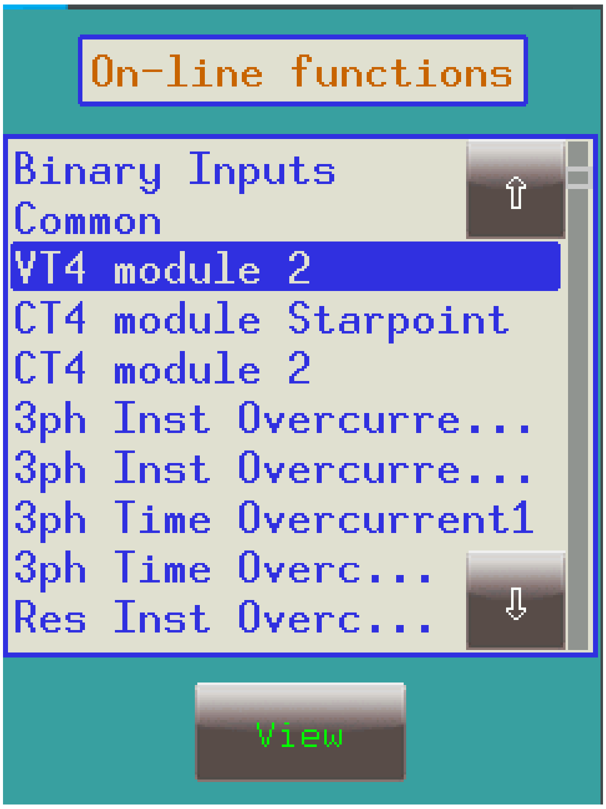
The OK button confirms the value in the "New value" field and returns the user to the previous screen. The Cancel button deletes a single digit from the "New value" field. The Erase button discards any changes to the current parameter and returns the user to the previous menu item.

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.

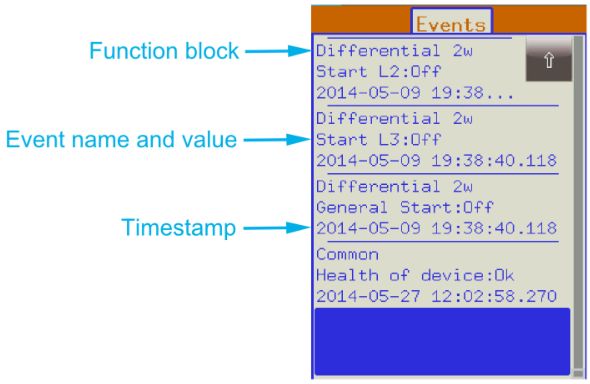


Events menu

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.

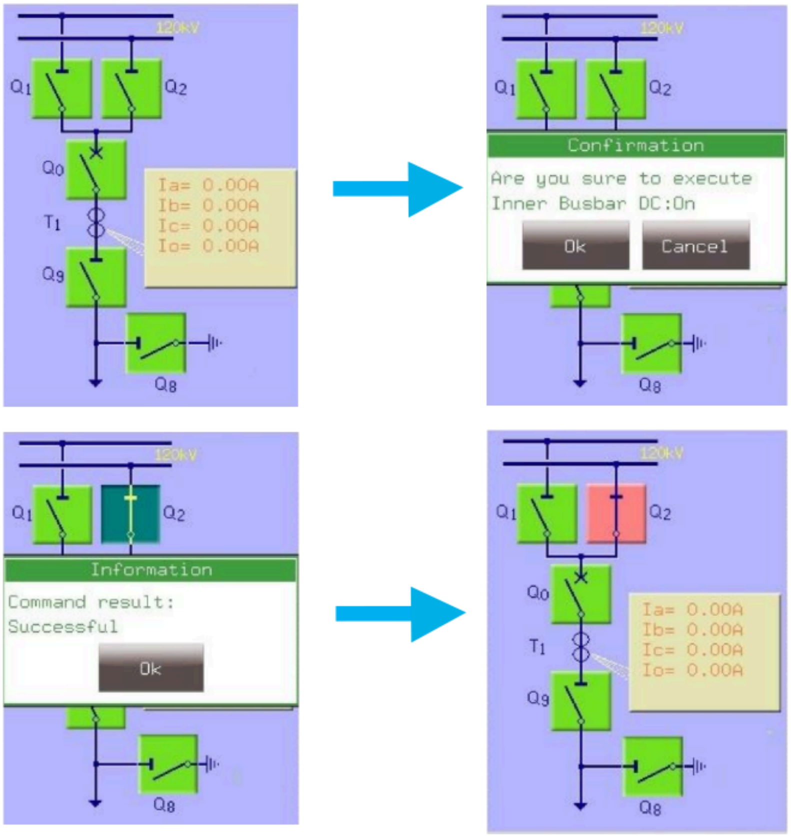
Setting	Description
System parameters and station bus settings (IP address, netmask, default gateway, DNS servers)	Please contact your local network administrator for further information about these settings.
Ethernet communication (IEC 61850 enabled, IEC 104 enabled)	Enables or disables the IEC 61850 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.

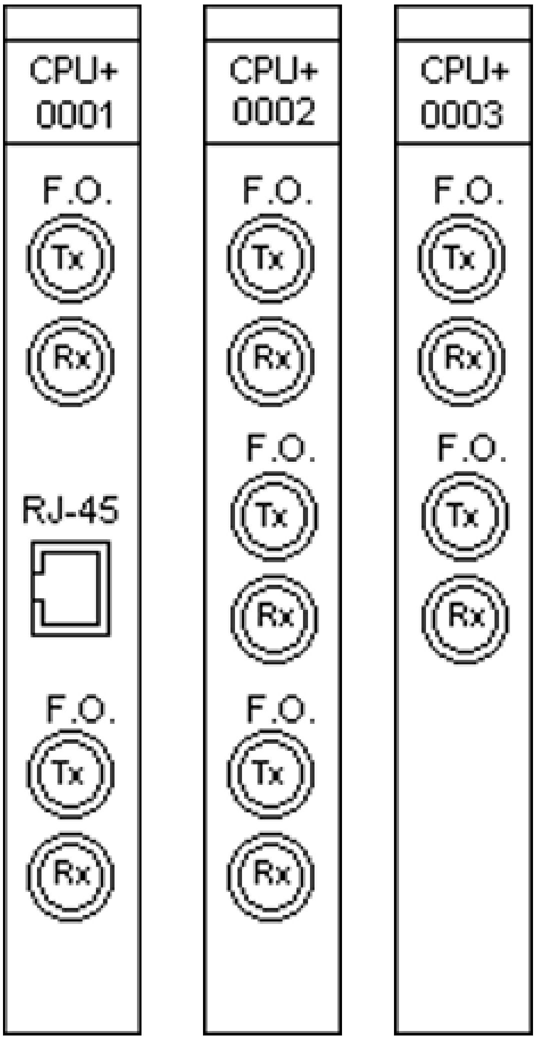
The following table catalogues the different Ethernet communication versions available for the different AQ-300 CPU versions.

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.

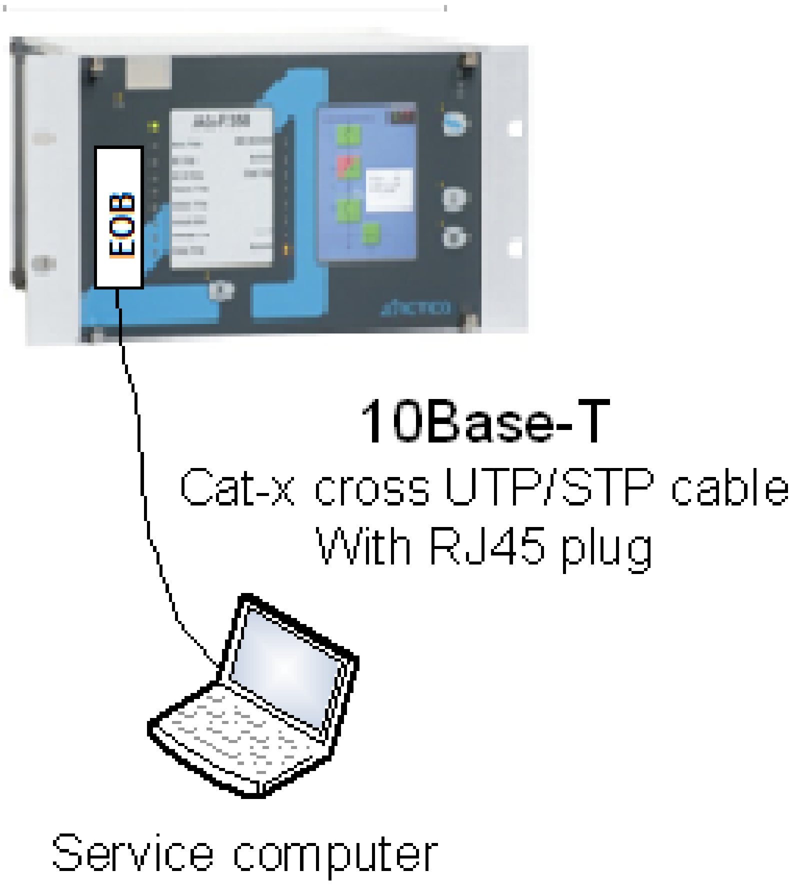
Web browser settings

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.

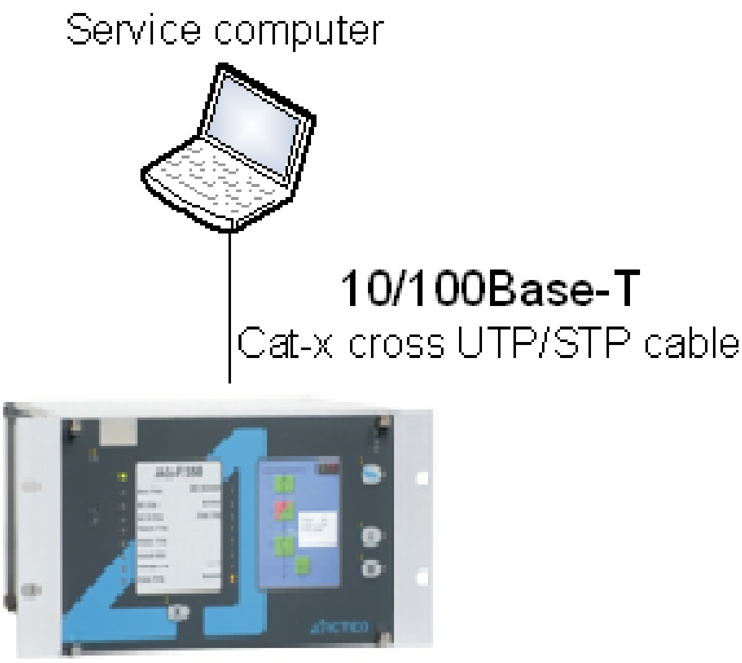


Please note that the RJ45 connector can also be connected to an Ethernet switch. When this is the case, all the network's IEDs with client functionalities (e.g. a computer) have access to the device.

RJ45 connection

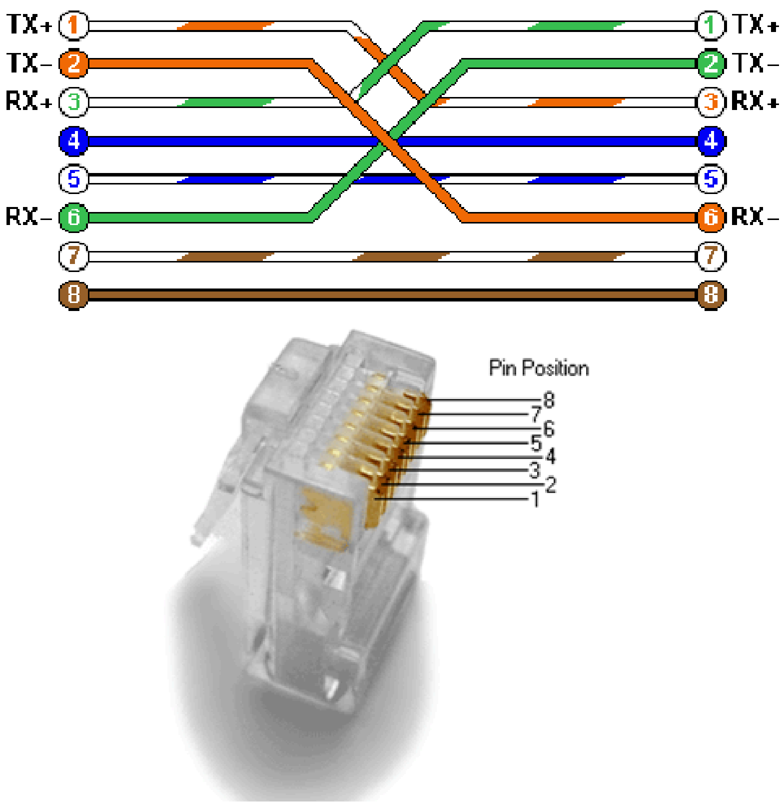
As seen in the beginning of this chapter, the CPU version "+0001" also has an integrated RJ4 port. When using a UTP crossover cable with RJ45 connectors at both ends, you can connect the device directly to a computer (see the figure below).

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.

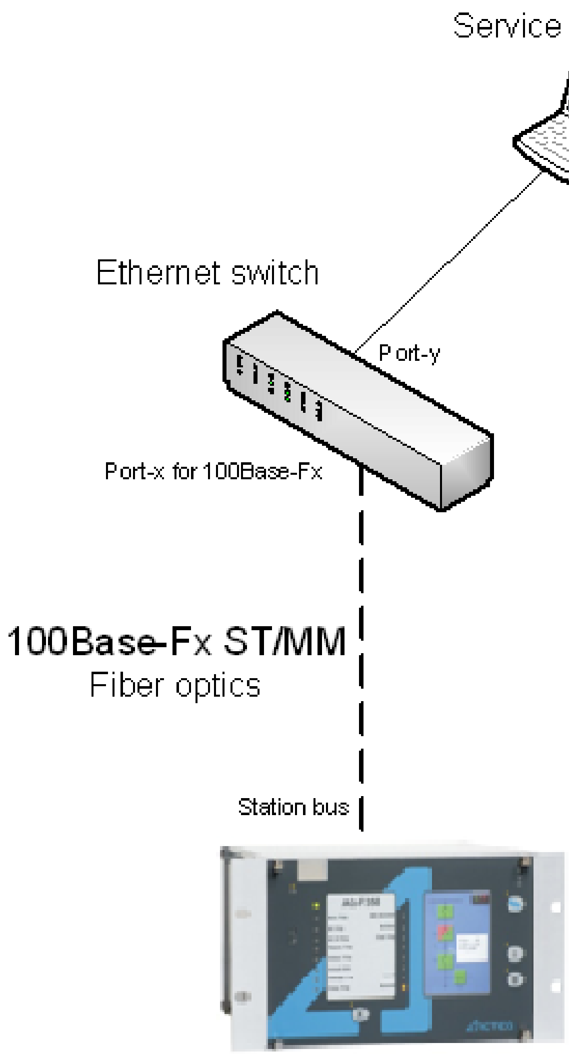


Please note that the cable's RJ45 connector can also be connected to an Ethernet switch. When this is the case, all the network's IEDs with client functionalities (e.g. a computer) have access to the device.

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).

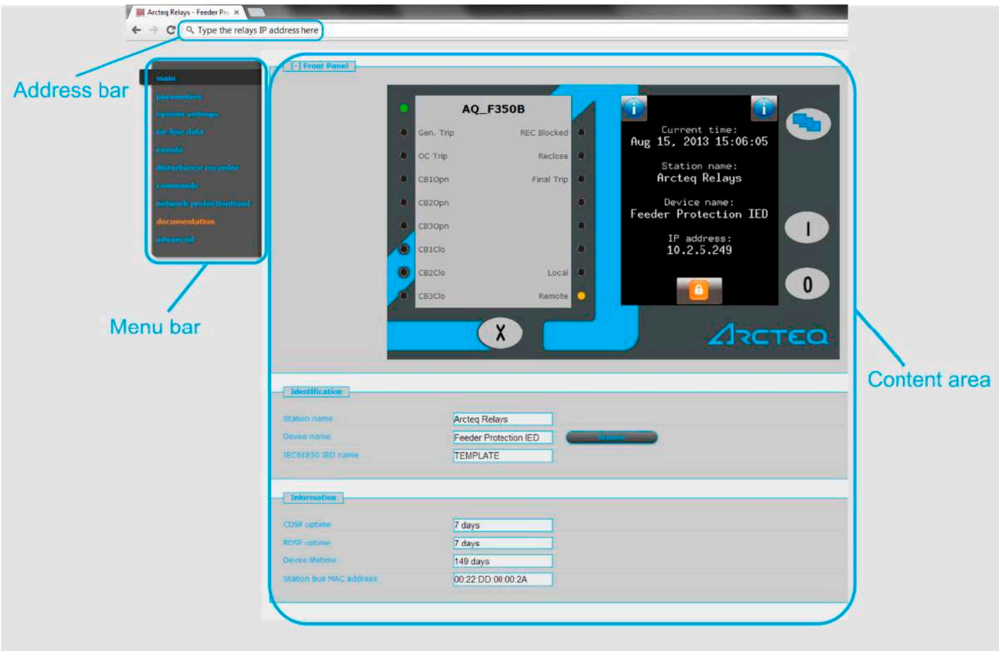
Figure. 5.4.1 - 16. Using the ST-type fiber optic connection to connect computers via an optical Ethernet switch.



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.



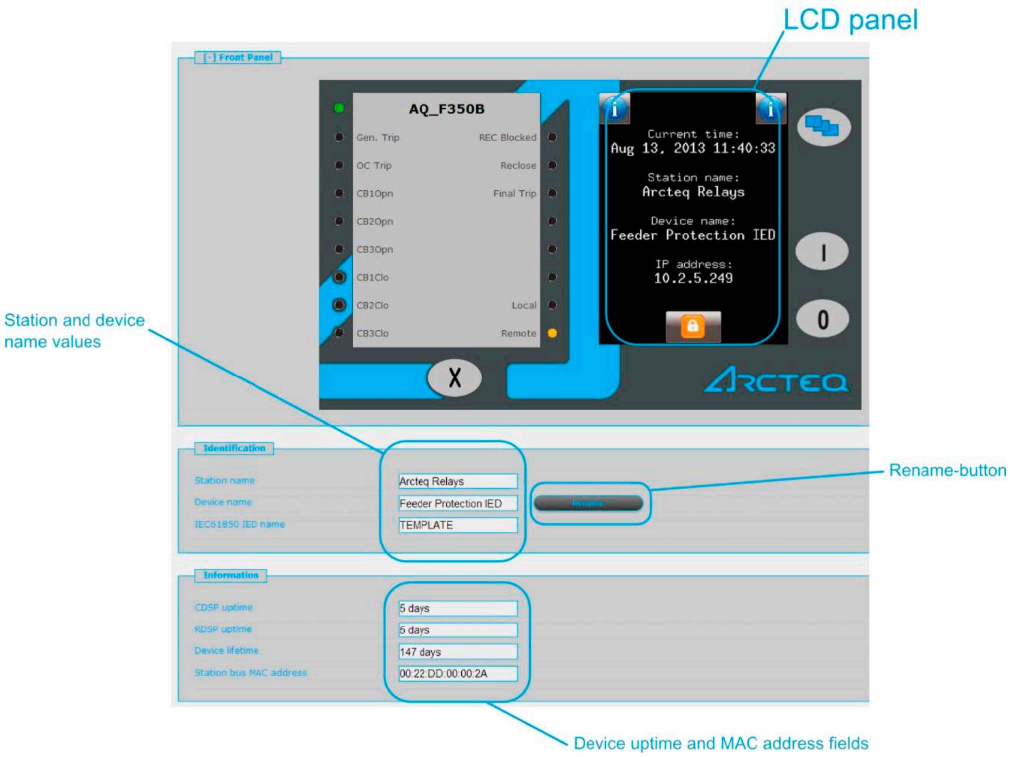
The menu that is currently selected is highlighted in black (in the image above, the main menu is selected). If the content area is too long to fit the browser window, you can scroll down; the menu bar will always be visible as it follows the user.

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.



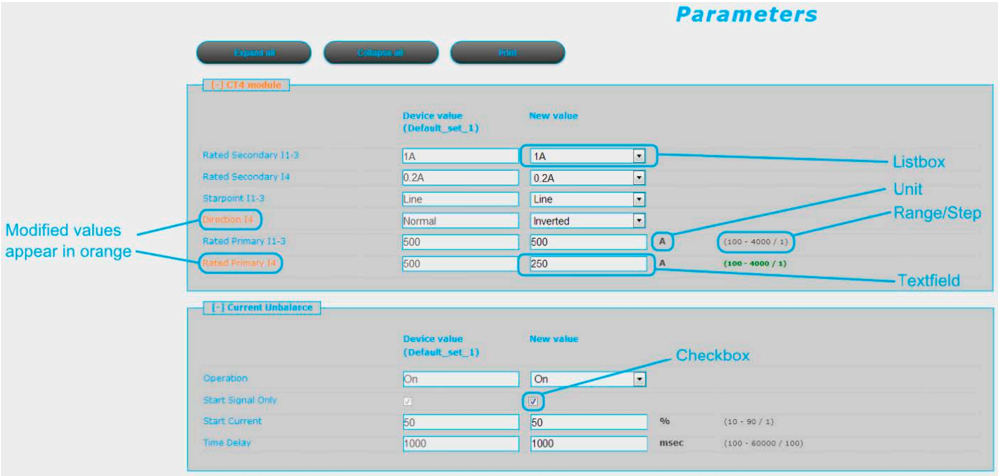
In the main menu you can control the device's front panel. The image of a touch screen (located on the right) behaves the same way as the actual touch screen. For more information on the touch screen, please refer to the "Touch screen" subchapter in the "IED user interface" main chapter.

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.

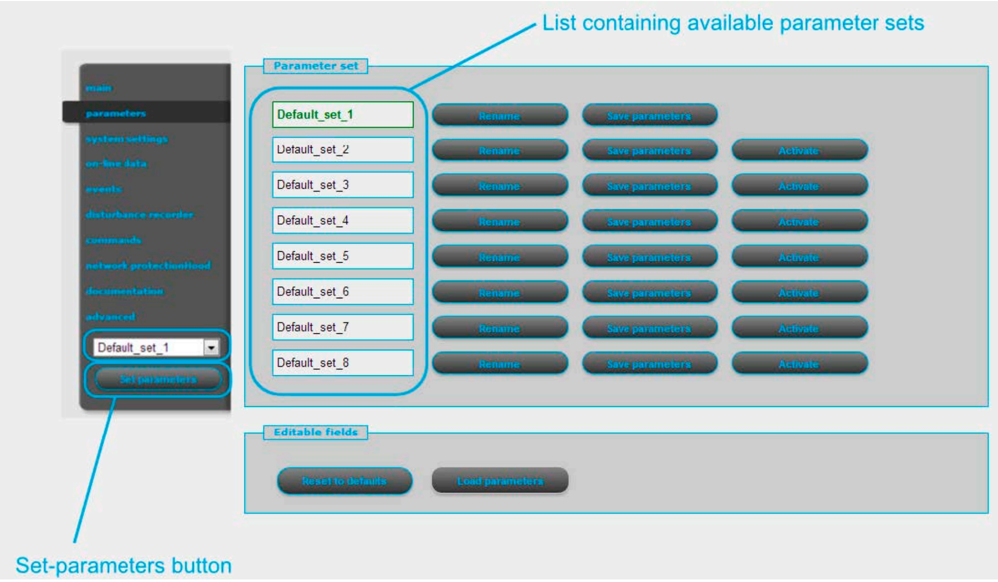
The parameter values are displayed in text fields, checkboxes, or listboxes. All of these can be modified; the name of the parameter whose value has been modifed appears in orange, as does the name of the function block (see the image above). When modifying *text fields*, please be mindful of the parameter 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.

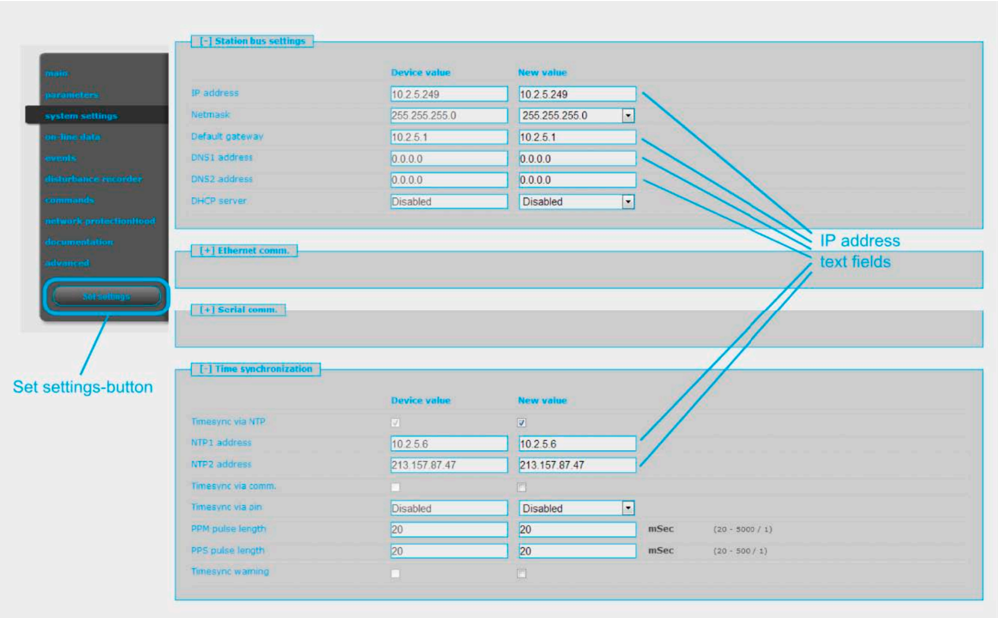


Table. 5.4.3 - 7. The system setting sections and their content.

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.

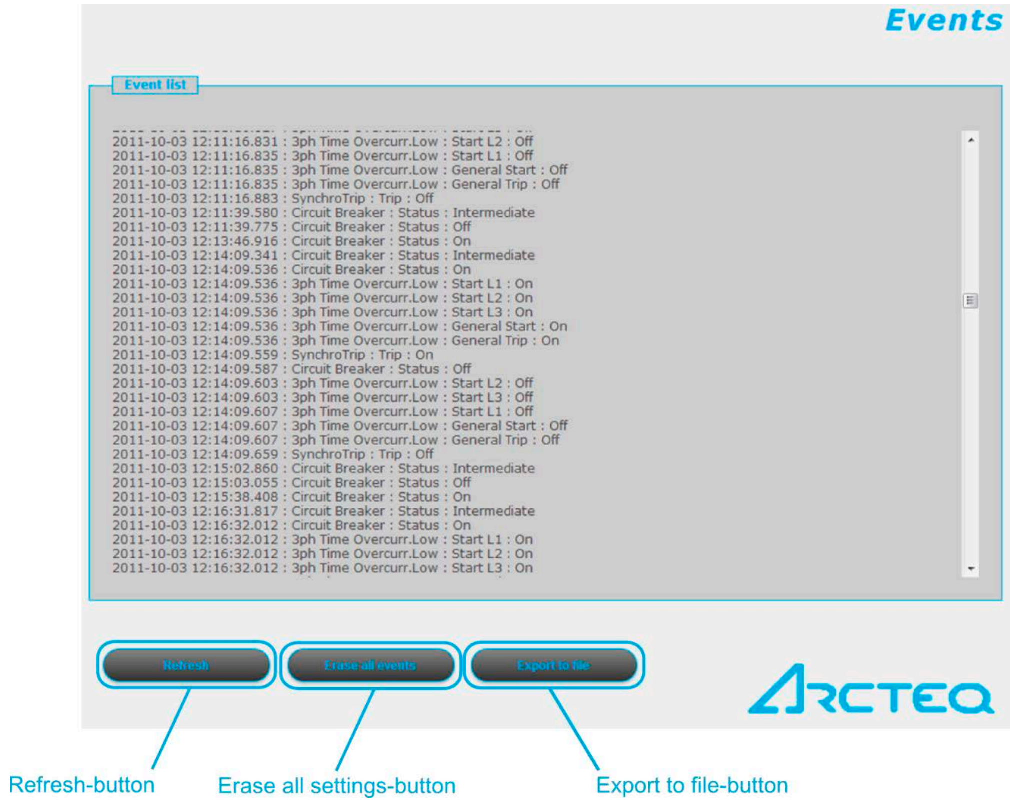
This menu displays the data measured by the device. Each block has their own section, and these sections can be expanded and collapsed individually as needed with the [+] and [–] signs in front of their names. The values on screen are updated every second, which may cause older systems to slow down or 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].

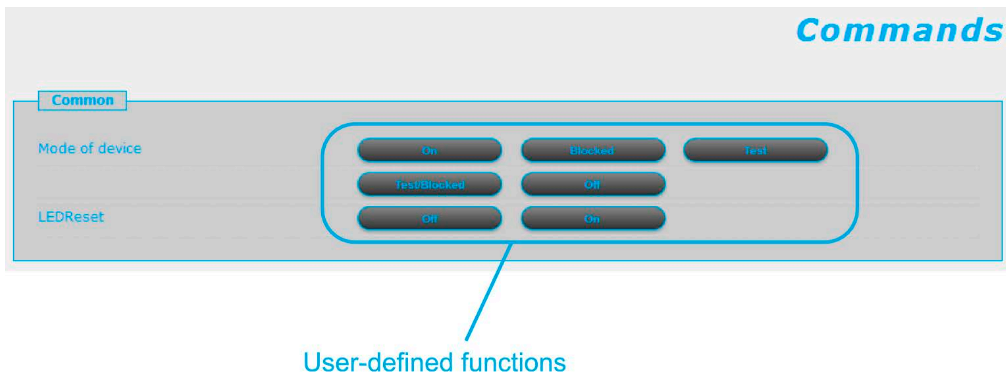
Figure. 5.4.3 - 23. Elements of the events menu.



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.

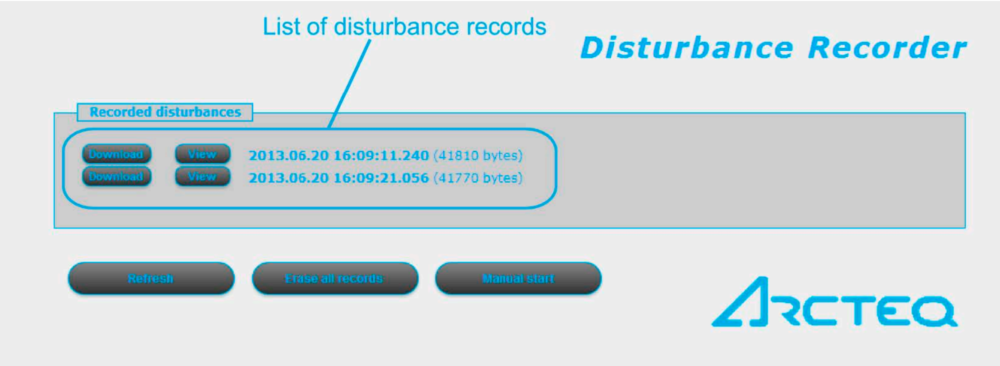


In the commands menu you can instruct the processor to carry out customized, user-defined commands. You can use the various mode buttons (**On**, **Blocked**, **Test**, **Test/Blocked**, **Off**) and LED buttons (**On**, **Off**) to define functions. A status update is always generated with a command, 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.

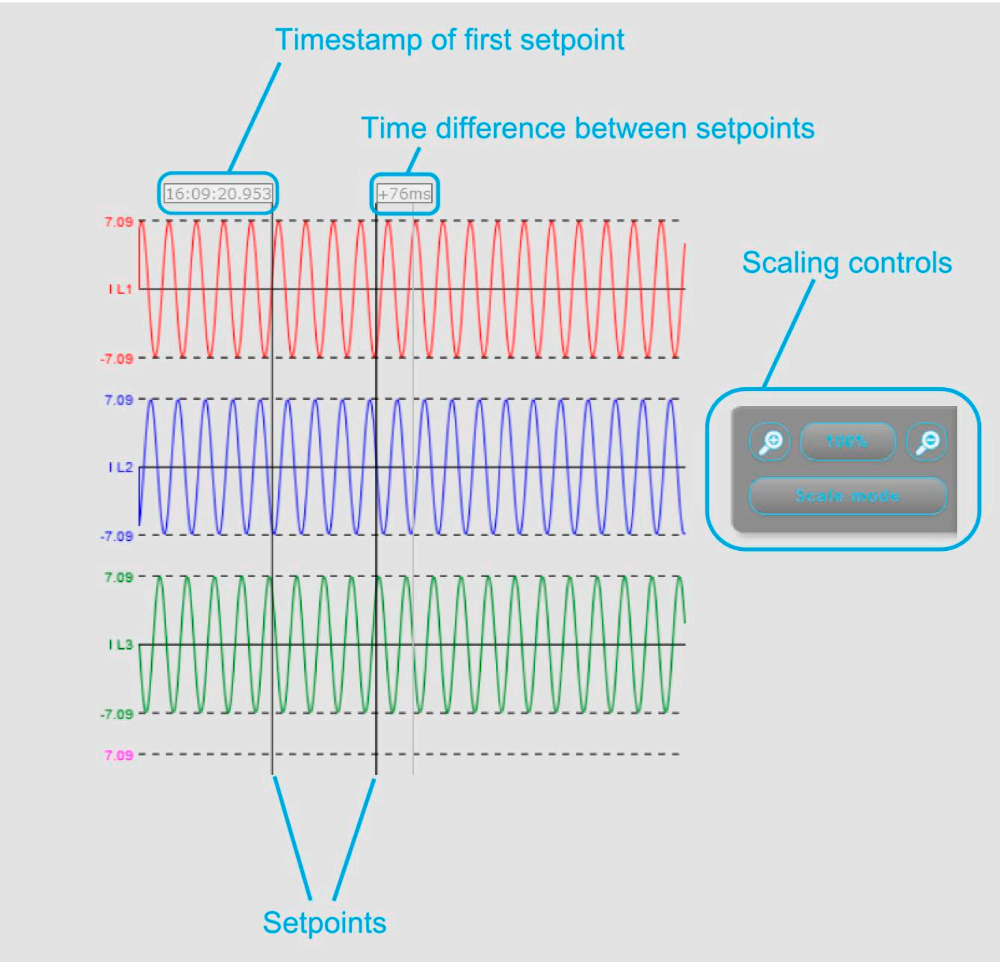
Figure. 5.4.3 - 25. Disturbance recorder.



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).

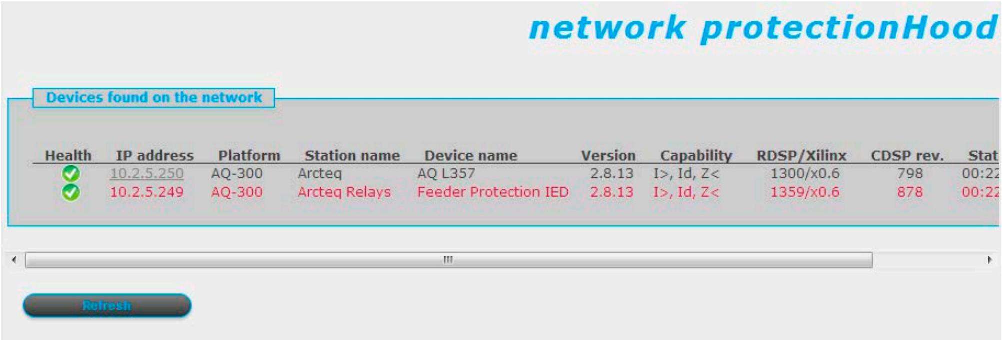
Figure. 5.4.3 - 26. Example of a disturbance record preview.



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

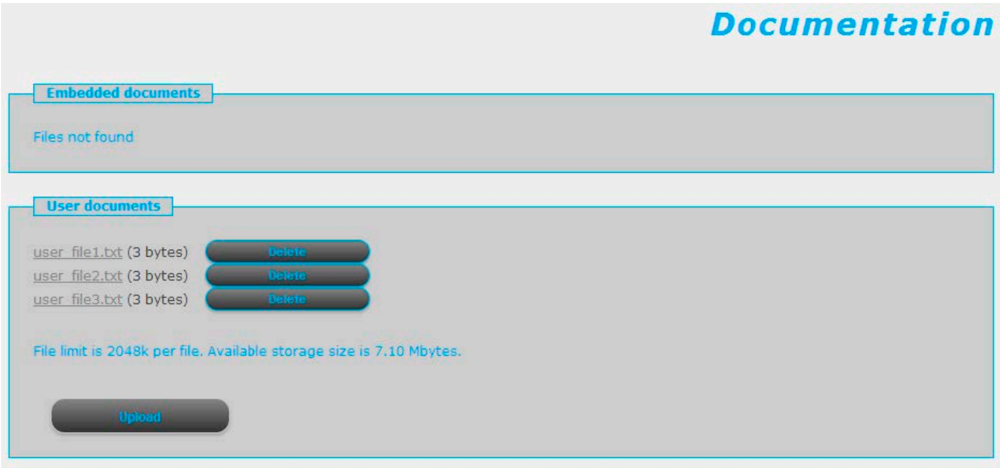
Figure. 5.4.3 - 27. The network protectionHood menu.



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.

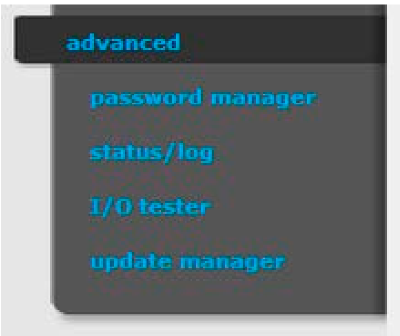


This page displays the documentation files on the device. You can upload other documents and files on the device, which are then saved and can be accessed later. One file can be up to 2048K , and there is storage for up to 8 MB of documentation.

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.

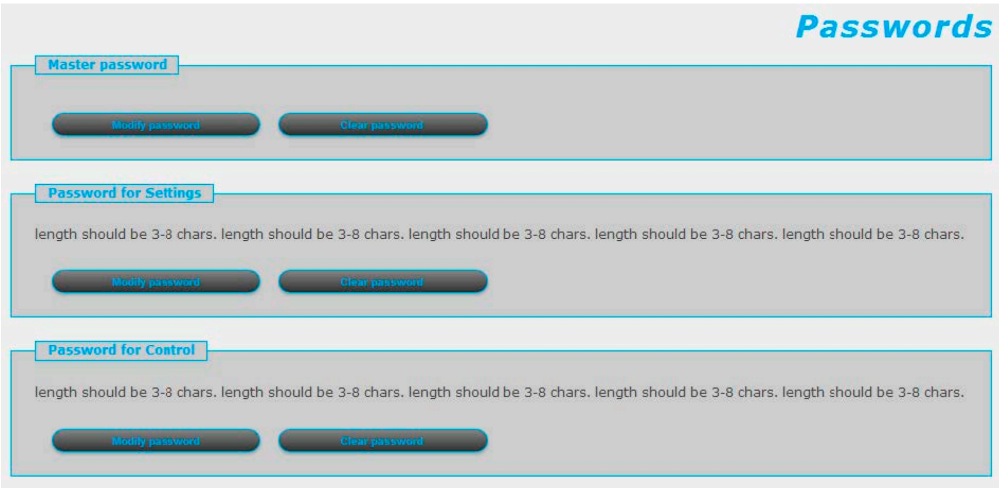


This menu displays the additional, more advanced options. You can set a password request before a user is allowed access to these options.

<u>Password manager</u>

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.



<u>Status/log</u>

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.

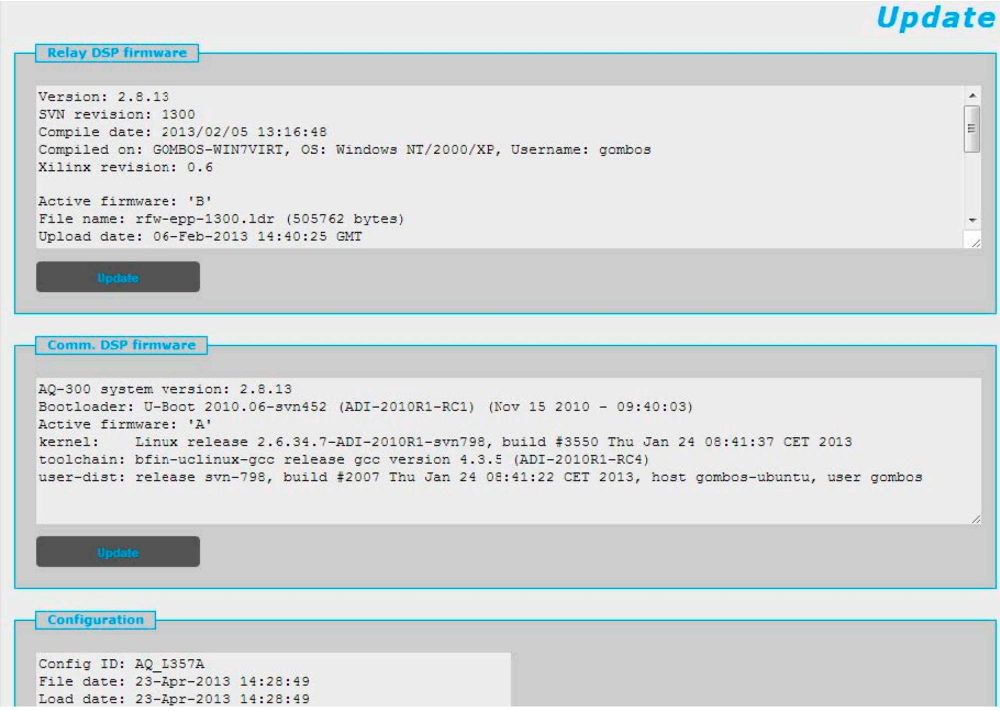
NOTICE!
All log files are in English, regardless of your language selection!

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-G3x7

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

Name	IEC	ANSI	Description
DIF87	3IdG>	87G	Generator differential protection
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
VOC51	Iv>	51V	Voltage restrained or voltage controlled 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	I2h >	68	Inrush detection and blocking
TOC46	I2	46	Negative sequence overcurrent
VCB60	Iub >	60	Current unbalance protection
TTR49L	T >	49	Thermal protection
TOV59_low TOV59_high	U > U >>	59	Definite time overvoltage protection
TUV27N_low TUV27N_high	U < U <<	27	Definite time undervoltage protection
TOV59N_low TOV59N_high	U0> U0>>	59N	Residual voltage protection
TOV64F3	U0f3>	64F3	100% stator earth fault 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
DOP32	P>	32	Reverse power / directional overpower protection
DUP32	P<	32	Directional underpower protection
IMP21	Z<	21	Underimpedance protection
PS78	PS	78	Pole slip
UEX40Z_low UEX40Z_high	X<	40	Loss of field/loss of excitation
VPH24	V/Hz	24	Overexcitation/Volts per hertz
BRF50MV	CBFP	50BF	Breaker failure protection

Table. 6.1 - 10. 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
Sag&Swell	-	-	Voltage sag and swell monitoring
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.

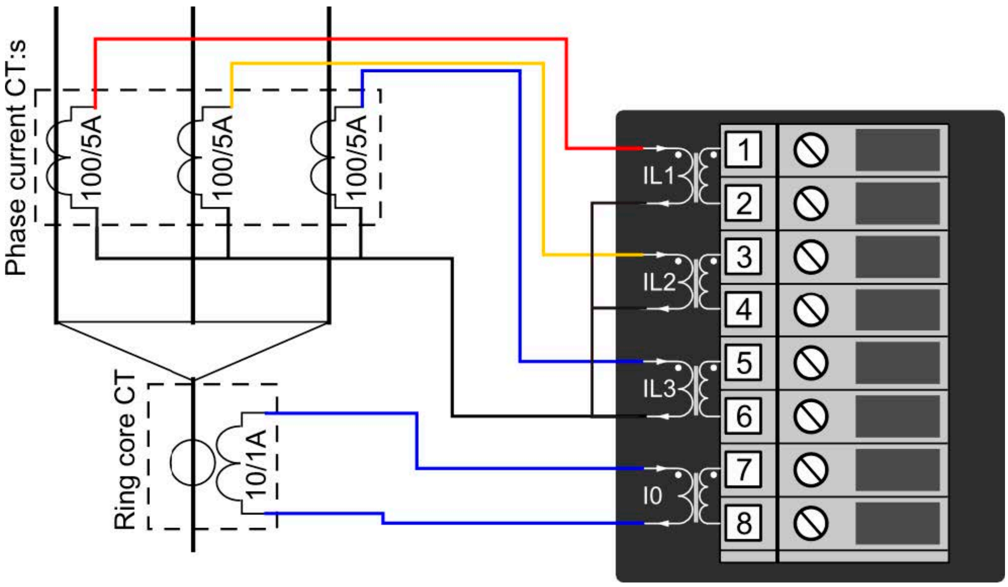


Table. 6.2.1 - 11. Values for the example above.

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.

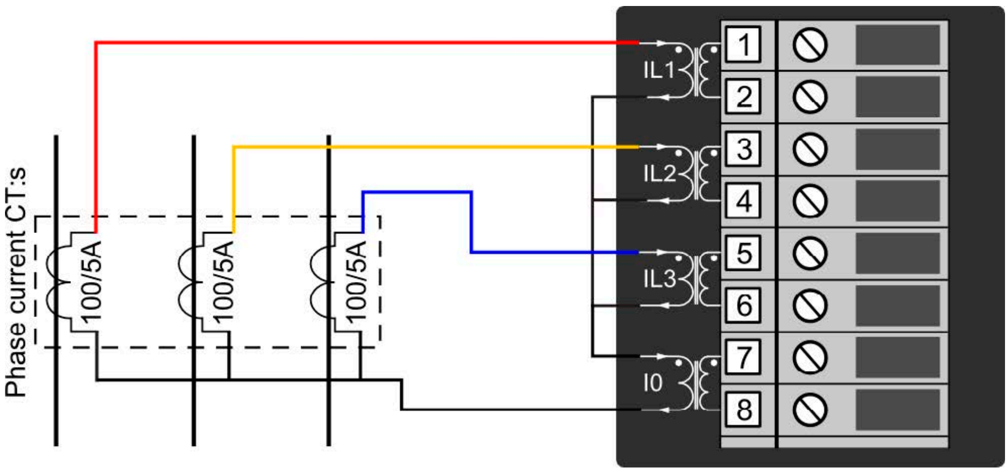


Table. 6.2.1 - 12. Values for the example above.

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.

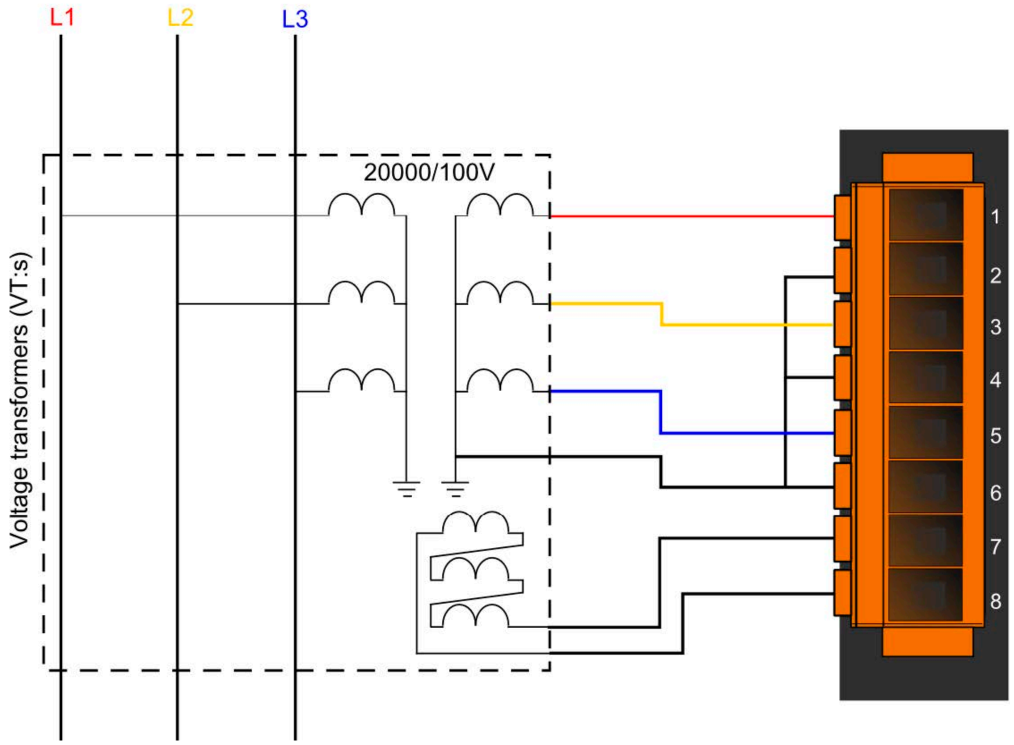
The voltage input function block receives the sampled voltage values from the internal operating system. The scaling (even hardware scaling) depends on a common parameter "Range" for type selection. The options to choose from are 100V or 200V, no hardware modification is needed. A small voltage is processed 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.

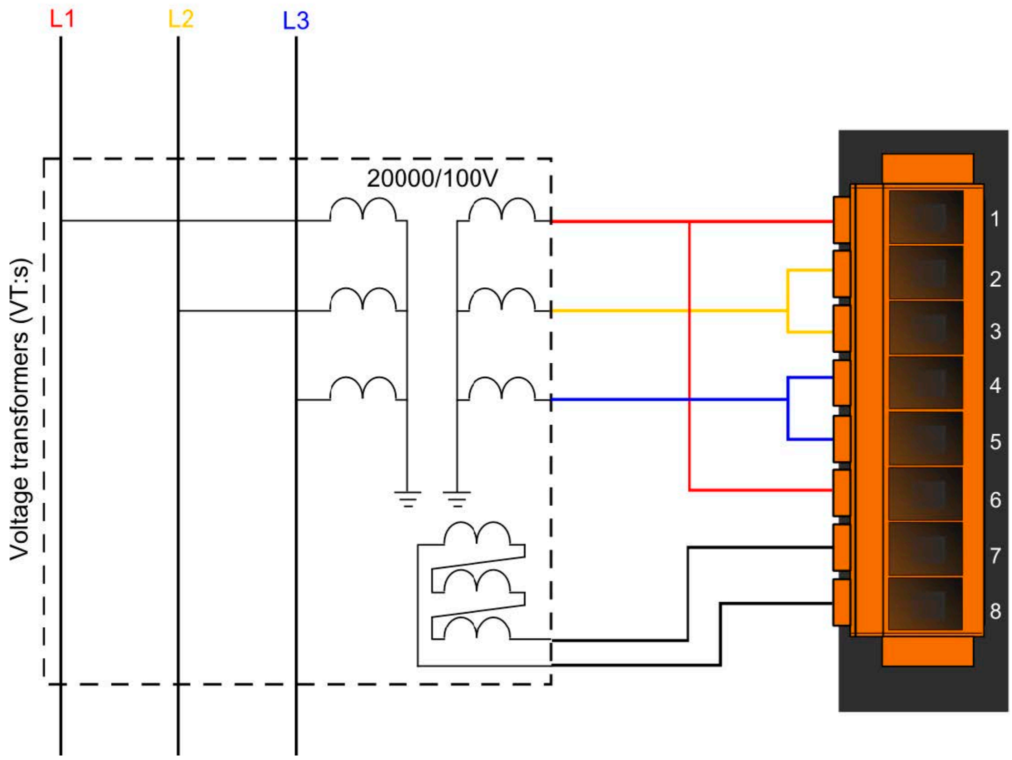
Figure. 6.2.2 - 35. Phase to neutral connection. Connection U1-3.



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

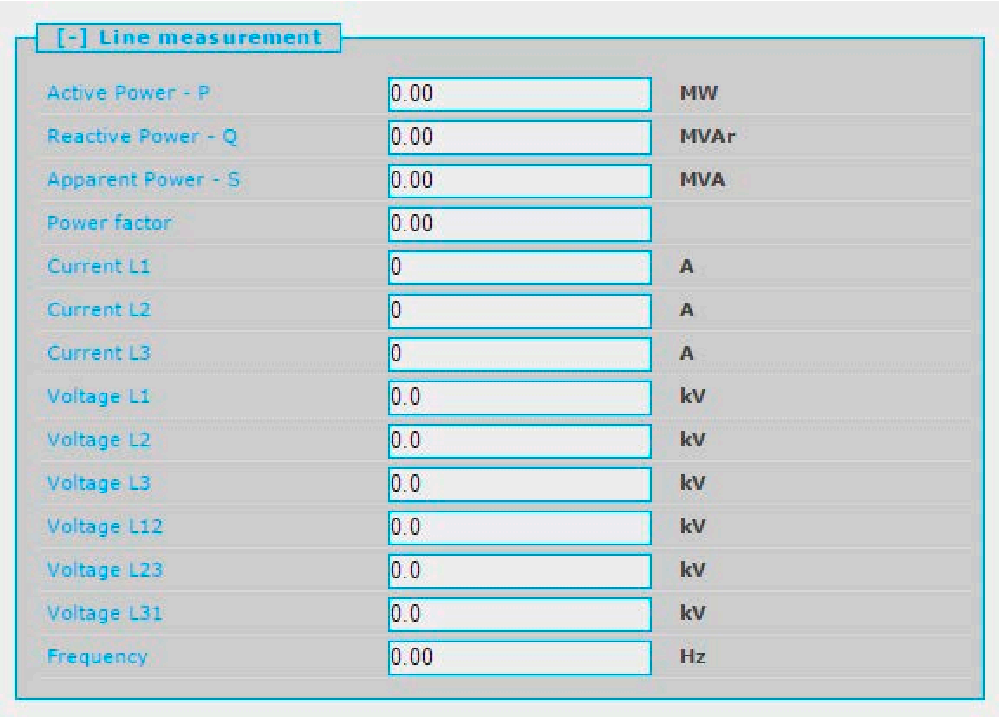
The measured values of the line measurement function depend on the hardware configuration. As an example, table shows the list of the measured values available in a configuration for solidly grounded networks.

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.

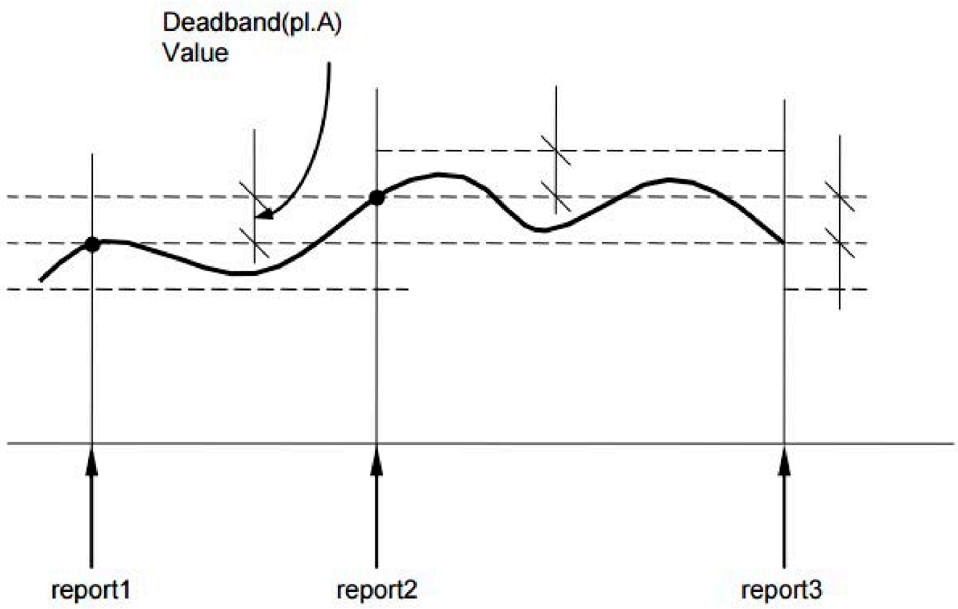
Parameter name	Title	Selection range	Default
Selection of the reporting mode for active power measurement			
MXU_PRepMode_EPar_	Operation ActivePower	Off, Amplitude, Integrated	Amplitude
Selection of the reporting mode for reactive power measurement			
MXU_QRepMode_EPar_	Operation ReactivePower	Off, 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.

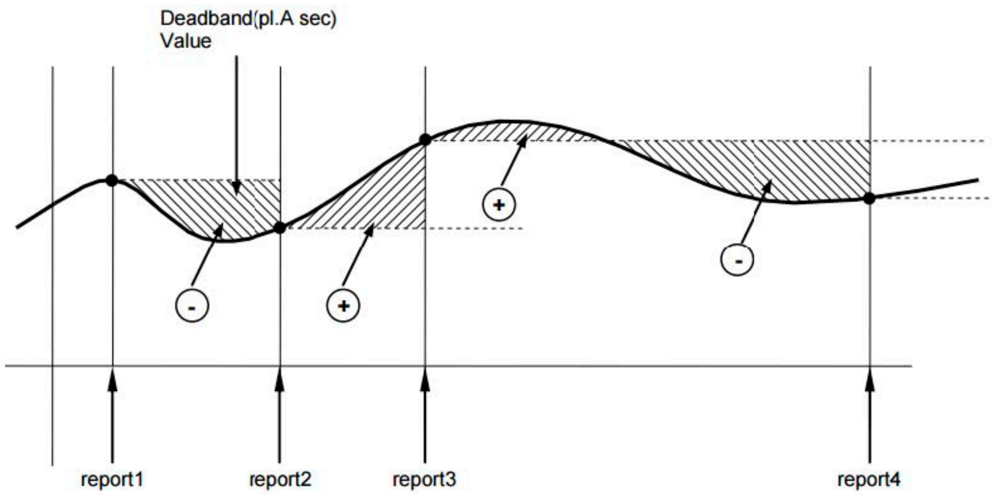
Parameter name	Title	Dim.	Min	Max	Step	Default
Deadband value for the active power						
MXU_PDeadB_FPar_	Deadband value - P	MW	0.1	100000	0.01	10
Range value for the active power						
MXU_PRange_FPar_	Range value - P	MW	1	100000	0.01	500
Deadband value for the reactive power						
MXU_QDeadB_FPar_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

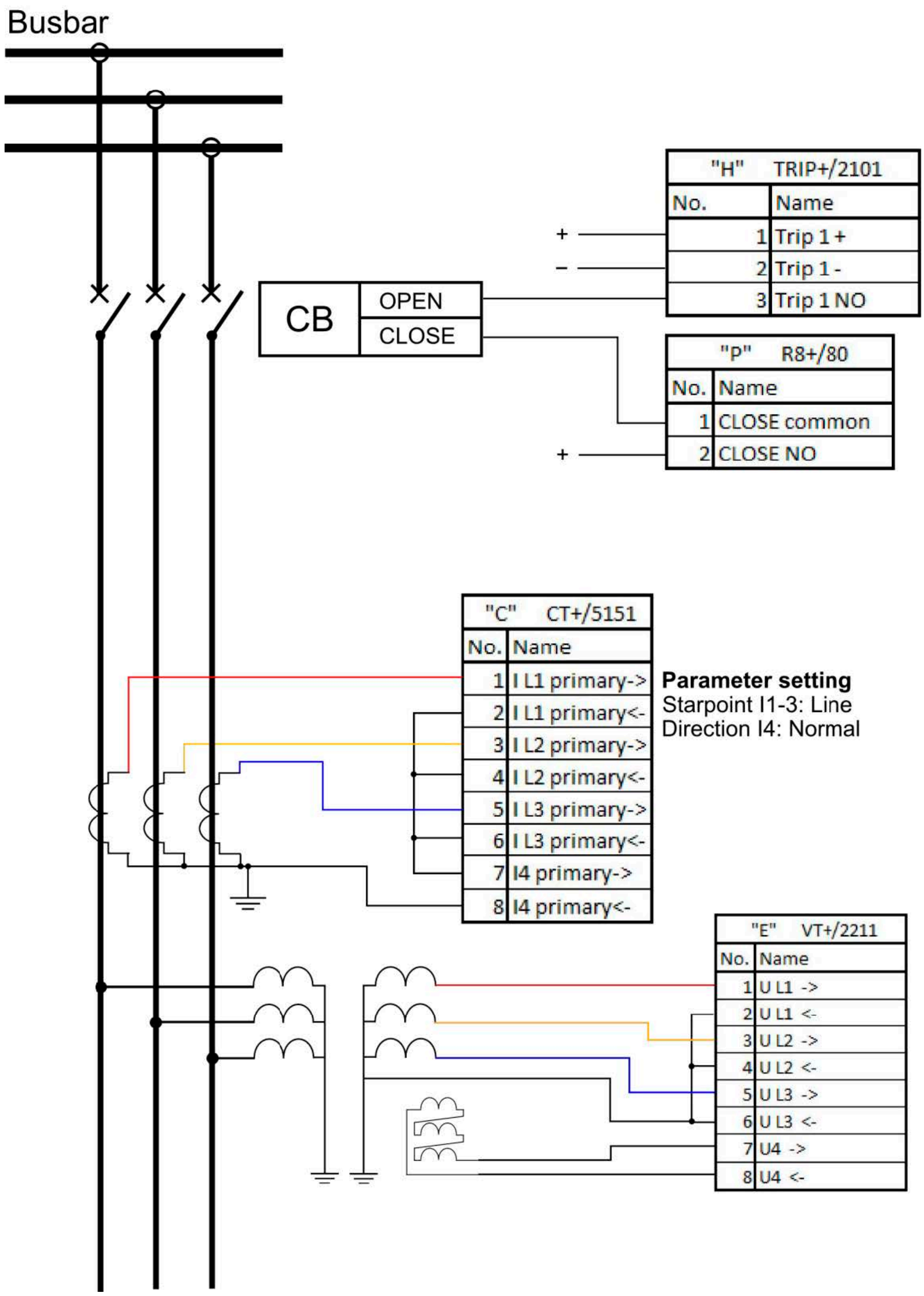
Parameter name	Title	Dim.	Min	Max	Step	Default
Deadband value for the phase-to-neutral voltage						
MXU_UPhDeadB_FPar_	Deadband value - U ph-N	kV	0.1	100	0.01	1
Range value for the phase-to-neutral voltage						
MXU_UPhRange_FPar_	Range value - U ph-N	kV	1	1000	0.1	231
Deadband value for the phase-to-phase 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”.

6.2.4 Measurement connection examples

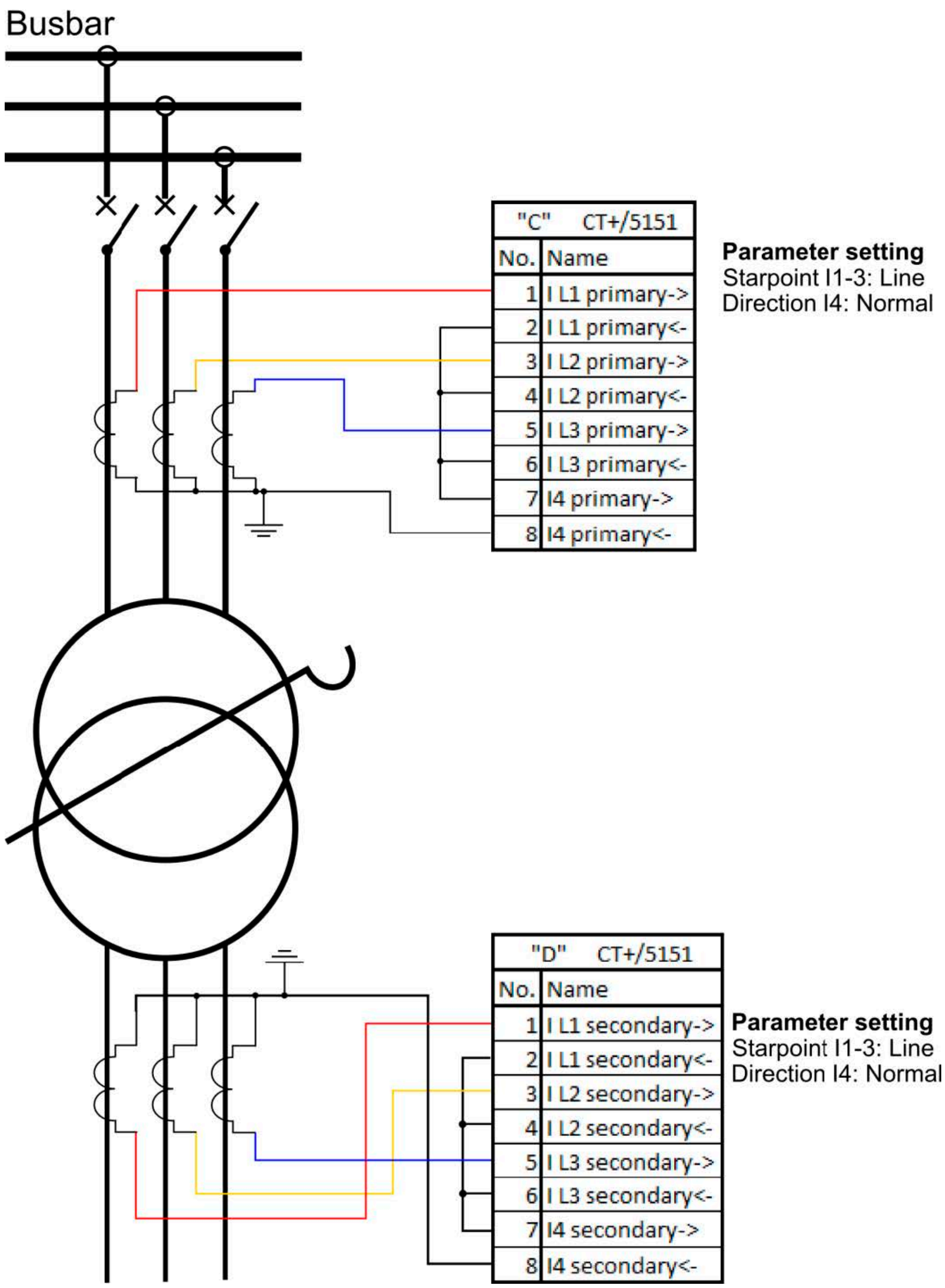
Connection example with a current breaker

Figure. 6.2.4 - 40. Connection example with a current breaker (open and closed connections, CT and VT connection).



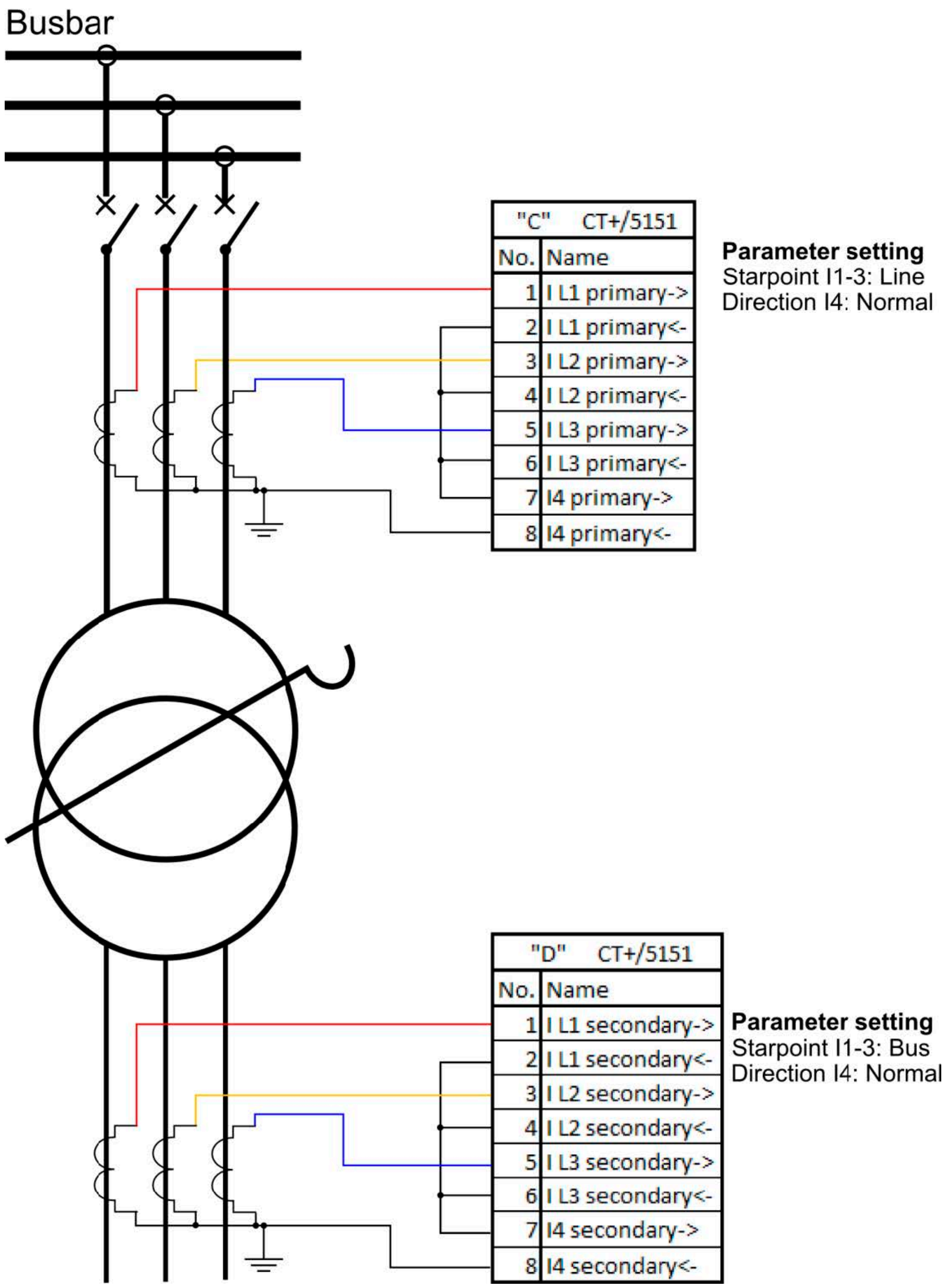
Connection example with two CTs (facing)

Figure. 6.2.4 - 41. Connection example with two CTs facing each other.



Connection example with two CTs (inverted secondary)

Figure. 6.2.4 - 42. Connection example with two CTs (the direction of the secondary side's starpoint has been inverted).

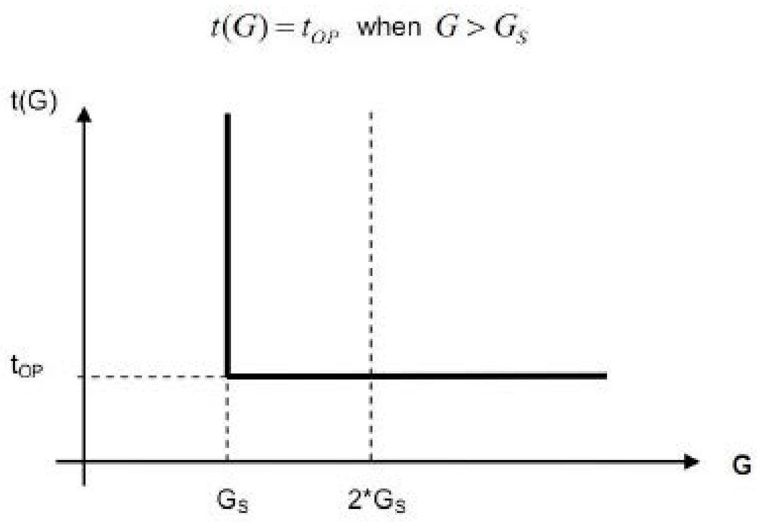


6.3 Protection functions

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 - 43. Operating characteristics of the instantaneous overcurrent protection function.



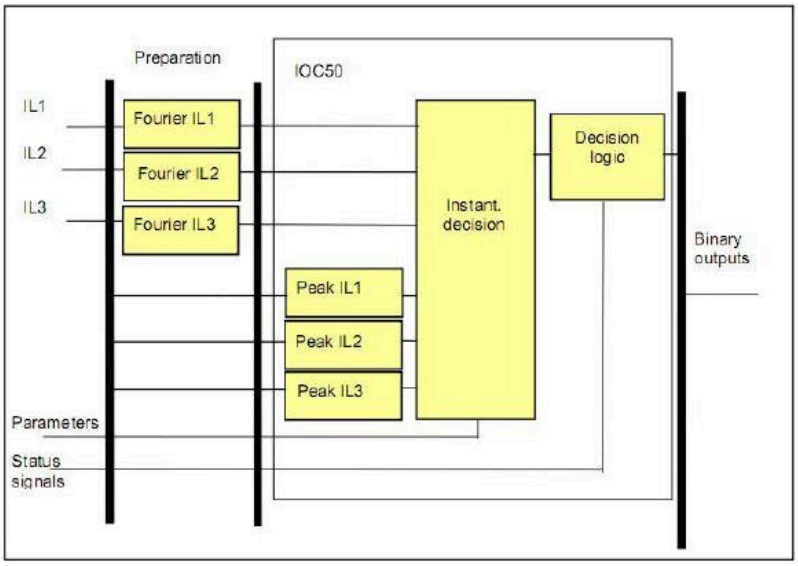
The variables in the image above are:

- 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 - 44. 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.

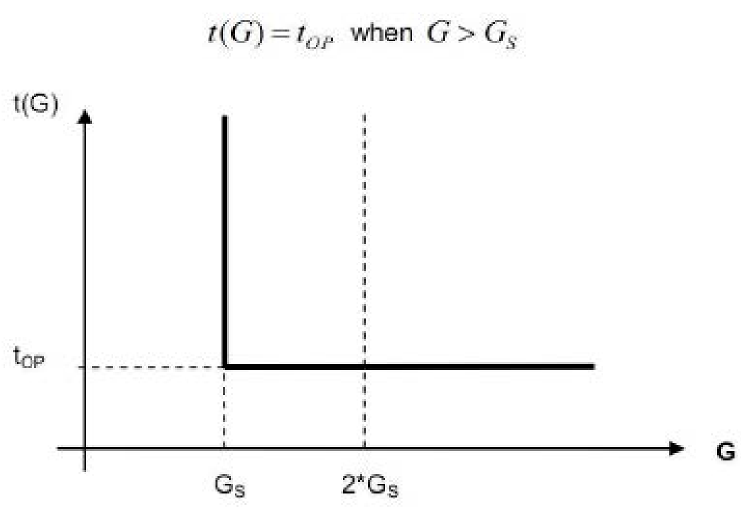
Table. 6.3.1 - 24. Setting parameters of the instantaneous overcurrent protection function.

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 - 45. Operating characteristics of the residual instantaneous overcurrent protection function.



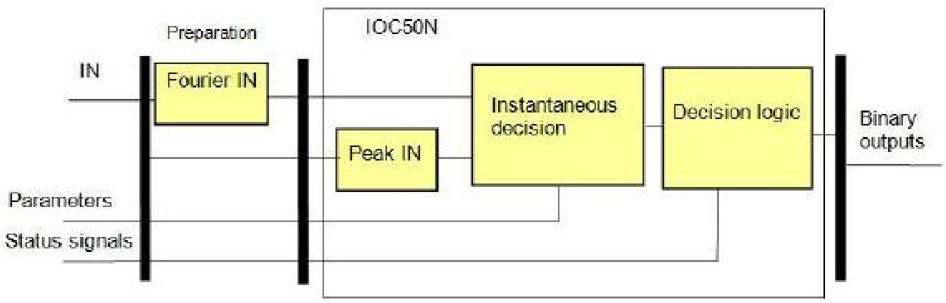
The variables in the image above are:

- 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 - 46. 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.

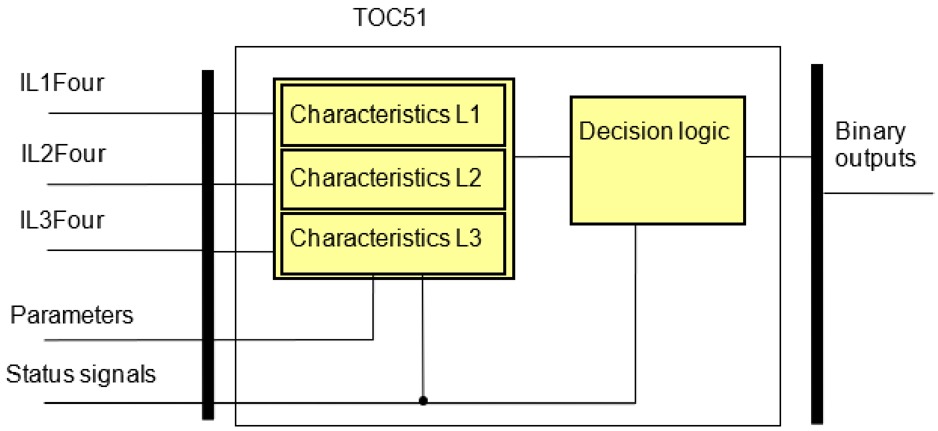
6.3.3 Three-phase time overcurrent protection (I>; 50/51)

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 - 47. The structure of the time overcurrent algorithm.



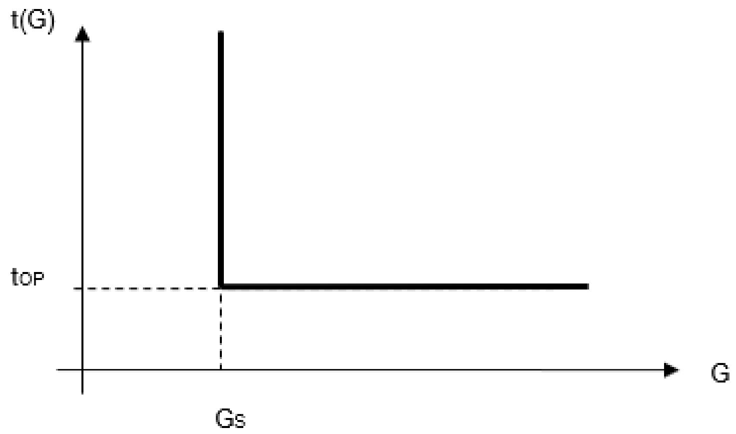
The algorithm generates a start signal based on the Fourier components of the phase currents or peak values of the phase currents in case if the user set pick-up value is exceeded. Trip signal is generated based into the selected definite time- or IDMT additional time delay is passed from the start conditions. 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 - 48. Operating characteristics of the instantaneous overcurrent protection function.

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



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

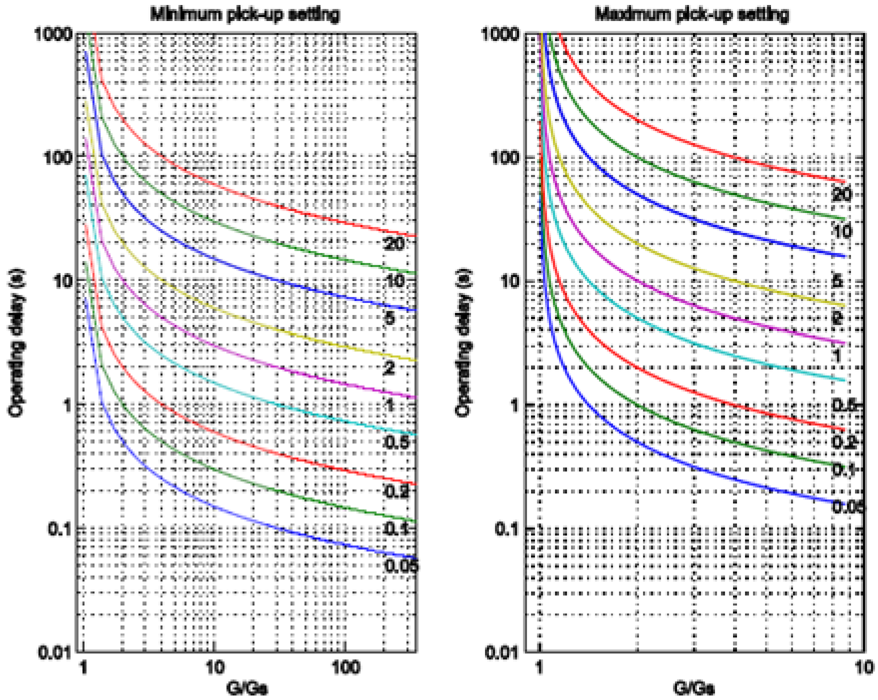


Figure. 6.3.3 - 50. IEC - VI operating curves with minimum and maximum pick-up settings and TMS settings from 0.05 to 20.

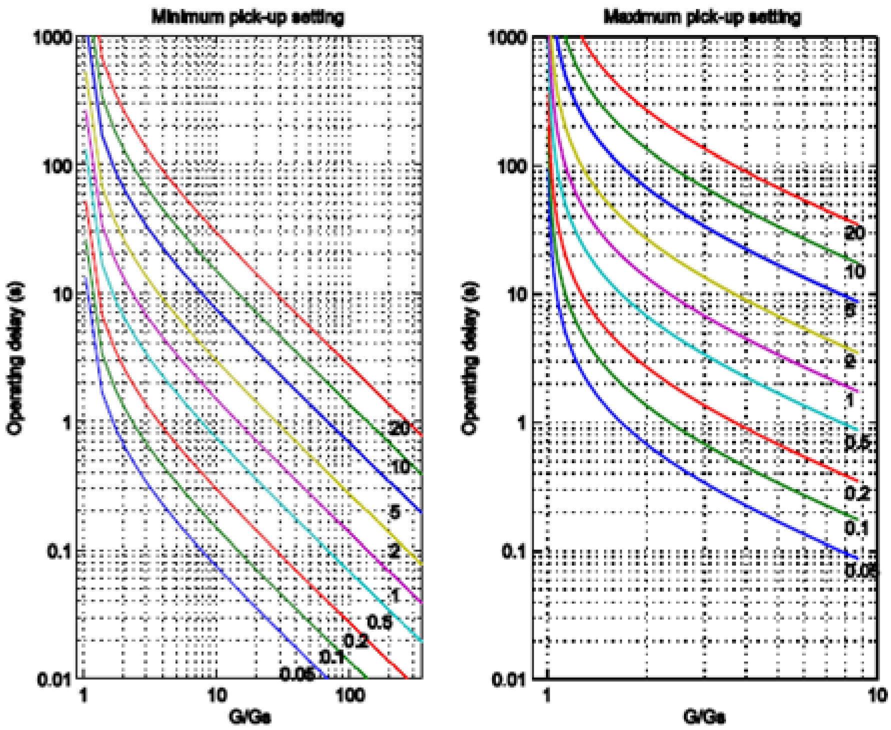


Figure. 6.3.3 - 51. IEC - EI operating curves with minimum and maximum pick-up settings and TMS settings from 0.05 to 20.

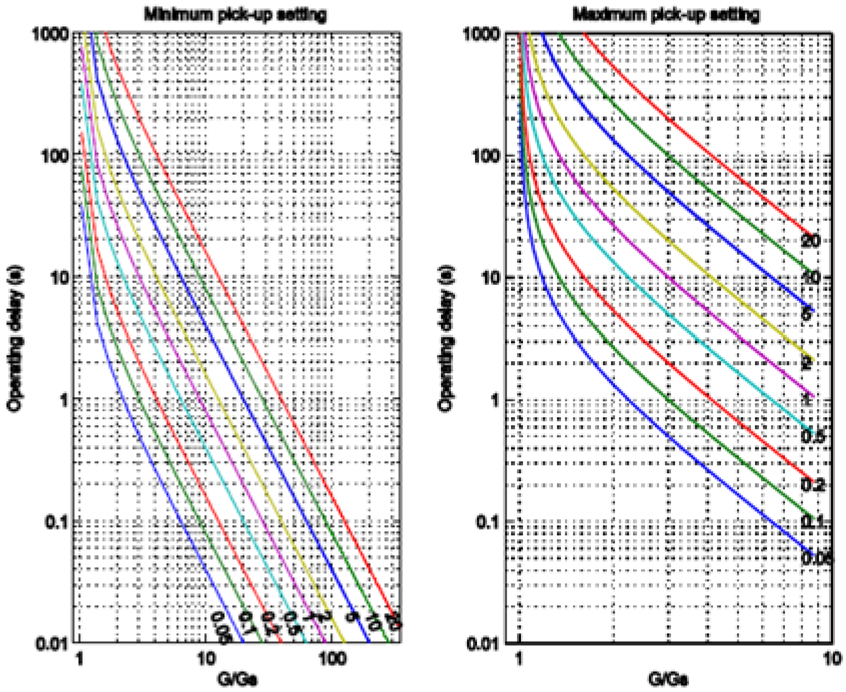


Figure. 6.3.3 - 52. IEC - LTI operating curves with minimum and maximum pick-up settings and TMS settings from 0.05 to 20.

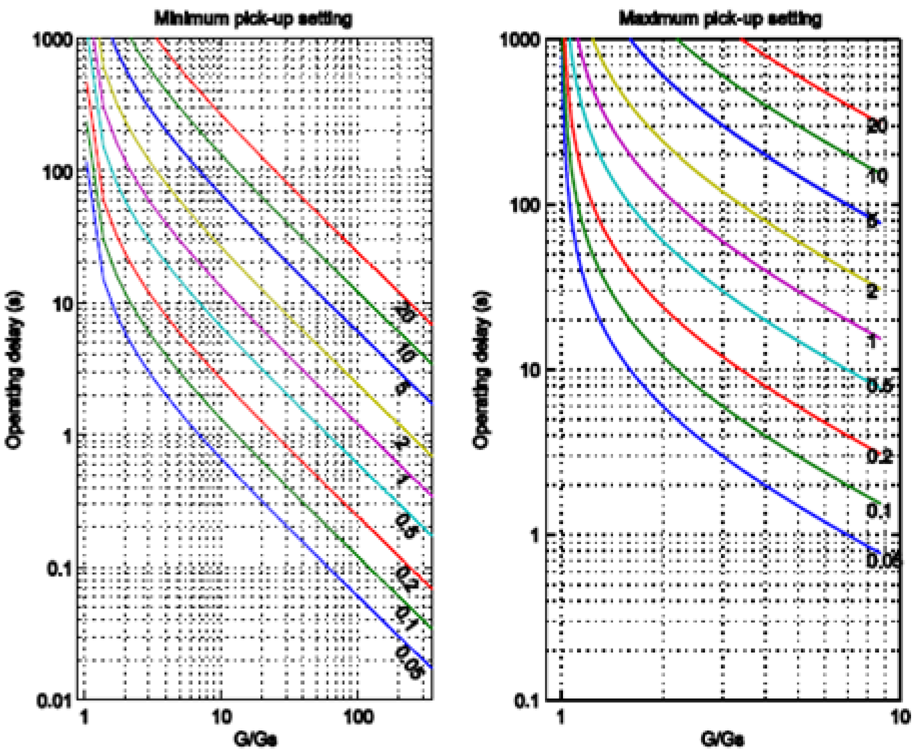


Figure. 6.3.3 - 53. IEEE/ANSI - NI operating curves with minimum and maximum pick-up settings and TMS settings from 0.05 to 20.

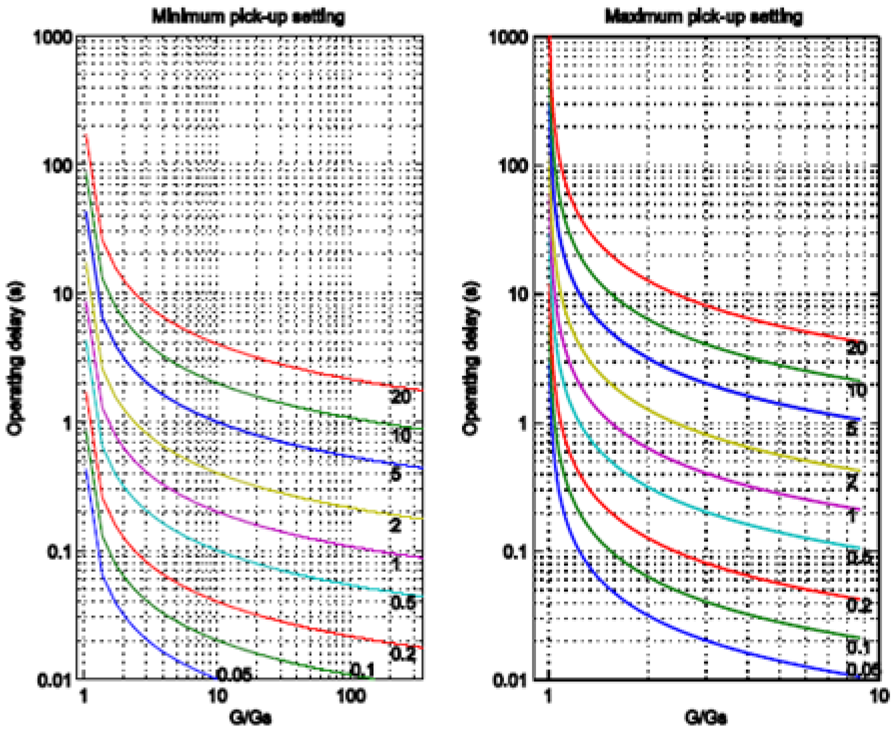


Figure. 6.3.3 - 54. IEEE/ANSI - MI operating curves with minimum and maximum pick-up settings and TMS settings from 0.05 to 20.

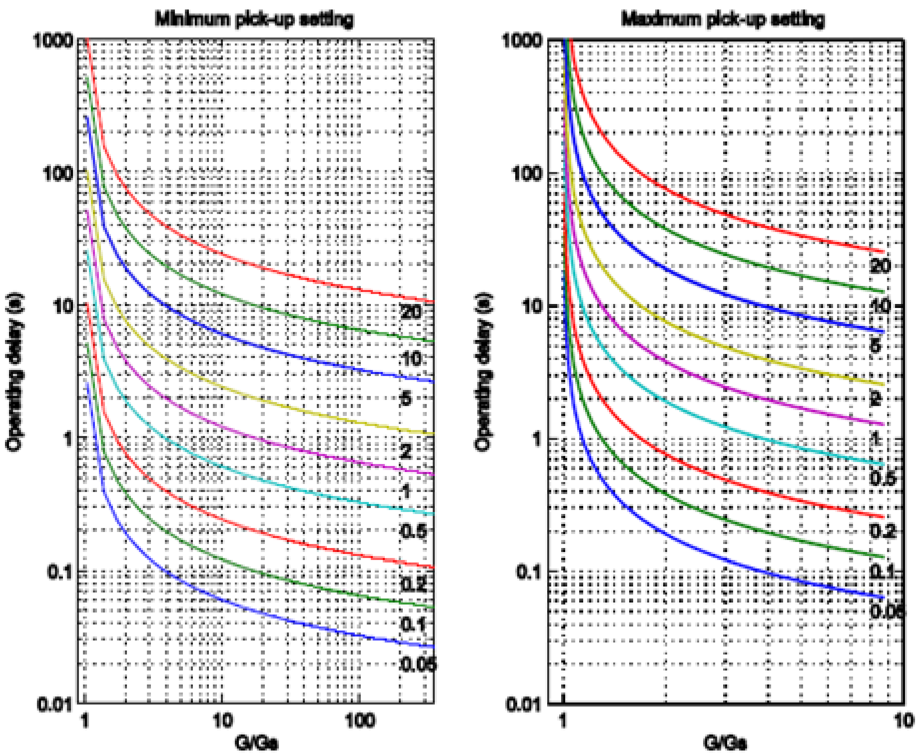


Figure. 6.3.3 - 55. IEEE/ANSI - VI operating curves with minimum and maximum pick-up settings and TMS settings from 0.05 to 20.

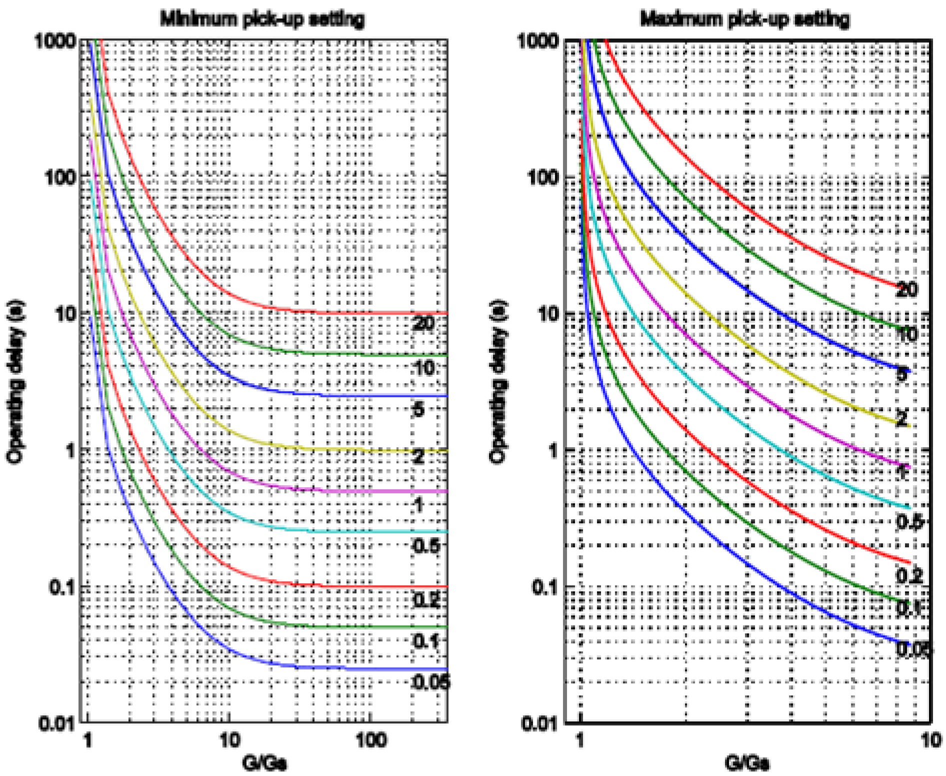


Figure. 6.3.3 - 56. IEEE/ANSI - EI operating curves with minimum and maximum pick-up settings and TMS settings from 0.05 to 20.

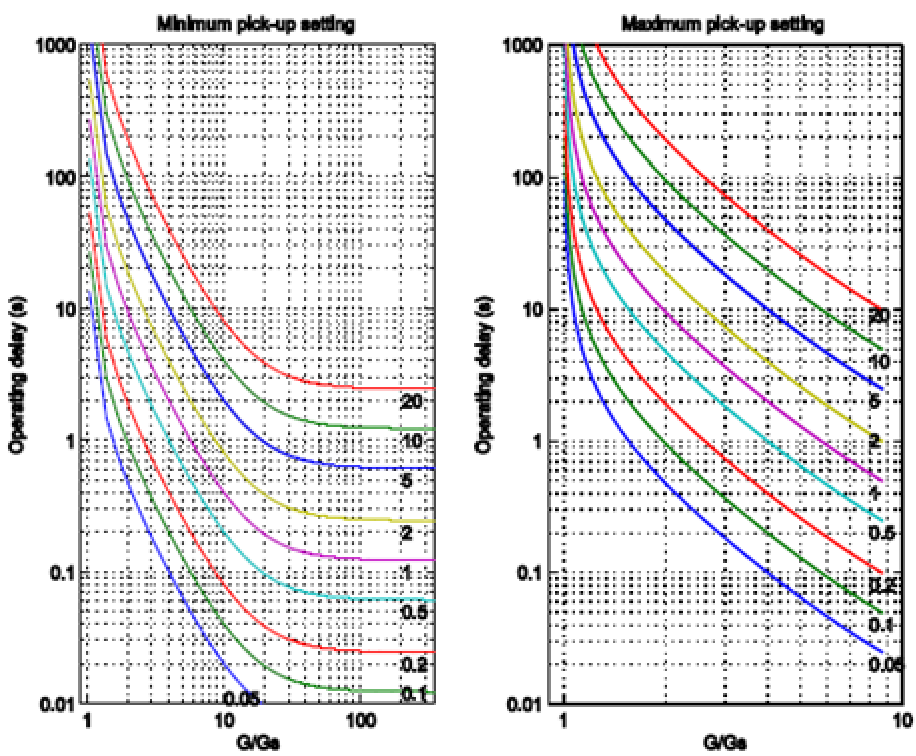


Figure. 6.3.3 - 57. IEEE/ANSI - LTI operating curves with minimum and maximum pick-up settings and TMS settings from 0.05 to 20.

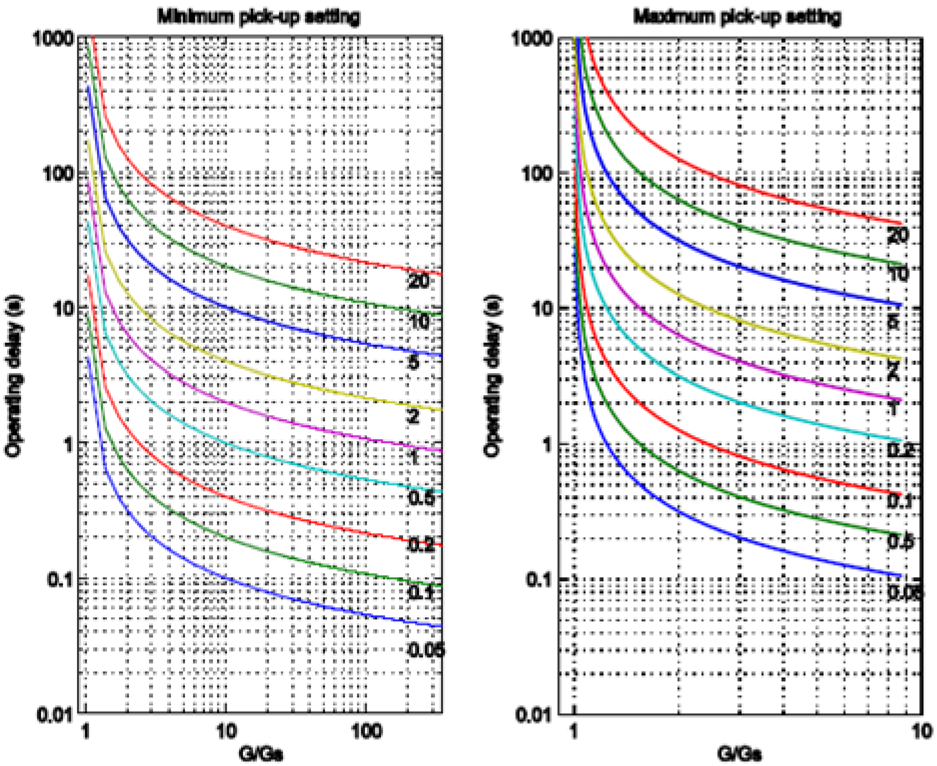


Figure. 6.3.3 - 58. IEEE/ANSI - LTVI operating curves with minimum and maximum pick-up settings and TMS settings from 0.05 to 20.

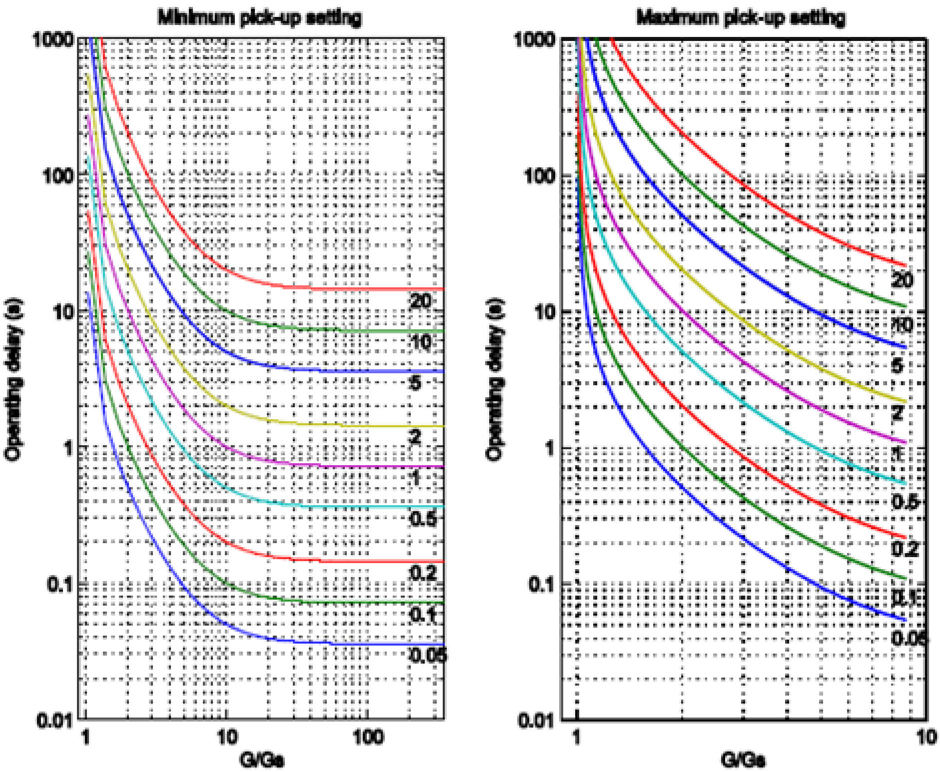
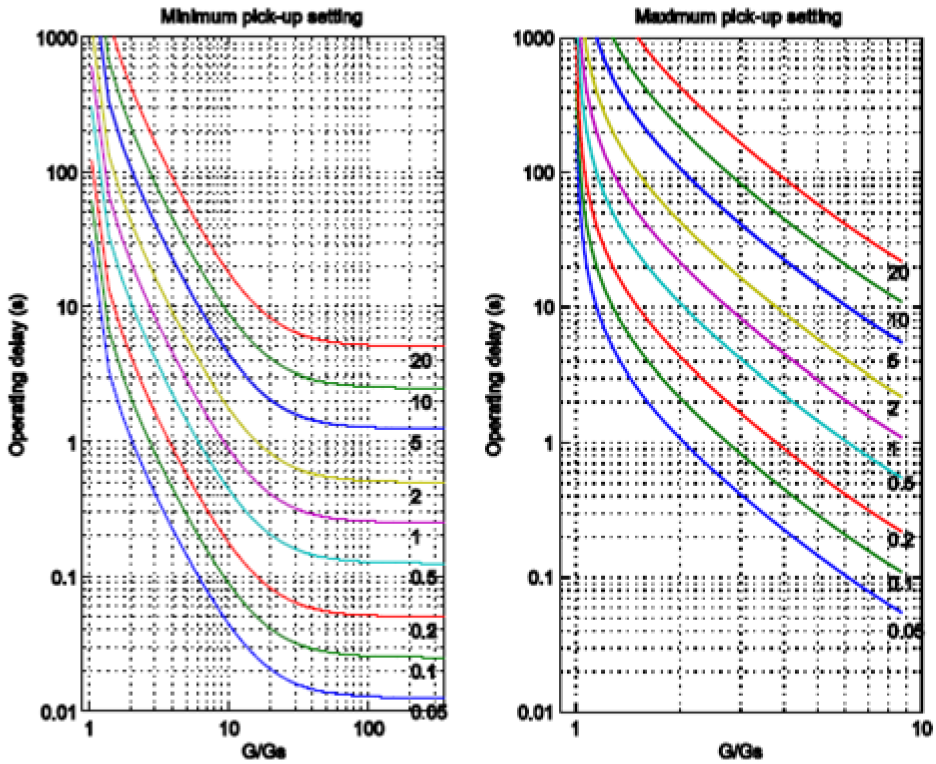


Figure. 6.3.3 - 59. IEEE/ANSI - LTEI operating curves with minimum and maximum pick-up settings and TMS settings from 0.05 to 20.



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 - 60. Resetting characteristics for ANSI/IEEE IDMT.

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

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.

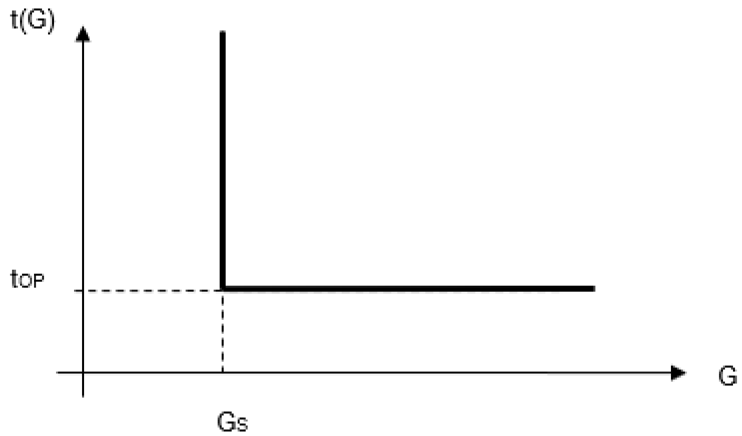
Parameter	Setting value / range	Step	Default	Description
Operation	Off DefinitTime IEC Inv IEC VeryInv IEC ExtInv IEC LongInv ANSI Inv ANSI ModInv ANSI VeryInv ANSI ExtInv ANSI LongInv ANSI LongVeryInv ANSI LongExtInv	-	DefinitTime	Operating mode selection of the function. Can be disabled, Definite time 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.

Parameter	Setting value / range	Step	Default	Description
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.

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



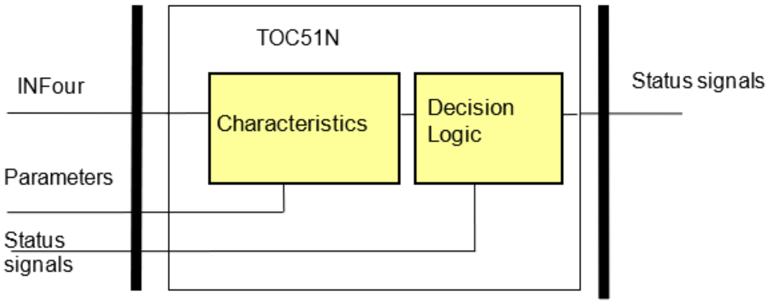
The variables in the image above are:

- 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 - 61. 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.

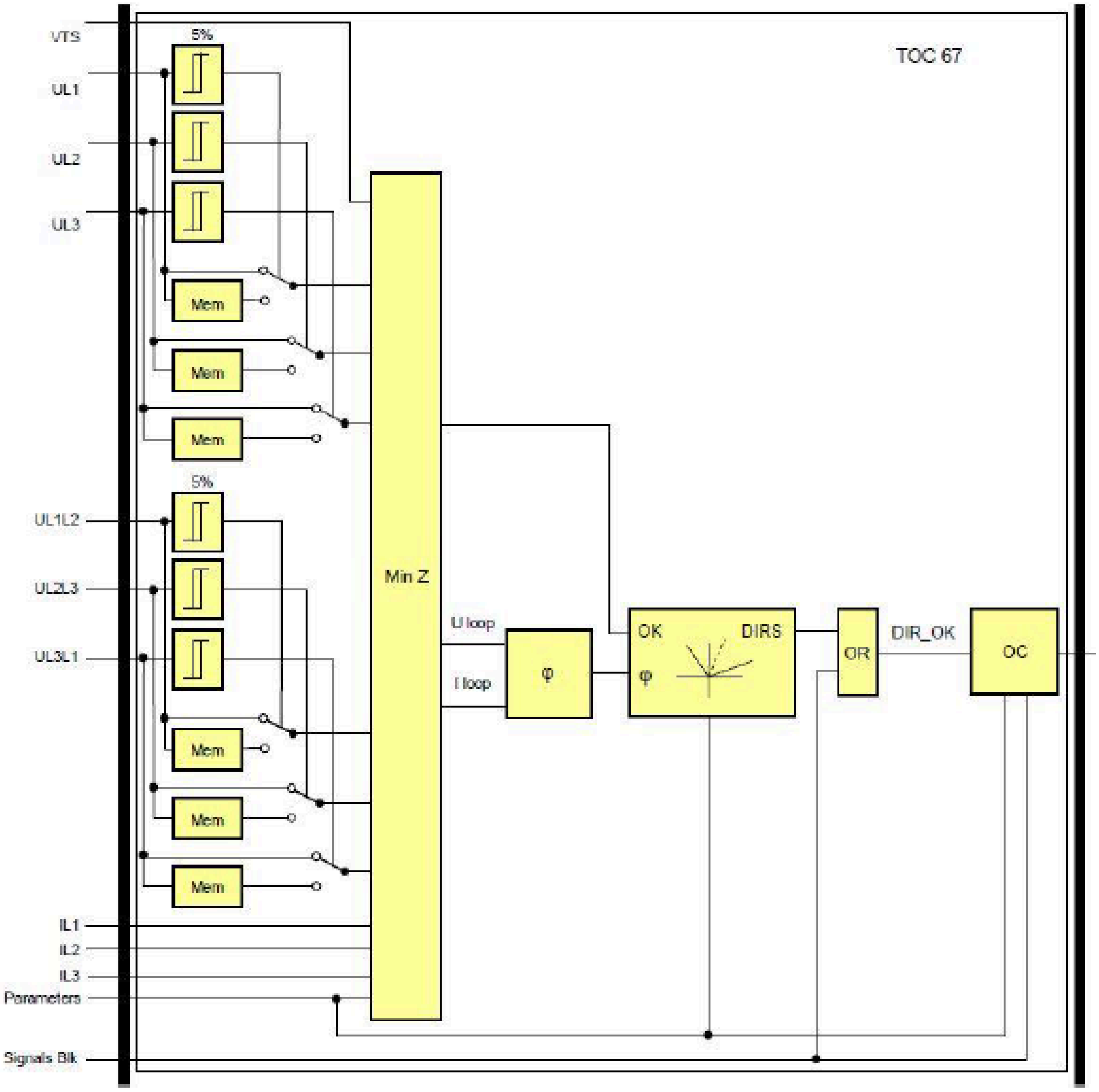
Table. 6.3.4 - 29. Setting parameters of the residual time overcurrent function.

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)

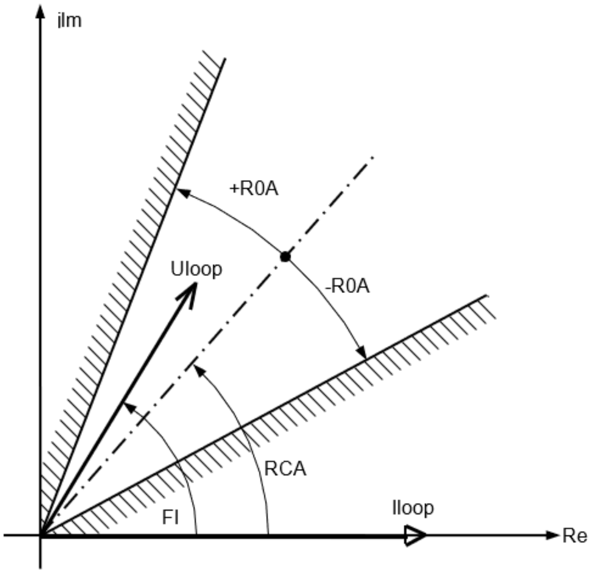
The directional three-phase overcurrent protection function can be applied on networks where the overcurrent protection must be supplemented with a directional decision. The inputs of the function are the Fourier basic harmonic components of the three phase currents and those of the three phase voltages.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

Figure. 6.3.5 - 62. 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 - 63. 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.

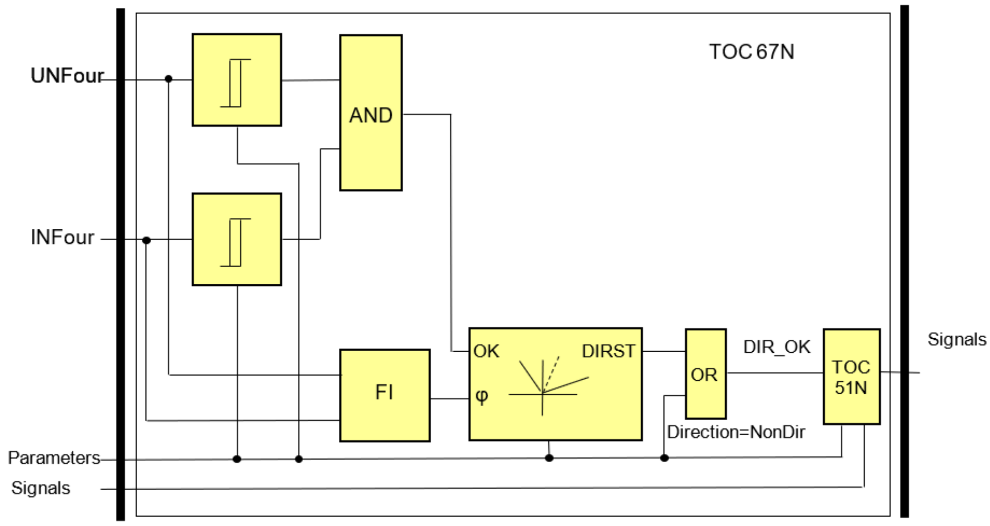
Parameter	Setting value / range	Step	Default	Description
Operation	Off DefinitTime IEC Inv IEC VeryInv IEC ExtInv IEC LongInv ANSI Inv ANSI ModInv ANSI VeryInv ANSI ExtInv ANSI LongInv ANSI LongVeryInv ANSI LongExtInv	-	DefinitTime	Operating mode selection of the function. Can be disabled, Definite time 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.

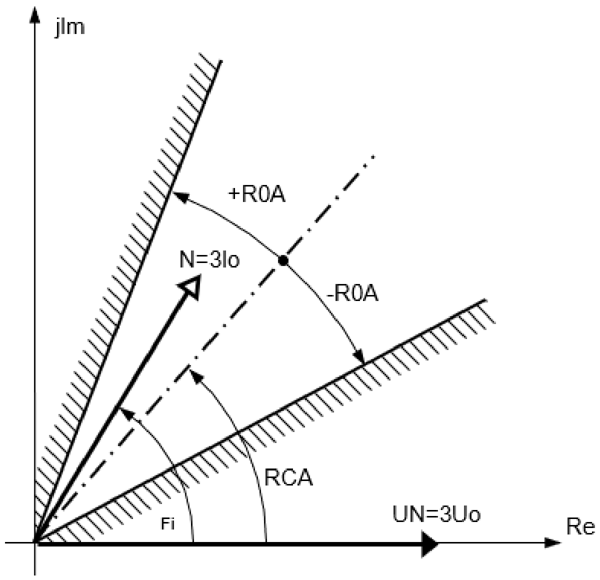
The inputs of the function are the Fourier basic harmonic components of the zero sequence current and those of the zero sequence voltage. In the figure below is presented the structure of the residual directional overcurrent algorithm.

Figure. 6.3.6 - 64. The structure of the residual directional overcurrent protection algorithm.



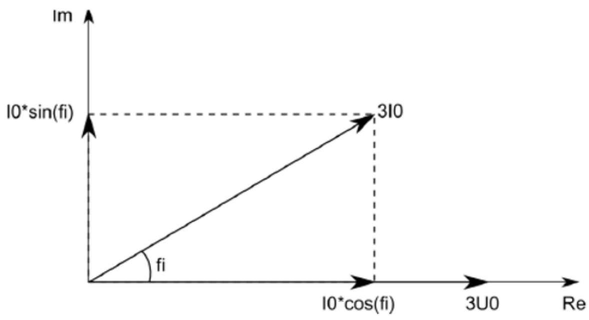
The block of the directional decision generates a signal of TRUE value if the UN=3Uo zero sequence voltage and the IN=-3Io current is sufficient for directional decision, and the angle difference between the vectors is within the preset range. This decision enables the output start and trip signal of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

Figure. 6.3.6 - 65. 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 - 66. 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 Voltage-dependent overcurrent protection (Iv>; 51V)

When overcurrent protection function is applied and the current in normal operation can be high, related to the lowest fault current then the correct setting is not possible based on current values only. In this case however, if the voltage during fault is considerably below the lowest voltage during operation then the voltage can be applied to distinguish between faulty state and normal operating state. This is the application area of the voltage dependent overcurrent protection function.

The function has two modes of operation, depending on the parameter setting:

- Voltage restrained
- Voltage controlled.

The overcurrent protection function realizes definite time characteristic based on three phase currents. The operation is restrained or controlled by three phase voltages. The function operates in three phases individually, but the generated general start signal and the general trip command is the OR relationship of the three decisions.

The function can be blocked by a user-defined signal or by the voltage transformer supervision function block, if the measured voltage is not available. This function can be applied as main protection for medium-voltage applications or generator overcurrent protection.

The function is basically a definite time overcurrent protection function, but the current threshold is influenced by the measured voltage. The function has two modes of operation, depending on the parameter setting:

- Voltage restrained (parameters “Restr. Mode” is set to “Restrained”)
- Voltage controlled (parameter “Restr. Mode” is set to “Controlled”).

Characteristics

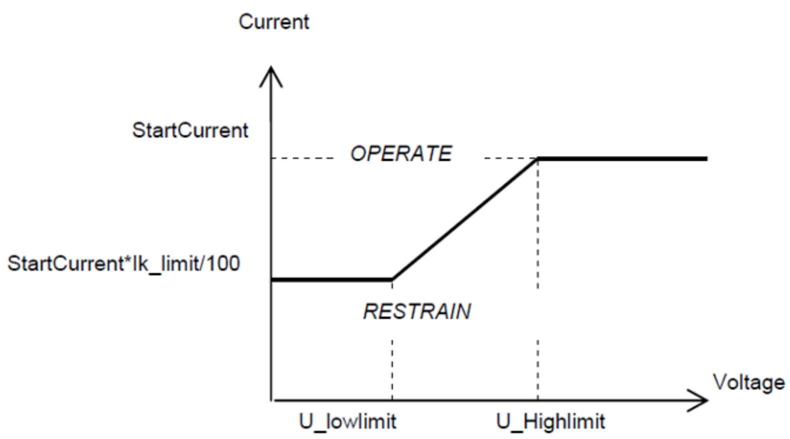
<u>Voltage restraint characteristics</u>

In this case the algorithm dynamically changes the threshold value of the current, based on the measured phase voltages:

- Above the “U_Highlimit” value then the function operates if the current is above the “StartCurrent” value.
- If the voltage is below the “U_lowlimit” value then the characteristic is lowered automatically to the “StartCurrent*Ik_limit/100.
- Between the two setting values the threshold value is increasing along a straight line.

The voltage restrained characteristic is shown in figure below.

Figure. 6.3.7 - 67. Voltage restraint characteristics.

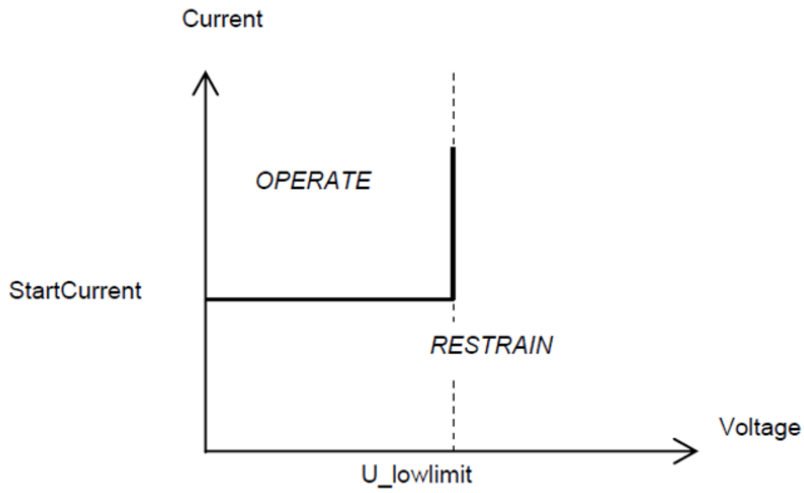


<u>Voltage controlled characteristics</u>

In this case the overcurrent protection operates only if the voltage is below the “U_lowlimit” value and the current is above the “SatrtCurrent” value. (No operation is expected if the voltage is above the U_lowlimit” value.)

The threshold current is the constant “StartCurrent” value. The voltage controlled characteristic is shown in figure below.

Figure. 6.3.7 - 68. Voltage controlled characteristics.



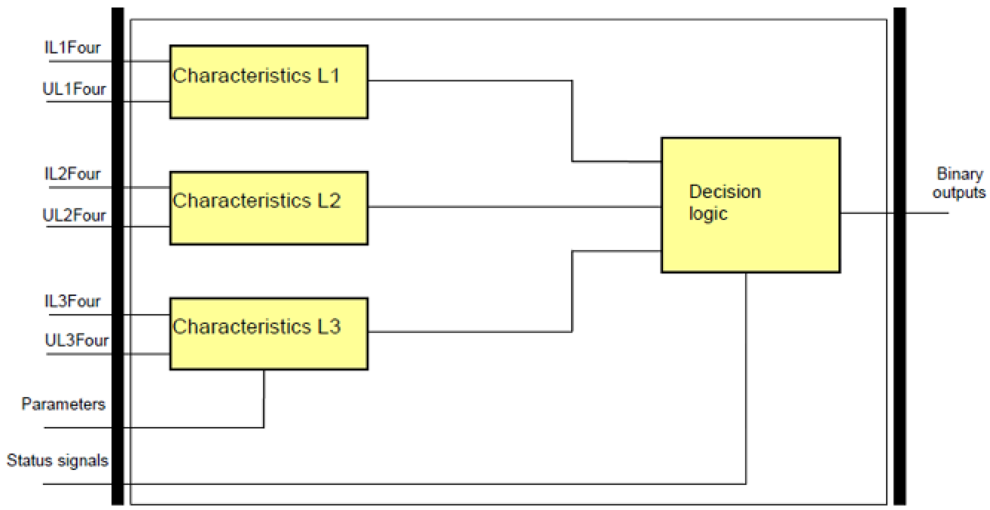
Definite time characteristics

The threshold value set dynamically according to the voltage restrained characteristic or set to constant value according to the voltage controlled characteristic. If the voltage-current point is in the "operate" range the definite time delay is calculated according to the timer setting "Time Delay".

Structure of the protection algorithm

Figure below describes the structure of voltage dependent overcurrent function.

Figure. 6.3.7 - 69. Structure of the voltage-dependent overcurrent protection algorithm.



The inputs are

- The RMS value of the fundamental Fourier component of three phase currents,
- The RMS value of the fundamental Fourier component of three phase voltages,
- Parameters,
- Status signals.

The outputs are

- The binary output status signals

The software modules of the voltage dependent overcurrent protection function:

Characteristics

This module

- Calculates the current threshold value based on the Fourier components of the phase voltages;
- Calculates required time delay based on the Fourier components of the phase currents;
- Decides the generation of the starting signal in the individual phases;
- Decides the generation of the trip command in the individual phases.

Decision logic

The decision logic module combines the status signals to generate the trip command of the function.The signals and commands are generated only if neither the general blocking signal nor the blocking signal of the voltage transformer supervision function stops the operation.The general start signal indicates the starting in any of the phases, the general trip command is generated if the current in any of the phases is above the calculated threshold value and the time delay expired.

Figure. 6.3.7 - 70. The function block of the voltage-dependent overcurrent protection function.

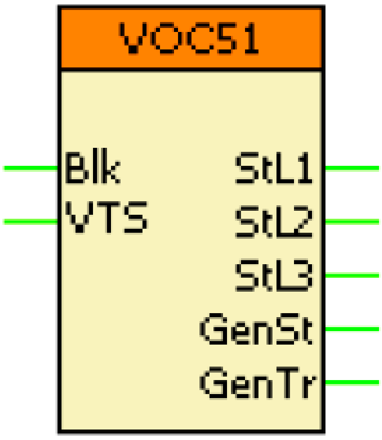


Table. 6.3.7 - 32. The binary input and output signals of the function.

Binary I/O signal	Signal title	Explanation
VOC51_StL1_GrI_	Start L1	Starting of the function in phase L1
VOC51_StL2_GrI_	Start L2	Starting of the function in phase L2
VOC51_StL3_GrI_	Start L3	Starting of the function in phase L3
VOC51_GenSt_GrI_	General Start	Starting of the function
VOC51_GenTr_GrI_	General Trip	Trip command of the function

Binary I/O signal	Signal title	Explanation
VOC51_Blk_GrO_	-	Output status defined by the user to disable the overcurrent protection function.
VOV51_VTS_GrO_	-	Output status defined by the user to disable the overcurrent protection function if the voltage transformer supervision block detects failure in the voltage measurement.

Table. 6.3.7 - 33. Parameters of the voltage-restrained overcurrent.

Parameter	Setting value / range	Step	Default	Description
Operation	Off On	-	On	Operating mode selection of the function.
Voltage mode	Restrained Controlled	-	Restrained	Voltage mode selection of the function.
Start current	20…3 000 %In	1 %In	200 %In	Pick-up setting of the function.
$U_{highlimit}$	60…110 %	1 %	-	In "Voltage controlled" mode the function is enabled only when the voltage is below "$U_{highlimit}$" level. In "Voltage restrained" mode the overcurrent pickup (and drop off) setting value is multiplied by the $k=U_{actual}/U_{nominal}$ factor when the voltage is within the $U_{highlimit}$–$U_{lowlimit}$ range. When the voltage is below $U_{highlimit}$ the current setting slope is linearized by parameters $U_{lowlimit}$ and $I_{lowlimit}$.
$U_{lowlimit}$	20…60 %	1 %	-	Lower voltage range of the current setting slope k.
$I_{lowlimit}$	20…60 %	1 %	-	Current setting slope k startpoint.

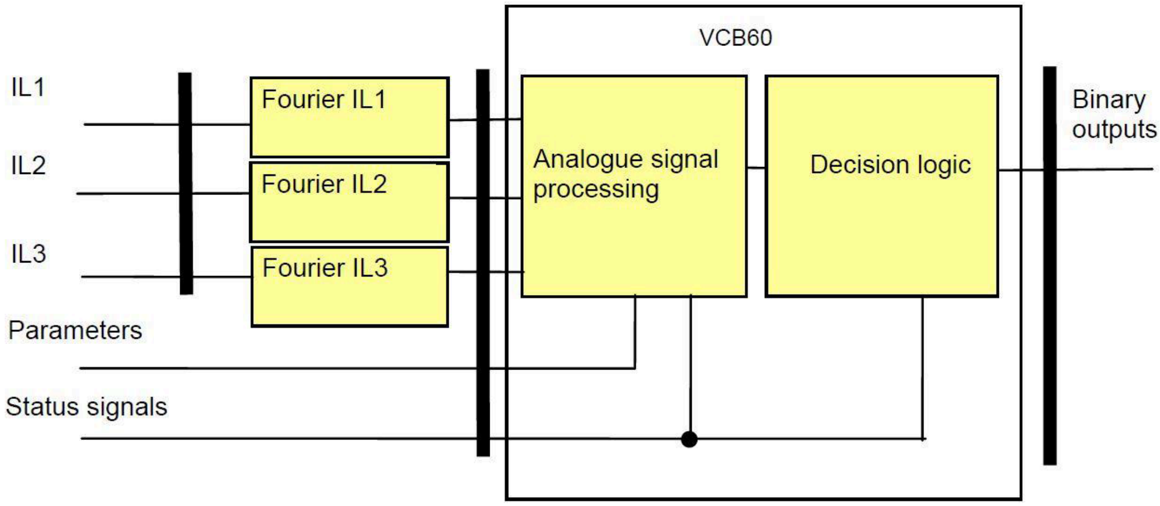
6.3.8 Current unbalance protection (60)

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.

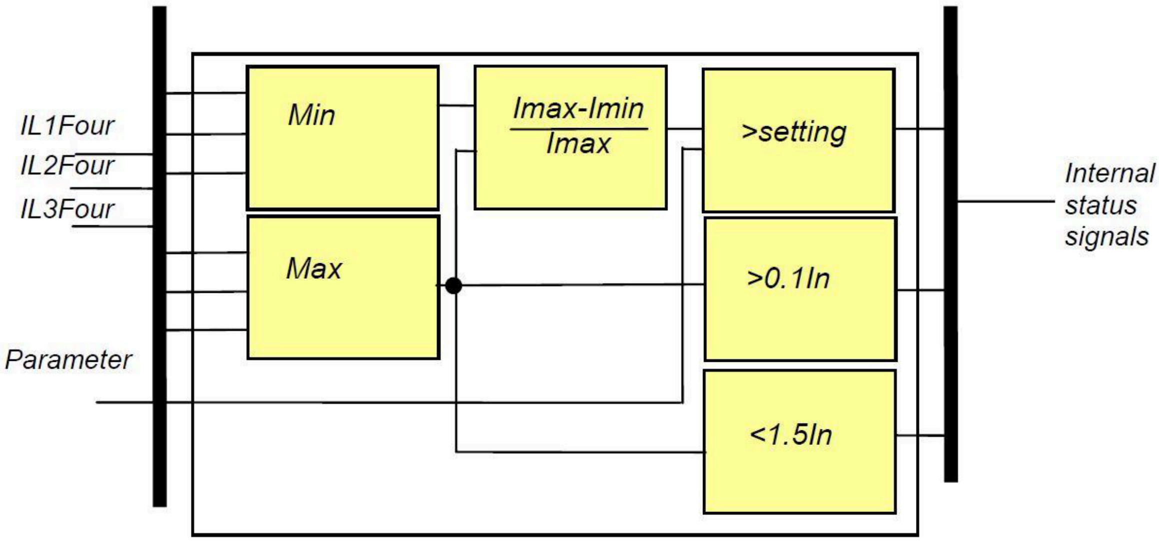
Structure of the current unbalance protection function is presented in the figure below

Figure. 6.3.8 - 71. The structure of the current unbalance protection algorithm.



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

Figure. 6.3.8 - 72. 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. 6.3.8 - 34. 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.

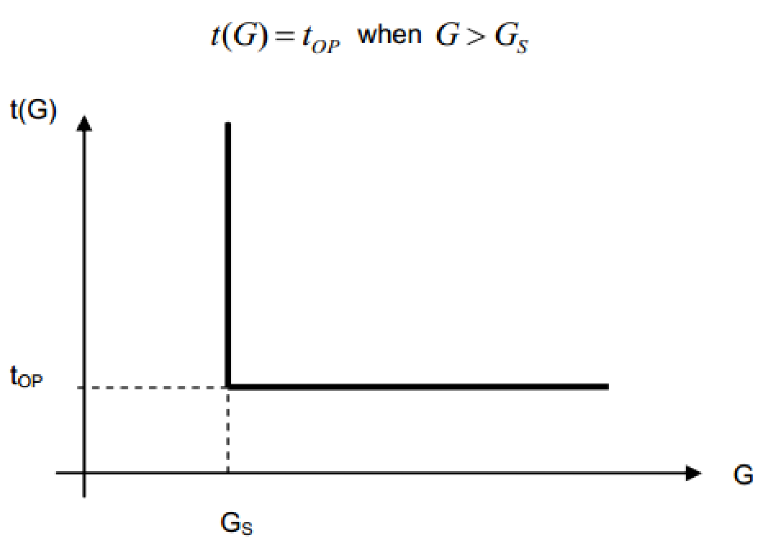
6.3.9 Negative sequence overcurrent protection (46)

The negative sequence overcurrent protection function (TOC46) block operates if the negative sequence current is higher than the preset starting value.

In the negative sequence overcurrent protection function, definite-time or inverse-time characteristics are implemented, according to IEC or IEEE standards. The function evaluates a single measured current, which is the RMS value of the fundamental Fourier component of the negative sequence current. The characteristics are harmonized with IEC 60255-151, Edition 1.0, 2009-08.

Definite time characteristics

Figure. 6.3.9 - 73. Overcurrent definite time characteristic.



The variables in the diagram above are:

- t_{OP} (seconds) = theoretical operating time if $G>G_S$, fix, according to the preset parameter
- G = measured value of the characteristic quantity, Fourier base harmonic of the negative sequence current
- G_S = preset starting value of the characteristic quantity (TOC46_StCurr_IPar_, Start current).

Standard dependent time characteristics

Operating characteristics

Figure. 6.3.9 - 74. Standard dependent time characteristics.

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

The variables in the diagram above are:

- t(G) (seconds) = theoretical operate time with constant value of G
- k, c = constants characterizing the selected curve (in seconds)
- α = constants characterizing the selected curve (no dimension)
- G = measured value of the characteristic quantity, Fourier base harmonic of the negative sequence current (INFour)
- G_S = preset value of the characteristic quantity (TOC46_StCurr_IPar_, Start current)
- TMS = preset time multiplier (no dimension).

Table. 6.3.9 - 35. The constants of the standard dependent time characteristics.

	IEC ref		k_r	c	α
1	A	IEC Inv	0.14	0	0.02
2	B	IEC VeryInv	13.5	0	1
3	C	IEC ExtInv	80	0	2
4		IEC LongInv	120	0	1
5		ANSI Inv	0.0086	0.0185	0.02
6	D	ANSI ModInv	0.0515	0.1140	0.02
7	E	ANSI VeryInv	19.61	0.491	2
8	F	ANSI ExtInv	28.2	0.1217	2
9		ANSI LongInv	0.086	0.185	0.02
10		ANSI LongVeryInv	28.55	0.712	2
11		ANSI LongExtInv	64.07	0.250	2

The end of the effective range of the dependent time characteristics (G_D) is:

$G_D = 20*G_S$

Above this value the theoretical operating time is definite (when $G>G_D$):

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

The inverse characteristic is valid above GT = 1.1*G_S. Above this value the function is guaranteed to operate.

<u>Resetting characteristics</u>

Figure. 6.3.9 - 75. Resetting characteristics.

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

The variables in the diagram above are:

- t(G) (seconds) = theoretical reset time with constant value of G (when G<G_S)
- k_r = constants characterizing the selected curve (in seconds)
- α = constants characterizing the selected curve (no dimension)
- G = measured value of the characteristic quantity, Fourier base harmonic of the phase current
- G_S = preset starting value of the characteristic quantity (TOC51_StCurr_IPar_, Start current)
- TMS = preset time multiplier (no dimension).

Table. 6.3.9 - 36. The constants of the standard dependent time characteristics.

	IEC ref		k_r	α
1	A	IEC Inv	Resetting after fix time delay, according to preset parameter TOC46_Reset_TPar_ "Reset delay"	
2	B	IEC VeryInv		
3	C	IEC ExtInv		
4		IEC LongInv		
5		ANSI Inv	0.46	2
6	D	ANSI ModInv	4.85	2
7	E	ANSI VeryInv	21.6	2
8	F	ANSI ExtInv	29.1	2
9		ANSI LongInv	4.6	2
10		ANSI LongVeryInv	13.46	2

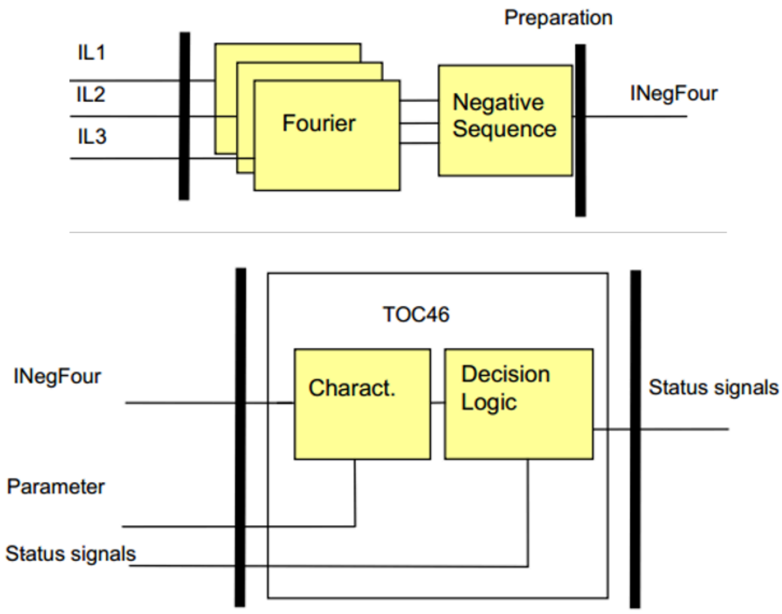
	IEC ref		k_r	α
11		ANSI LongExtInv	30	2

The inverse type characteristics are also combined with a minimum time delay, the value of which is set by user parameter TOC46_MinDel_TPar_ (Min. Time Delay)

Structure of the negative sequence overcurrent protection algorithm

Figure below shows the structure of the negative sequence overcurrent protection (TOC46) algorithm

Figure. 6.3.9 - 76. The structure of the negative sequence overcurrent protection algorithm.



For the preparation (not part of the TOC46 function):

The inputs are

- the sampled values of the three phase currents (IL1, IL2, IL3).

The output is

- the RMS value of the fundamental Fourier components of the negative sequence component of the phase currents.

For the TOC46 function:

The inputs are

- the RMS value of the fundamental Fourier component of the negative sequence component of the phase currents
- parameters
- status signals.

The outputs are

- the binary output status signals.

The software modules applied in the negative sequence overcurrent protection function are:

Fourier calculations
These modules calculate the basic Fourier current components of the phase currents

Negative sequence
This module calculates the basic Fourier current components of the negative sequence current, based on the Fourier components of the phase currents.

Characteristics
This module calculates the required time delay based on the Fourier components of the negative sequence current.

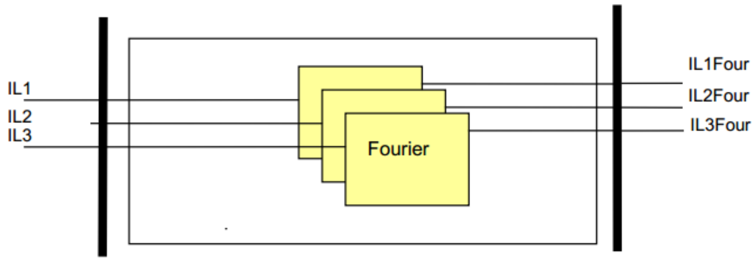
Decision logic
The decision logic module combines the status signals to generate the trip command of the function.

The following description explains the details of the individual components.

The Fourier calculation

These modules calculate the basic Fourier current components of the phase currents individually. These modules belong to the preparatory phase.

Figure. 6.3.9 - 77. Schema of the Fourier calculation.



The inputs are the sampled values of:

- The three phase currents of the primary side (IL1, IL2, IL3)

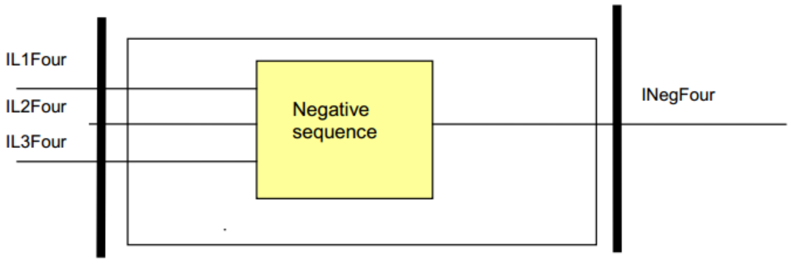
The outputs are the basic Fourer components of the analyzed currents (IL1Four, IL2Four, IL3Four).

The negative phase sequence calculation

This module calculates the negative phase sequence components based on the Fourier components of the phase currents. This module belongs to the preparatory phase. The inputs are the basic Fourier components of the phase currents (IL1Four, IL2Four, IL3Four).

The output is the basic Fourier component of the negative sequence current component (INegFour).

Figure. 6.3.9 - 78. Schema of the negative sequence component calculation.



The definite time and inverse type characteristics

This module calculates the required time delay based on the Fourier components of the negative sequence current. The formulas applied are described in Chapter 1.1.

The input is the basic Fourier component of the negative sequence current (INegFour) and parameters.

The outputs are the internal status signals of the function. These indicate the started state and the generated trip command if the time delay determined by the characteristics expired.

Figure. 6.3.9 - 79. Schema of the characteristic calculation.

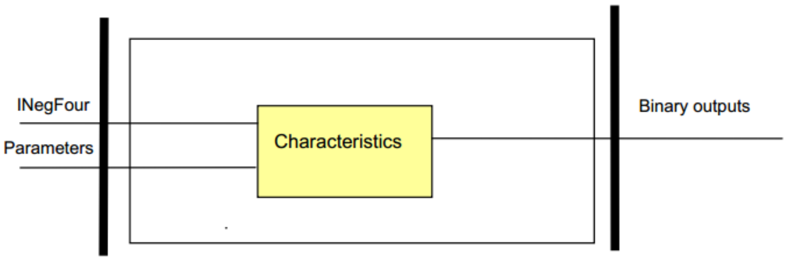


Table. 6.3.9 - 37. Setting parameters of the residual directional overcurrent function.

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 into IEC or ANSI/IEEE standards.

Parameter	Setting value / range	Step	Default	Description
Start current	5…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. This parameter is not in use when IDMT characteristics is selected for the operation.
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 when definite time and IEC IDMT characteristics.
Time Mult	100…6000	1	100	Time multiplier / time dial setting of the IDMT operating characteristics. This parameter is not in use with definite time characteristics.

The decision logic

The decision logic module combines the binary status signals to generate the trip command of the function.

Figure. 6.3.9 - 80. The logic scheme of the negative sequence overcurrent protection function.

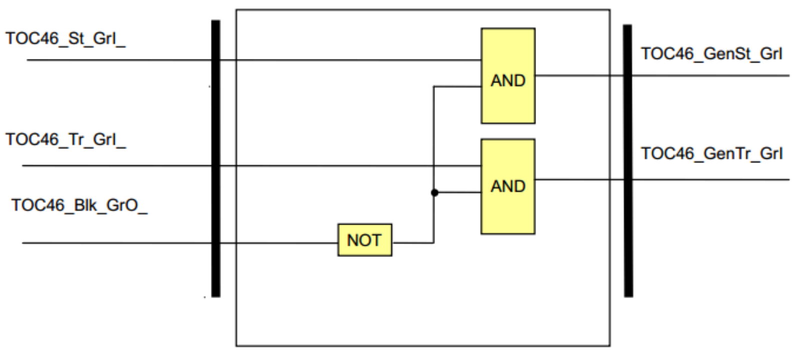


Table. 6.3.9 - 38. The binary status signals of the decision logic.

Binary status signal	Signal title	Explanation
TOC46_St_GrI_	Start	Starting of the function
TOC46_Tr_GrI_	Trip	Trip command of the function

The negative sequence overcurrent 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 graphic equation editor.

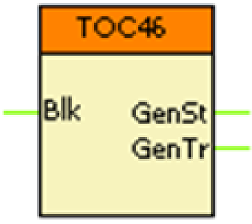
Table. 6.3.9 - 39. The binary input signal of the negative sequence overcurrent protection function.

Binary input status signal	Explanation
TOC46_Blk_GrO_	Output status of a graphic equation defined by the user to disable the negative sequence overcurrent protection function.

Table. 6.3.9 - 40. The binary output status signals of the negative sequence overcurrent protection function.

Binary output signal	Signal title	Explanation
TOC46_GenSt_GrI_	General Start	General starting of the function
TOC46_GenTr_GrI_	General Trip	General trip command of the function

Figure. 6.3.9 - 81. The function block of the negative sequence overcurrent protection function.



6.3.10 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. 6.3.10 - 82. Operation logic of the CBFP function.

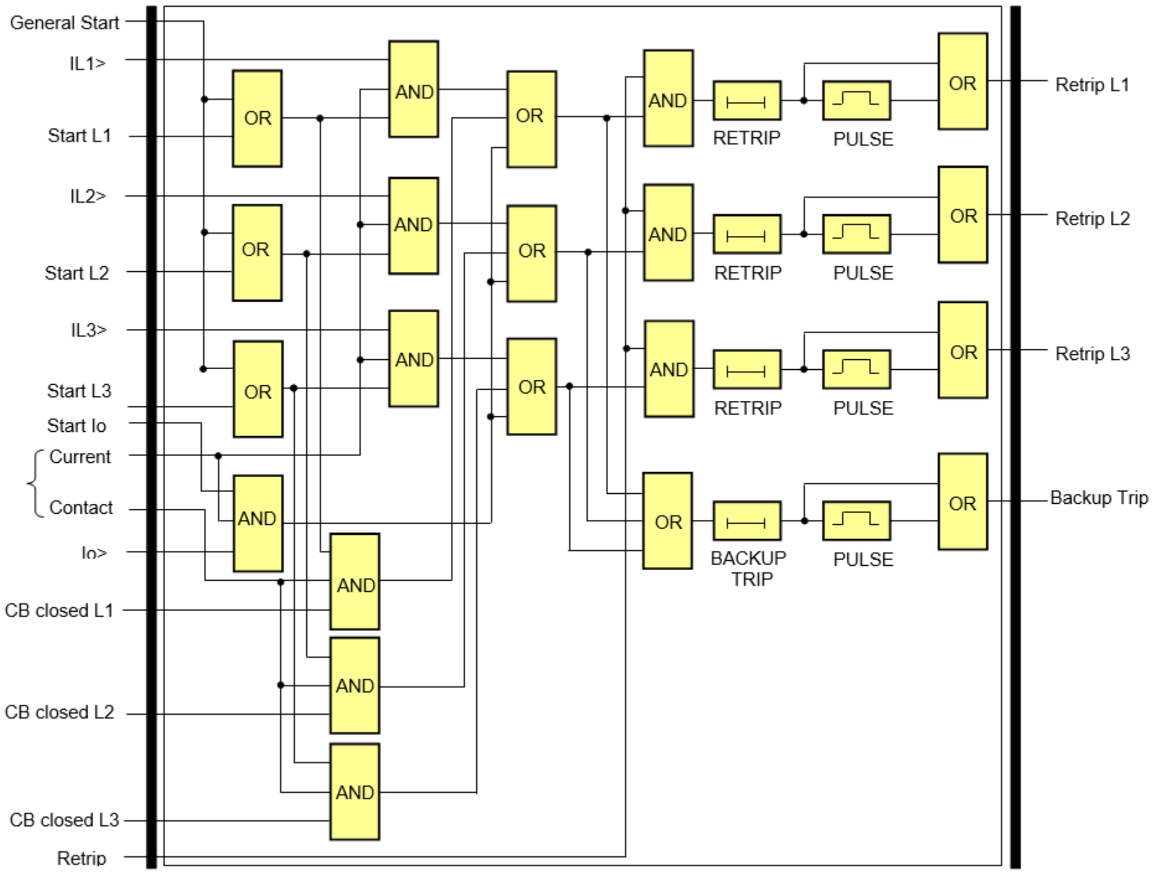


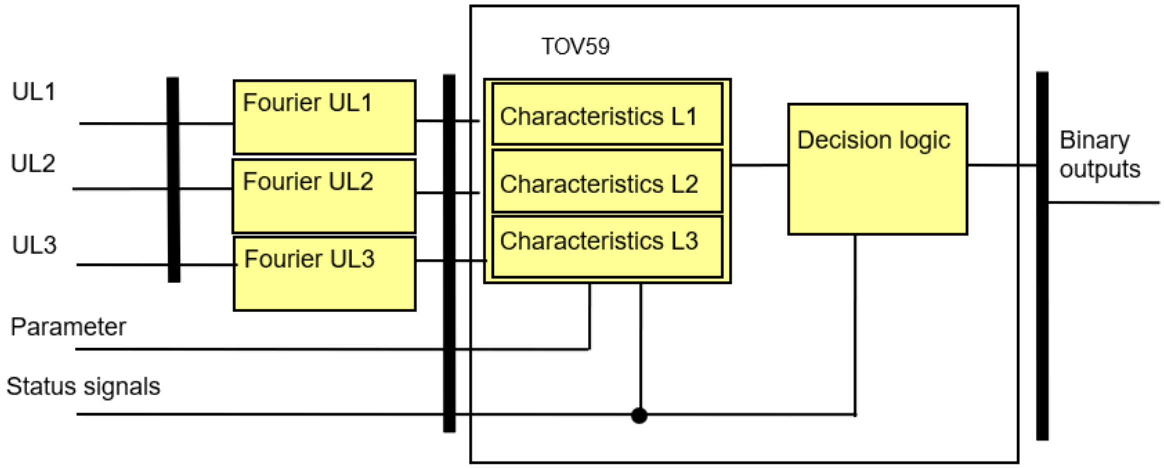
Table. 6.3.10 - 41. Setting parameters of the CBFP function.

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.

6.3.11 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. 6.3.11 - 83. 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.

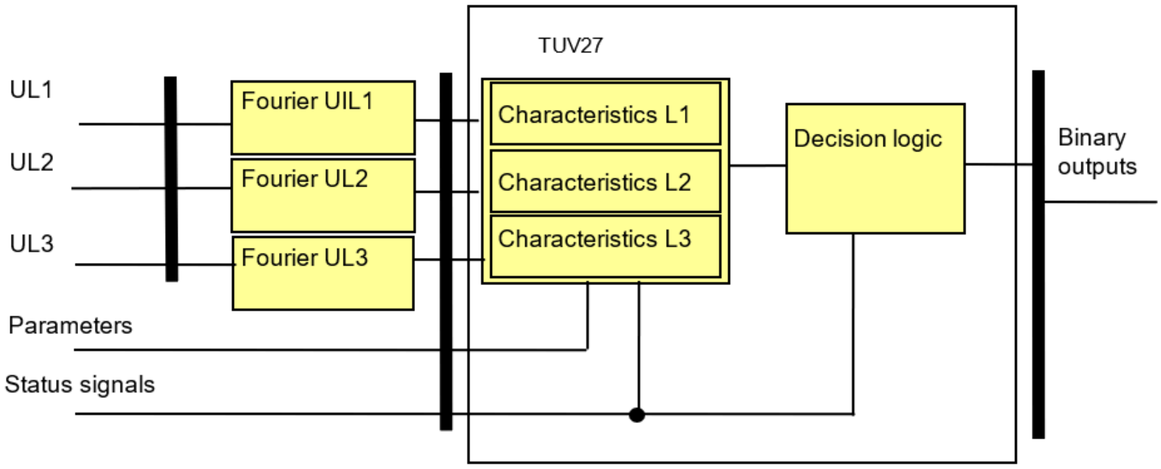
Table. 6.3.11 - 42.

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.

6.3.12 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. 6.3.12 - 84. 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.

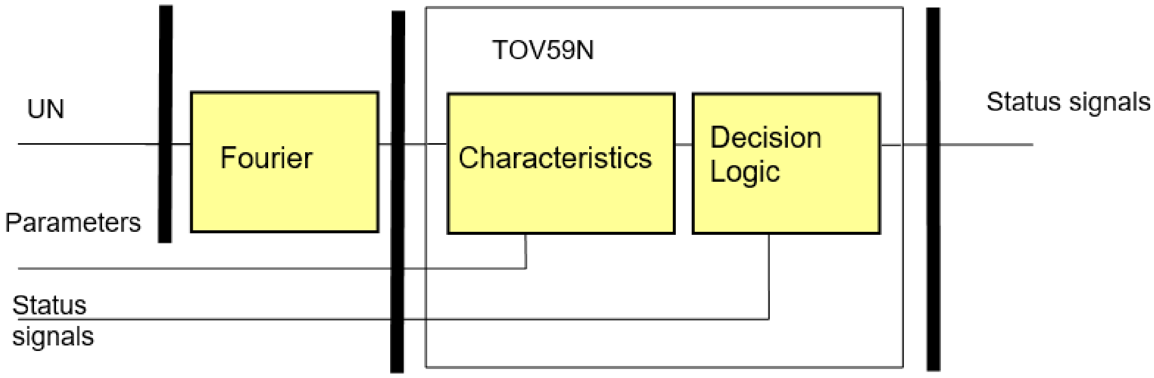
Table. 6.3.12 - 43. Setting parameters of the undervoltage function.

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.

6.3.13 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. 6.3.13 - 85. 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. 6.3.13 - 44. 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.

6.3.14 Harmonic undervoltage protection (64H)

The definite time third harmonic undervoltage protection function can be applied to extend the stator earth fault protection system for a generator to 100% stator earth fault protection. Other protection functions, based on network frequency quantities, cannot detect the stator earth-faults near to the neutral point of the generator. This is due to the low value of the generated voltage in this range of the stator coil. These functions operate only if the earth-fault is relatively far from the neutral point.

The basic principle of extending the protected zone to the area near to the neutral point is the third harmonic voltage detection. It can be applied if a generator is connected to the unit transformer, the connection group of which isolates the generator form the network, regarding the zero sequence voltage and current.

Along the stator windings of the phases, due to the construction of a generator, a third harmonic voltage component is generated, which is of zero sequence nature. This zero sequence third harmonic voltage is divided between the distributed capacitances of the system (generator and transformer earth capacitance, etc.). As a consequence, in normal, symmetric operation a certain amount of third harmonic voltage can be measured in the neutral of the generator.

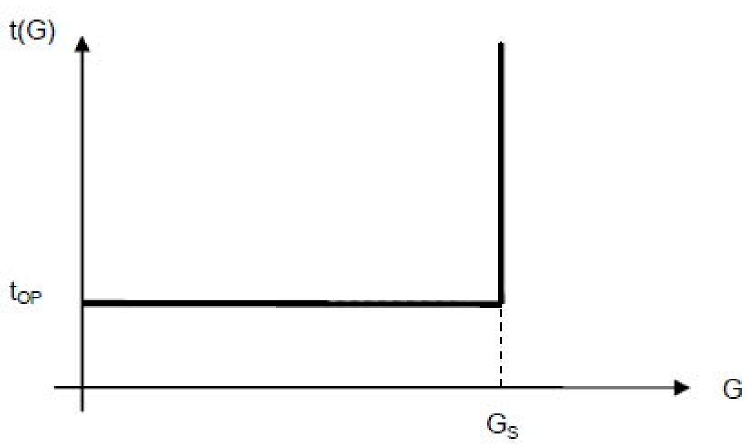
In case of a single phase-to-ground fault near to the neutral point of the generator, this voltage decreases, and the third harmonic undervoltage protection function detects the earth fault.

The function generates start signal if the third harmonic voltage component is below the setting value. The function generates a trip command only if the time delay has expired.

The function can be disabled via binary input if e.g. the basic harmonic voltage is low, indicating a not excited state of the generator. This needs the application also of a network frequency undervoltage function.

$t(G) = t_{OP}$ (when $G<G_S$)

Figure. 6.3.14 - 86. Third harmonic undervoltage independent time characteristic.



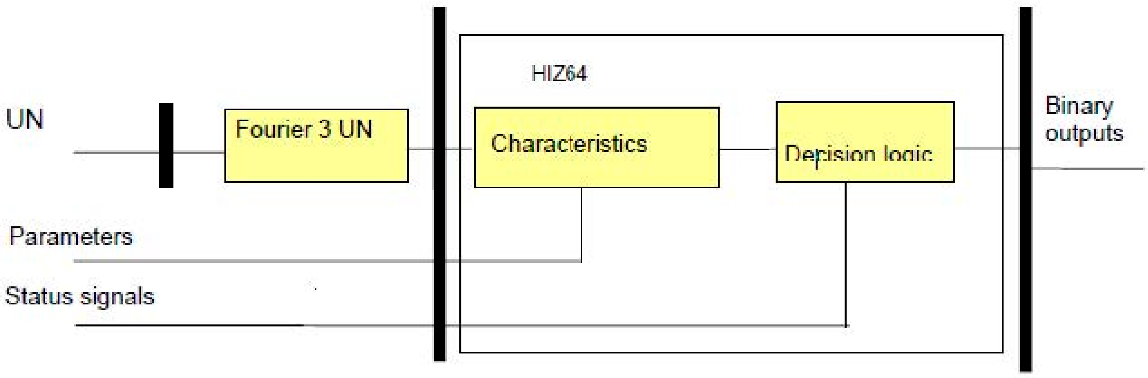
The variables in the above diagram are as follows:

- t_{OP} (seconds) = theoretical operating time if G>GS, according to parameter setting value
- G = measured value of the characteristic quantity, Fourier third harmonic of the neutral voltage
- G_S = setting value of the characteristic quantity.

Structure of third harmonic undervoltage protection

Figure below shows the structure of the definite time third harmonic undervoltage protection (HIZ64) algorithm.

Figure. 6.3.14 - 87. Structure of third harmonic undervoltage protection.



The inputs are

- The RMS value of the third harmonic Fourier component of the generator neutral voltage
- Parameters
- Status signals.

The outputs are

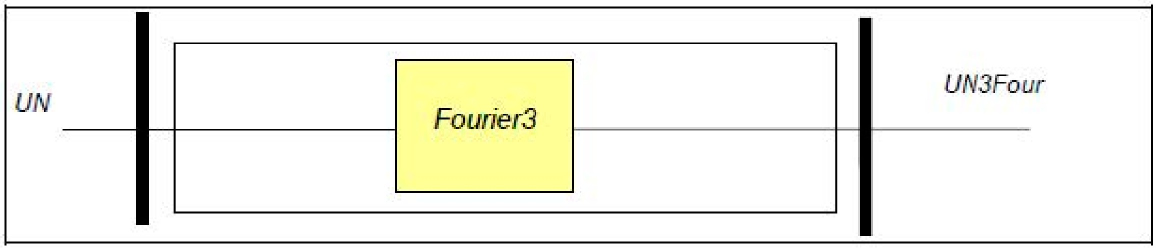
- The binary output status signals.

The software modules of the third harmonic undervoltage protection function:

Fourier3 calculation

This module calculates the third harmonic Fourier component of the generator neutral point voltage (not part of the HIZ64 function). This is not part of the HIZ64 function; it belongs to the preparatory phase.

Figure. 6.3.14 - 88. Fourier calculation.



Characteristics

This module decides the stating of the function based on the third harmonic Fourier component of the generator neutral point voltage and it counts the time delay. The time delay is defined by the parameter setting, if the voltage is below the setting value.

The inputs are the third harmonic Fourier component of the phase voltages (N3Four) and parameters. The outputs are the internal status signals. These indicate the started state and the generated trip command if the time delay determined by the setting is expired.

Decision logic

The decision logic module combines the status signals to generate the trip command of the function.

Function block

The function block of third harmonic undervoltage protection function is shown in figure below. All binary input and output status signals applicable in the AQtivate 300 software are explained below.

Figure. 6.3.14 - 89. The function block of the harmonic undervoltage protection function with offset characteristic.

Table. 6.3.14 - 45. Binary I/O signals.

Binary status signal	Title	Explanation
HIZ64_Start_GrI_	Start	Start signal
HIZ64_Trip_GrI_	Trip	Trip command
HIZ64_Blk_GrO_	Block	Blocking of the third harmonic undervoltage protection function

Table. 6.3.14 - 46. Setting parameters of the harmonic undervoltage 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 voltage	2…60 %	1 %	30 %	Voltage pick-up setting
Start signal only	Activated Deactivated	-	Deactivated	Selection if the function issues either “Start” signal alone orboth “Start” and after set time delay “Trip” signal.
Time delay	0…60 000 ms	1 ms	100 ms	Operating time delay setting for the “Trip” signal from the“Start” signal.

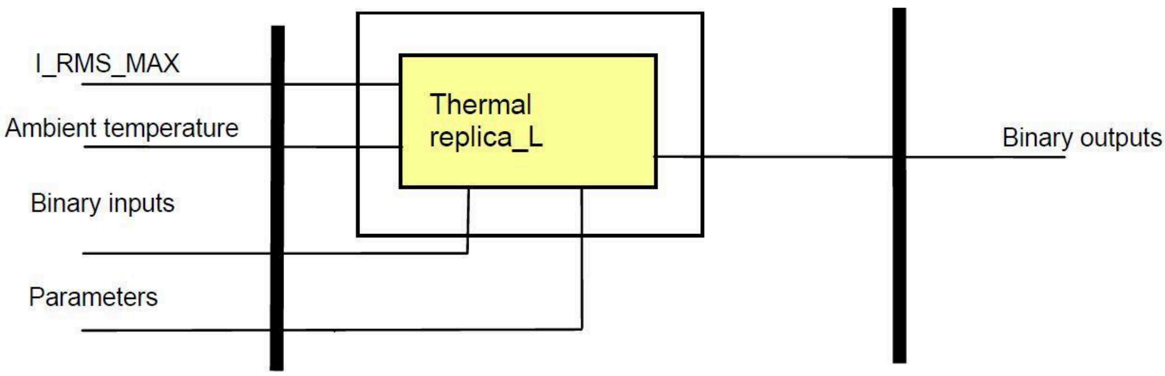
6.3.15 Thermal overload protection (T>; 49)

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. 6.3.15 - 90. 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. 6.3.15 - 47. Setting parameters of the thermal overload function.

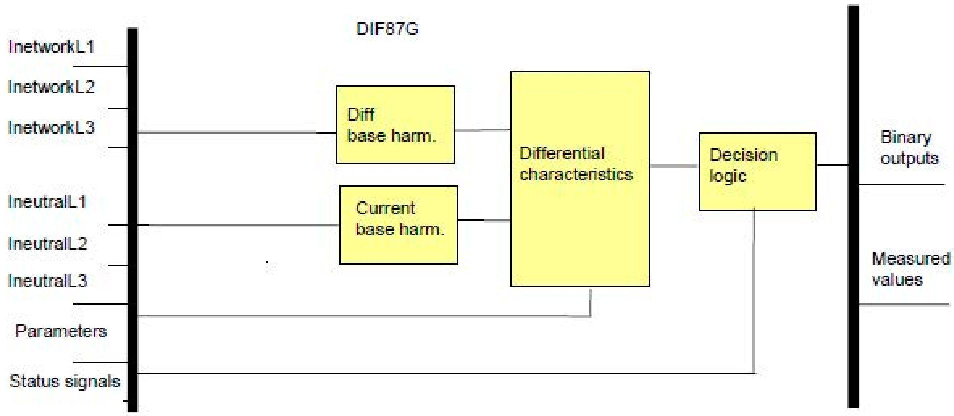
Parameter	Setting value / range	Step	Default	Description
Operation	Off Pulsed Locked	-	Pulsed	Operating mode selection. "Pulsed" operation means that the function gives tripping pulse when the calculated thermal load exceeds the set thermal load. "Locked" means that the trip signal releases when the 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.
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.

Parameter	Setting value / range	Step	Default	Description
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.

6.3.16 Generator differential protection (87G)

The generator differential protection function provides main protection for generators or large motors. The application needs current transformers in all three phases both on the network side and on the neutral side.

Figure. 6.3.16 - 91. The principal scheme of the generator differential protection function's algorithm.



The inputs are

- the sampled values of three phase currents measured at the network side
- the sampled values of three phase currents measured at the neutral connection
- parameters
- status signals.

The outputs are

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

The software modules of the generator differential protection function:

- Diff base harm.
  This module calculates the basic Fourier components of the three differential currents. These results are needed also for the high-speed differential current decision.
- Current base harm.
  This module calculates the basic Fourier components of the of the phase currents both for the network side and for the neutral side. The result of this calculation is needed for the differential characteristic evaluation.
- Differential characteristics
  This module performs the necessary calculations for the evaluation of the percentage differential characteristics.

- 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.

Differential current calculation

The differential currents in the phases are calculated as the difference between the currents measured on the network side and those on the neutral side.

This module calculates the basic Fourier components of three differential currents. These results are needed also for the high-speed differential current decision.

Principle of harmonic analysis (the differential currents):

$$\begin{bmatrix} IdL1 \\ IdL2 \\ IdL3 \end{bmatrix} = \begin{bmatrix} InetworkL1 \\ InetworkL2 \\ InetworkL3 \end{bmatrix} - \begin{bmatrix} IneutralL1 \\ IneutralL2 \\ IneutralL3 \end{bmatrix}$$

The outputs are the magnitude of the base harmonic Fourier components of the differential currents:

$$\begin{bmatrix} F1IdL1 \\ F1IdL2 \\ F1IdL3 \end{bmatrix}$$

These values are processed by the “Differential characteristics” software module evaluating the currents according to the differential characteristics.

Harmonic analysis of the phase currents

The inputs are the “sampled values” of the phase currents:

Current of the network side:

$$\begin{bmatrix} InetworkL1 \\ InetworkL2 \\ InetworkL3 \end{bmatrix}$$

Currents of the neutral side:

$$\begin{bmatrix} IneutralL1 \\ IneutralL2 \\ IneutralL3 \end{bmatrix}$$

The outputs are the magnitude of the base harmonic Fourier components of these currents:

The base harmonic Fourier components of the network side:

$$\begin{bmatrix} F1InetworkL1 \\ F1InetworkL2 \\ F1InetworkL3 \end{bmatrix}$$

The base harmonic Fourier components of the neutral side:

$$\begin{bmatrix} F1IneutralL1 \\ F1IneutralL2 \\ F1IneutralL3 \end{bmatrix}$$

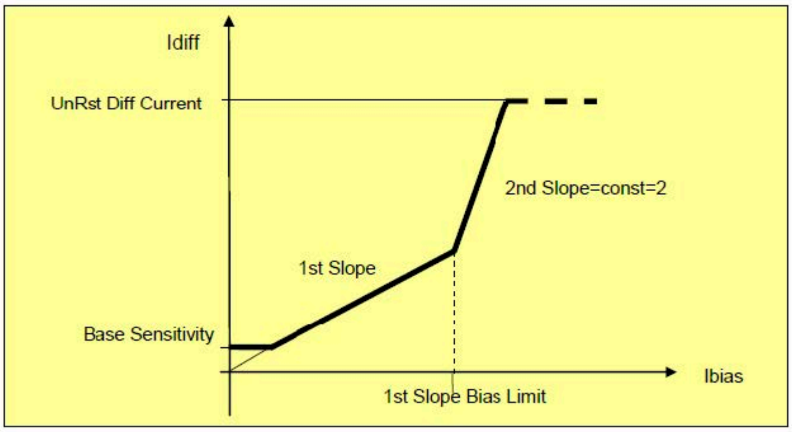
These values are processed by the software module evaluating the currents according to the differential characteristics.

Restrained and unrestrained differential characteristics

Restrained differential characteristics

The restrained differential characteristic is drawn in the figure below.

Figure. 6.3.16 - 92. Restrained differential characteristics.



Additionally separate status-signals are set to “true” value if the differential currents in the individual phases are above the limit, set by parameter (see “Unrestrained differential function”).

Restrained differential characteristics

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.

Measured values

The measured and displayed values of the generator differential protection function are listed in below table.

Table. 6.3.16 - 48. The measured values of the generator differental protection function.

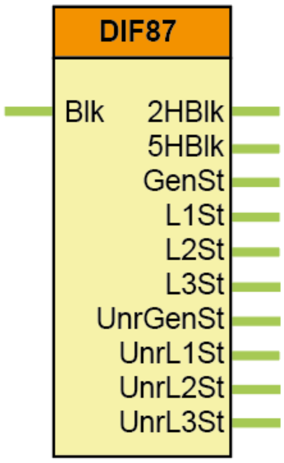
Measured value	Dim.	Explanation
Idiff. L1	In %	The calculated differential current in phase L1
Idiff. L2	In %	The calculated differential current in phase L2
Idiff. L3	In %	The calculated differential current in phase L3

Measured value	Dim.	Explanation
Ibias L1	In %	The calculated restraint current in phase L1
Ibias L2	In %	The calculated restraint current in phase L2
Ibias L3	In %	The calculated restraint current in phase L3

Function block

The function block of the generator differential function is shown in figure below.

Figure. 6.3.16 - 93. The function block of the generator differential protection function.



This block shows all binary input and output status signals that are applicable in the AQtivate 300 software.The binary input and output signals of the generator differential protection function are listed in table below.

Table. 6.3.16 - 49. The binary input and output signals.

Binary input signal	Explanation	
DIF87G_Bk_GrO_	Output status of a graphic equation defined by the user to disable the differential protection function.	
Binary output signal	Signal title	Explanation
Restrained differential protection function		
DIF87G_L1St_GrI_	Start L1	Start of the restrained differential protection function is phase L1 (after vector group compensation)
DIF87G_L2St_GrI_	Start L2	Start of the restrained differential protection function is phase L2 (after vector group compensation)
DIF87G_L3St_GrI_	Start L3	Start of the restrained differential protection function is phase L3 (after vector group compensation)
DIF87G_GenSt_GrI_	General Start	General start of the restrained differential protection function
Unrestrained differential protection function		

Binary input signal	Explanation	
DIF87G_UnRL1St_Grl_	Start L1 unrestr.	Start of the unrestrained differential protection function in phase L1 (after vector group compensation)
DIF87G_UnRL2St_Grl_	Start L2 unrestr.	Start of the unrestrained differential protection function in phase L2 (after vector group compensation)
DIF87G_UnRL3St_Grl_	Start L3 unrestr.	Start of the unrestrained differential protection function in phase L3 (after vector group compensation)
DIF87G_UnRGenSt_Grl_	General Start unrestr.	General start of the unrestrained differential protection function

6.3.17 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. 6.3.17 - 50. 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.

6.3.18 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. 6.3.18 - 51. 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.

6.3.19 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. 6.3.19 - 52. 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".
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.

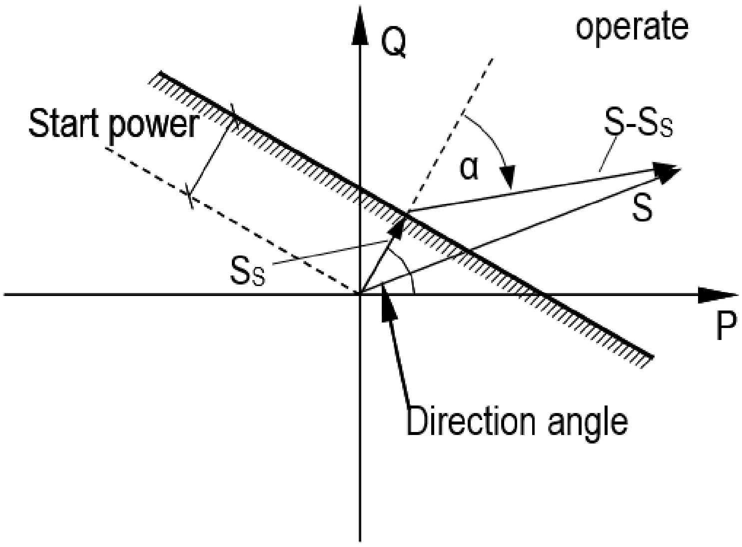
6.3.20 Directional overpower protection (P>; 32O)

The directional under-power protection function can be applied mainly to protect any elements of the electric power system, mainly generators, if the active and/or reactive power has to be limited in respect of the allowed minimum power.

The inputs of the function are the Fourier basic harmonic components of the three phase currents and those of the three phase voltages.

Based on the measured voltages and currents, the block calculates the three-phase active and reactive power (point S in figure below) and compares the P-Q coordinates with the defined characteristics on the power plane. The characteristic is defined as a line laying on the point SS and perpendicular to the direction of SS. The SS point is defined by the “Start power” magnitude and the “Direction angle”. The over-power function operates if the angle of the S-SS vector related to the directional line is below 90 degrees and above -90 degrees. At operation, the “Start power” value is decreased by a hysteresis value.

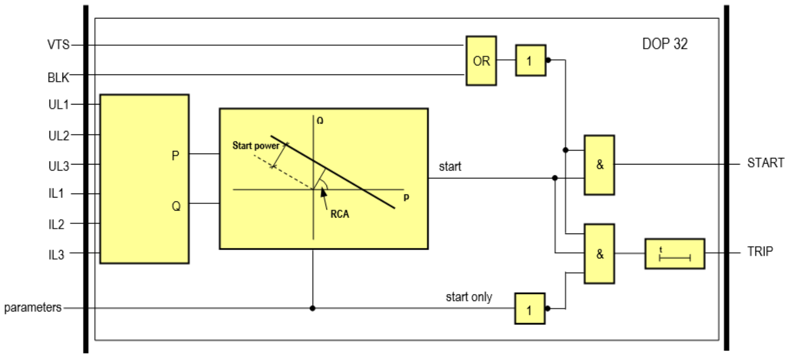
Figure. 6.3.20 - 94. Directional overpower decision.



Structure of directional overpower protection

Figure below shows the structure of the directional underpower protection (DOP32) algorithm.

Figure. 6.3.20 - 95. Structure of directional overpower protection.



The inputs are

- The RMS value of the fundamental Fourier component of the three phase currents (IL1, IL2, IL3)
- The RMS value of the fundamental Fourier component of the three phase voltages (UL1, UL2, UL3)
- Parameters
- Status signals.

The function can be enabled or disabled (BLK input signal). The status signal of the VTS (voltage transformer supervision) function can also disable the directional operation.

The outputs are

- The binary output status signals.

Software modules of the function block are as follows:

P-Q Calculation

Based on the RMS values of the fundamental Fourier component of the three phase currents and of the three phase voltages, this module calculates the three-phase active and reactive power values. The input signals are the RMS values of the fundamental Fourier components of the three phase currents and three phase voltages. The internal output signals are the calculated three-phase active and reactive power values.

Directional decision

This module decides if, on the power plane, the calculated complex power is closer to the origin than the corresponding point of the characteristic line, i.e. if the point S is on the "Operate" side of the P-Q plane. The internal input signals are the calculated active and reactive power values. The internal output signal is the start signal of the function.

Decision logic

This part of the function block combines status signals to make a decision to start. Additionally to the directional decision, the function may not be blocked by the general "Block" signal, and may not be blocked by the signal "Block for VTS" of the voltage transformer supervision function. If the parameter setting requires also a trip signal (DOP32_StOnly_BPar_=0), then the measurement of the definite time delay is started. The expiry of this timer results in a trip command.

Function block

The function block of directional overpower protection function is shown in figure below. All binary input and output status signals applicable in the AQtivate 300 software are explained below.

Figure. 6.3.20 - 96. The function block of the directional overpower protection function.

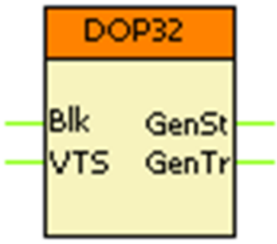


Table. 6.3.20 - 53. Binary status signals

Binary status signal	Title	Explanation
DOP32_GenSt_Grl_	General Start	General start signal of the function
DOP32_GenTr_Grl_	General Trip	Trip command of the function
DOP32_VTS_GrO_	Bloc from VTS	Blocking signal from the voltage transformer supervision function
DOP32_Blk_GrO_	Block	General blocking signal

Setting parameters

Table. 6.3.20 - 54. 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.
Direction angle	–179…180	1	0	Power direction angle setting, angle between P and Q.
Start power	1…200 %	0.1 %	10 %	Minimum power setting.
Time delay	0…60 000 ms	1 ms	100 ms	Definite time delay of the trip command.

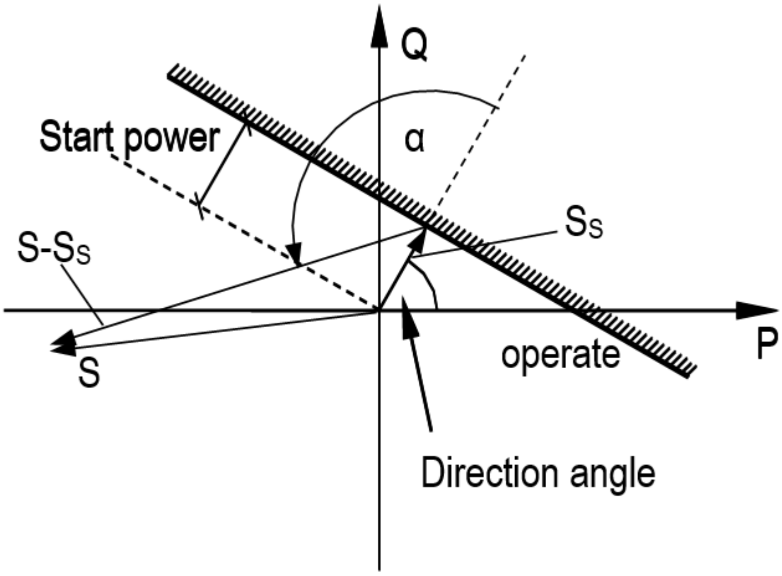
6.3.21 Directional underpower protection (P<; 32U)

The directional under-power protection function can be applied mainly to protect any elements of the electric power system, mainly generators, if the active and/or reactive power has to be limited in respect of the allowed minimum power.

The inputs of the function are the Fourier basic harmonic components of the three phase currents and those of the three phase voltages.

Based on the measured voltages and currents, the block calculates the three-phase active and reactive power (point S in figure below) and compares the P-Q coordinates with the defined characteristics on the power plane. The characteristic is defined as a line laying on the point SS and perpendicular to the direction of SS. The SS point is defined by the “Start power” magnitude and the “Direction angle”. The under-power function operates if the angle of the S-SS vector related to the directional line is above 90 degrees or below -90 degrees, i.e. if the point S is on the “Operate” side of the P-Q plane. At operation, the “Start power” value is increased by a hysteresis value.

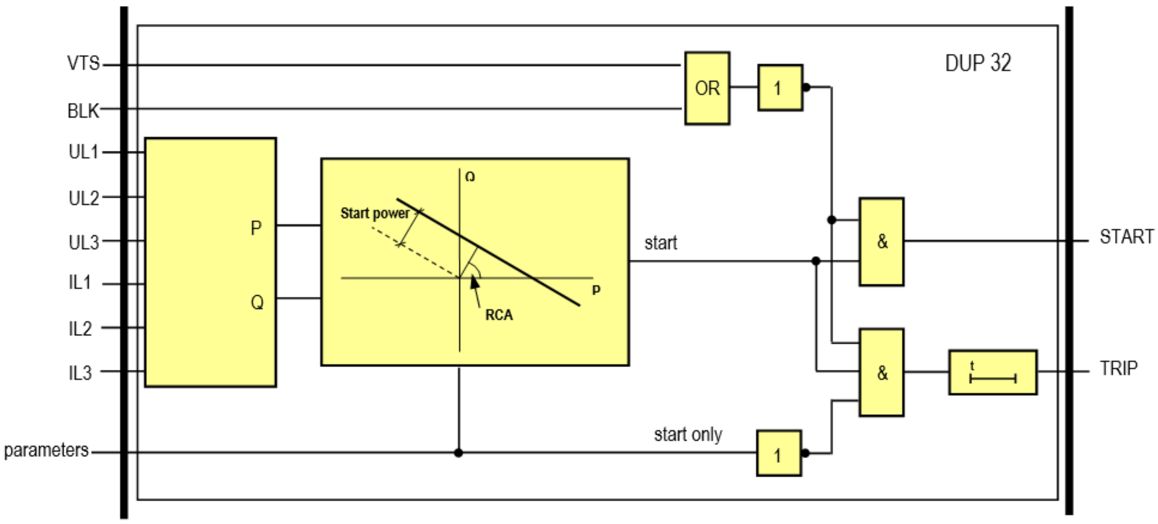
Figure. 6.3.21 - 97. Directional underpower decision.



Structure of directional underpower protection

Figure below shows the structure of the directional underpower protection (DUP32) algorithm.

Figure. 6.3.21 - 98. Structure of directional underpower protection.



The inputs are

- The RMS value of the fundamental Fourier component of the three phase currents (IL1, IL2, IL3)
- The RMS value of the fundamental Fourier component of the three phase voltages (UL1, UL2, UL3)
- Parameters
- Status signals.

The function can be enabled or disabled (BLK input signal). The status signal of the VTS (voltage transformer supervision) function can also disable the directional operation.

The outputs are

- The binary output status signals.

Software modules of the function block are as follows:

P-Q Calculation

Based on the RMS values of the fundamental Fourier component of the three phase currents and of the three phase voltages, this module calculates the three-phase active and reactive power values. The input signals are the RMS values of the fundamental Fourier components of the three phase currents and three phase voltages.The internal output signals are the calculated three-phase active and reactive power values.

Directional decision

This module decides if, on the power plane, the calculated complex power is closer to the origin than the corresponding point of the characteristic line, i.e. if the point S is on the “Operate” side of the P-Q plane. The internal input signals are the calculated active and reactive power values. The internal output signal is the start signal of the function.

Decision logic

This part of the function block combines status signals to make a decision to start. Additionally to the directional decision, the function may not be blocked by the general “Block” signal, and may not be blocked by the signal “Block for VTS” of the voltage transformer supervision function.If the parameter setting requires also a trip signal (DUP32_StOnly_BPar_=0), then the measurement of the definite time delay is started. The expiry of this timer results in a trip command.

Function block

The function block of directional underpower protection function is shown in figure below. All binary input and output status signals applicable in the AQtivate 300 software are explained below.

Figure. 6.3.21 - 99. The function block of the directional underpower protection function.

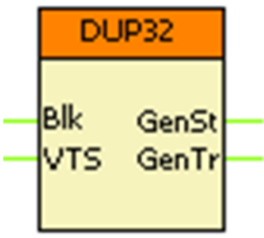


Table. 6.3.21 - 55. Binary I/O signals

Binary status signal	Title	Explanation
DUP32_GenSt_GrI_	General Start	General start signal of the function
DUP32_GenTr_GrI_	General Trip	Trip command of the function
DUP32_VTS_GrO_	Block from VTS	Blocking signal from the voltage transformer supervision function
DUP32_Blk_GrO_	Block	General blocking signal

Setting parameters

Table. 6.3.21 - 56. Setting parameters of the directional underpower 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.
Direction angle	–179…180	1	0	Power direction angle setting, angle between P and Q.
Start power	1…200 %	0.1 %	10 %	Minimum power setting.
Time delay	0…60 000 ms	1 ms	200 ms	Operating time delay setting for the “Trip” signal from the “Start” signal.

6.3.22 Impedance protection (Z<; 21)

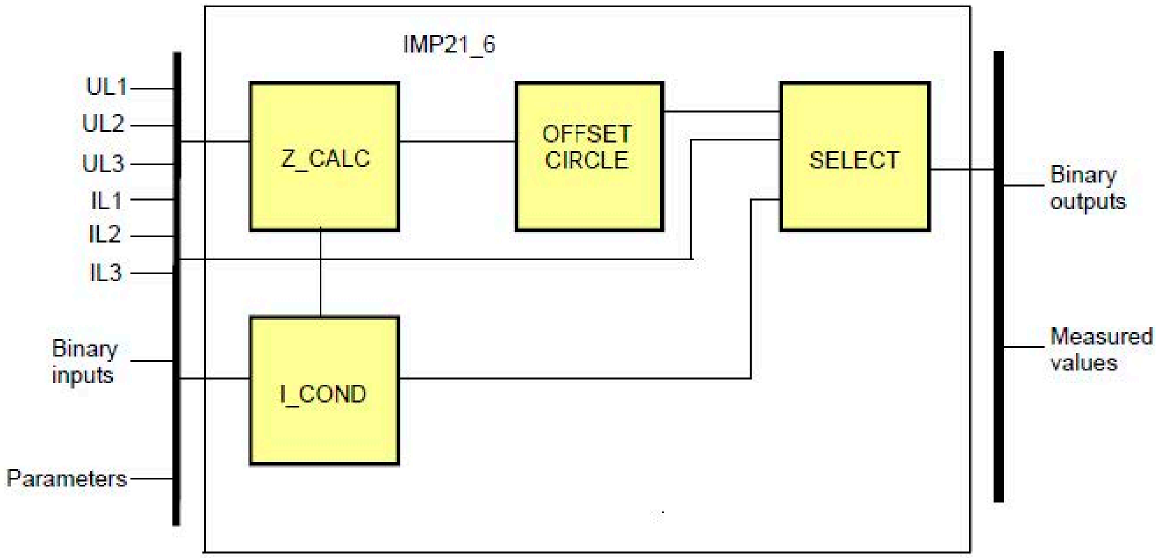
This impedance protection function can be applied as impedance protection with an offset circular characteristic or as a loss-of-field protection function for synchronous machines. Its main features are:

- A full-scheme system provides continuous measurement of impedances separately in three independent phase-to-phase measuring loops as well as in three independent phase-to-earth measuring loops.
- Impedance calculation is conditional on the values of phase currents being sufficient.
- Full-scheme faulty phase identification is provided.
- The operate decision is based on offset circle characteristics.
- The impedance calculation is dynamically based on:
    - Measured loop voltages if they are sufficient for decision
    - Voltages stored in the memory if they are available
    - Optionally, the decision can be non-direction; in that case, the center of the circle is not shifted away from the origin.
- Binary input signals and conditions can influence the operation:
    - Blocking/enabling.
    - VT failure signal.

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.

Figure. 6.3.22 - 100. Structure of the impedance protection.



The inputs are:

- Fourier components of three phase voltages
- Fourier components of three phase currents
- Binary inputs
- Setting parameters.

The outputs are:

- Binary output status signals
- Measured values.

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.
- OFFSET CIRCLE compares the calculated impedances with the setting values of the compounded circle characteristics. The result is the decision for all six measuring loops if the impedance is within the offset circle.
- SELECT is the phase selection algorithm 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.

Principle of the impedance calculation

The impedance 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 table below 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.

Table. 6.3.22 - 57. 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 contains the formula for calculation. The formulas referred to in the right-hand-side column yield the same impedance value.

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

Earth fault compensation factor equation 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.

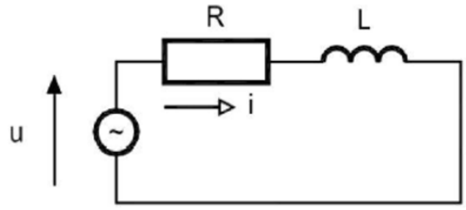
The separation of the two types of equation is based on the presence or absence of the earth (zero sequence) current. In case of a fault involving the earth (on a solidly grounded network), and if the earth current is over a certain level, the formula containing the complex earth fault compensation factor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

The numerical processes apply the following simple model.

Figure. 6.3.22 - 101. 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 substitutedin this equation, two equations are derived with the two unknown values R and L, so they canbe 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:

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

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

i_{L1} = the faulty phase

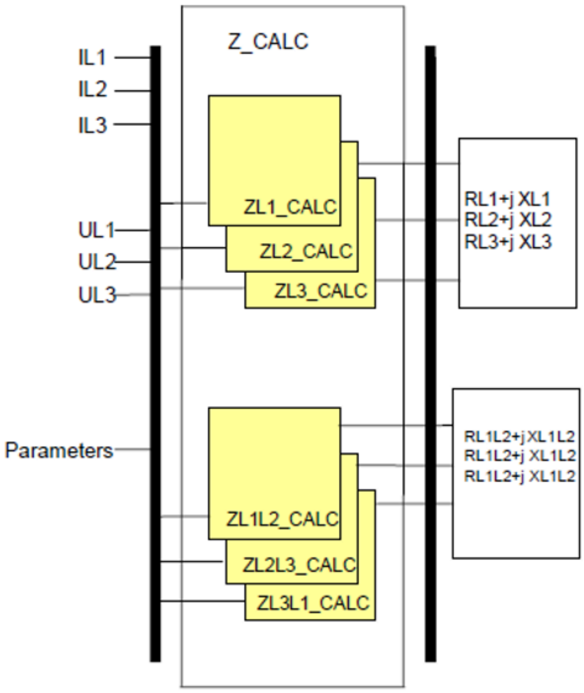
$3i_0 = i_{L1} + i_{L2} + i_{L3}$
the sampled value of the zero sequence current of the projected object

$\alpha_R = (R_0 – R_1)/3R_1$

$\alpha_L = (L_0 – L_1)/3L_1 = (X_0 – X_1)/3X_1$

The formula above shows that the factors for multiplying R and L values contain different "" factors but they are real (not complex) numbers. The applied numerical method is solving the differential equation of the faulty loop, based on the orthogonal components of the Fourier fundamental component vectors. To achieve better filtering effect, the calculation is performed using the fundamental Fourier components of the voltages, currents and current derivatives. The calculation results complex impedances on the network frequency.

Figure. 6.3.22 - 102. The principal scheme of impedance calculation.



The inputs are Fourier components of

- Three phase voltages
- Three phase currents
- Parameters.

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

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

Table. 6.3.22 - 58. Calculated values of the impedance module.

Measured value	Dim.	Explanation
RL1+j XL1	ohm	Measured positive sequence impedance in the L1N loop
RL2+j XL2	ohm	Measured positive sequence impedance in the L2N loop
RL3+j XL3	ohm	Measured positive sequence impedance in the L3N loop
RL1L2+j XL1L2	ohm	Measured positive sequence impedance in the L1L2 loop
RL2L3+j XL2L3	ohm	Measured positive sequence impedance in the L2L3 loop

Measured value	Dim.	Explanation
RL3L1+j XL3XL1	ohm	Measured positive sequence impedance in the L13L1 loop

Z_CALC includes six practically identical software modules for impedance calculation:

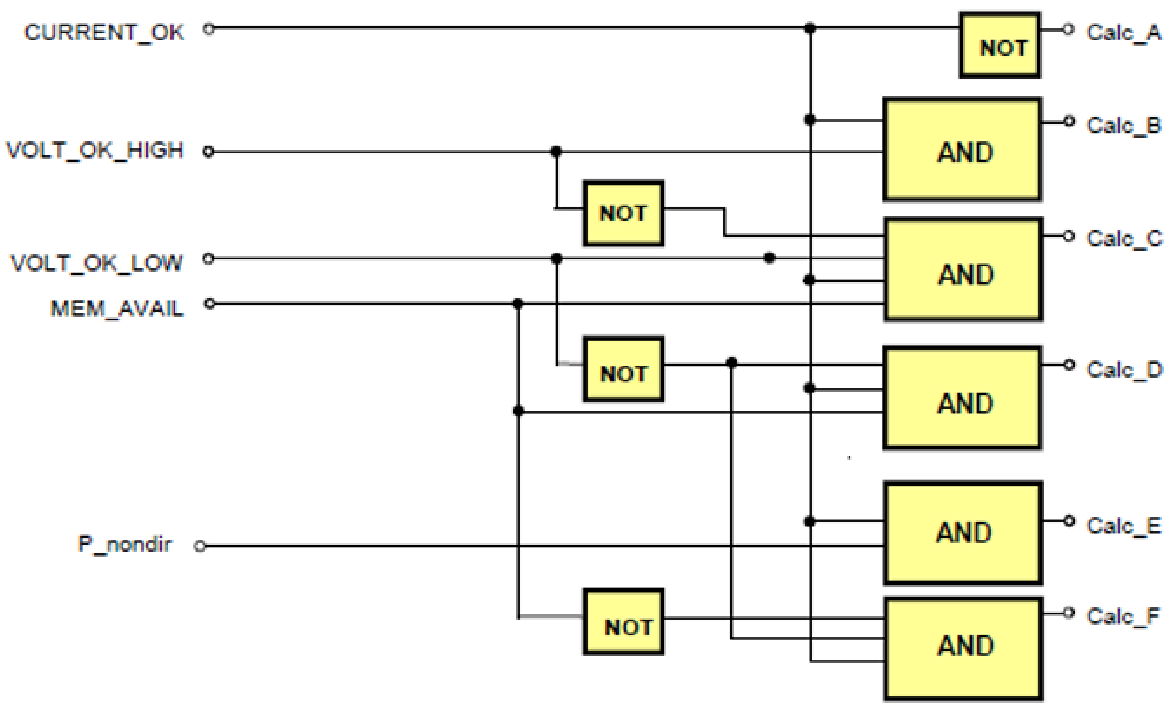
- The three routines of the phase group are activated by phase voltages, phase currents and the zero sequence current calculated from the phase current.
- The three routines for the phase-to-phase loops get line-to-line voltages calculated from the sampled phase voltages and they get differences of the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

The calculated impedances are analogue outputs of the impedance protection function. They serve the purpose of checking possibility at commissioning.

Internal logic of the impedance calculation

The figure below shows the internal logic of the impedance calculation.

Figure. 6.3.22 - 103. 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 - 59. Internal logic parameters of the impedance calculation.

Parameter	Explanation
P_nondir_	This logic variable is true if no directionality is programmed, i.e. the IMP21_Zn_EPar_(Operation) parameter is set to *"NonDirectional"*.

Table. 6.3.22 - 60. 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 IMP21_Imin_IPar_ (I minimum) and in case of phase-ground loops on parameters IMP21_I0Base_IPar_ (I0 Base sens.) and IMP21_I0Bias_IPar_ (I0 Bias).
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.

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

Table. 6.3.22 - 61. Calculation methods applied in the impedance calculation module.

Calculation method	Explanation
Calc(A)	No current is available, the impedances are supposd 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

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

Offset circle characteristics

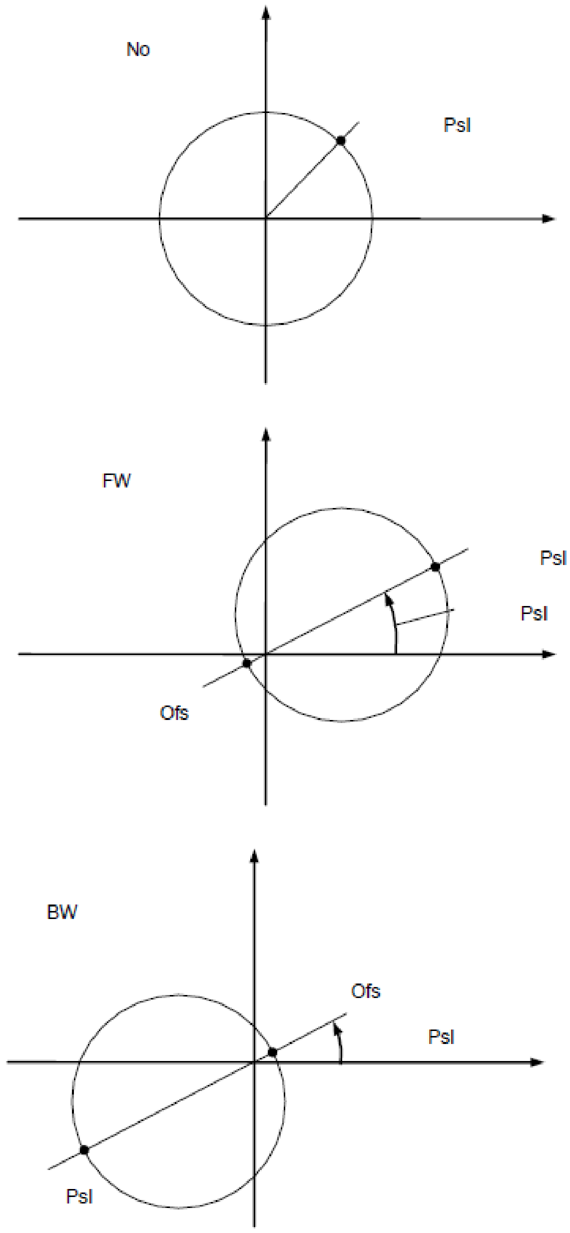
The operate decision is based on offset circle characteristics.

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 „offset circle" characteristics of the impedance protection, shown in figures below. The main setting values of "Rcompaund" and "Xcompaund" refer to the positive sequence impedance of the fault loop, including the fault positive sequence resistance of the possible electric arc and, in case of a ground fault, the tower grounding positive sequence resistance 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.)

Parameter settings decide the size and the position of the circle. Optionally, the center of the circle can be the origin of the impedance plane or the circle can be shifted along an impedance lime. The possibilities are shown in figures below.

- Off
- NoCompound
- FWCompound
- BWCompound

Figure. 6.3.22 - 104. The offset characteristic.



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

Offset characteristics logic

The calculated impedance values are compared one by one with the setting values of the „offset circle" characteristics. This procedure is shown schematically in the figure below.

The procedure is processed for each line-to-ground loop and for each line-to-line loop. The result is the setting of 6 status variables. This indicates that the calculated impedance is within the processed "offset circle" characteristics.

Figure. 6.3.22 - 105. Offset characteristics logic.

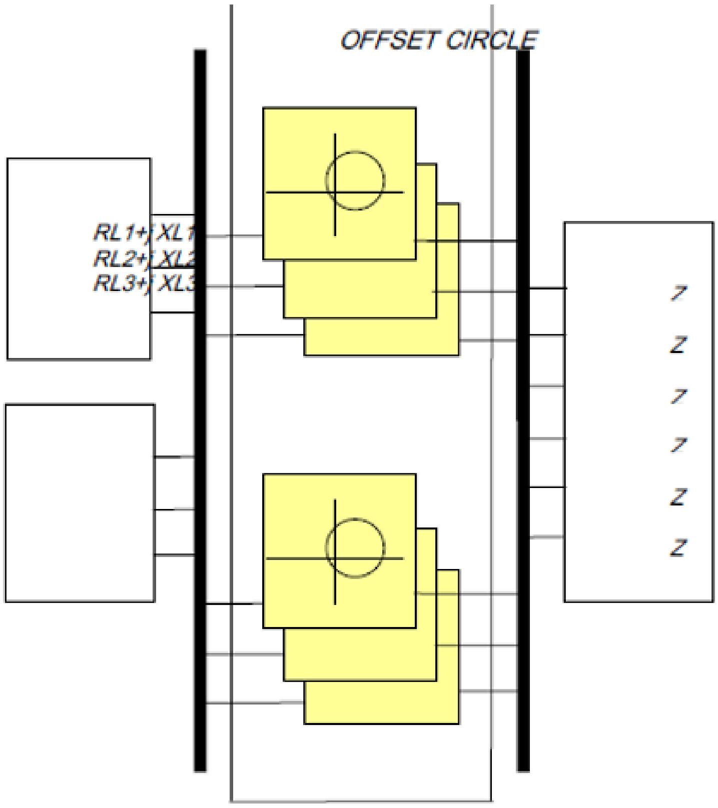


Table. 6.3.22 - 62. Input impedances for the characteristics logic.

Input values	Zones	Explanation
RL1+j XL1	1…5	Calculated impedance in the fault loop L1N
RL2+j XL2	1…5	Calculated impedance in the fault loop L2N
RL3+j XL3	1…5	Calculated impedance in the fault loop L3N
RL1L2+j XL1L2	1…5	Calculated impedance in the fault loop L1L2
RL2L3+j XL2L3	1…5	Calculated impedance in the fault loop L2L3
RL3L1+j XL3L1	1…5	Calculated impedance in the fault loop L3L1

Table. 6.3.22 - 63. 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

Output values	Zones	Explanation
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

The phase selection logic and timing

In case of faults, the calculated impedance value for the faulty loop is inside a polygon. If the fault is near the relay location, the impedances in the loop containing the faulty phase can also be inside the polygon. To ensure selective tripping, phase selection is needed. This chapter explains the operation of the phase selection logic.

Table. 6.3.22 - 64. Inputs needed to decide start of impedance protection.

Input status signals	Zones	Explanation
ZL1L2_n	n = 1…5	The calculated impedance of fault loop L1L2 is within the characteristic.
ZL2L3_n	n = 1…5	The calculated impedance of fault loop L2L3 is within the characteristic.
ZL3L1_n	n = 1…5	The calculated impedance of fault loop L3L1 is within the characteristic.
DIS21_cIL1_Grl	n = 1…5	The current in phase L1 is sufficient for impedance calculation.
DIS21_cIL2_Grl	n = 1…5	The current in phase L2 is sufficient for impedance calculation.
DIS21_cIL3_Grl	n = 1…5	The current in phase L3 is sufficient for impedance calculation.

Table. 6.3.22 - 65. Binary output signals of the phase selection

Binary status signal	Title	Explanation
IMP21_StL1_Grl_	Start L1	The impedance of phase L1 is within the characteristics.
IMP21_StL2_Grl_	Start L2	The impedance of phase L2 is within the characteristics.
IMP21_StL3_Grl_	Start L3	The impedance of phase L3 is within the characteristics.
IMP21_GenSt_Grl_	General Start	General start signal of the function
IMP21_GenTr_Grl_	General Trip	General trip signal of the function

Three phase fault detection

The logic processing of diagrams in the following figures is sequential. If the result of one of them is true, no further processing is performed.

Figure below shows that if

- All three line-line loops caused start of the polygon impedance logic, and
- the currents in all three phases are above the setting limit, then a three-phase fault is detected and no further check is performed. The three-phase fault detection resets only if none of the three line-to-line loops detect fault any longer.

Figure. 6.3.22 - 106. Three phase fault.

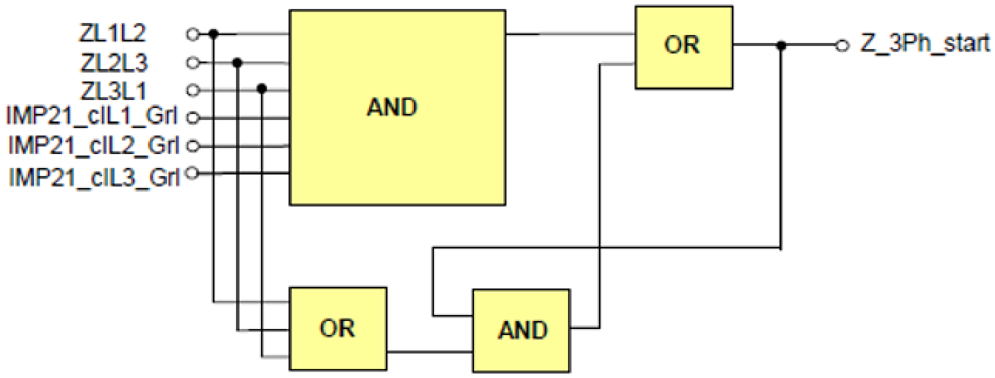


Table. 6.3.22 - 66. Output signals for three phase start decision of the impedance protection function.

Output status signal	Explanation
Z_3Ph_start	Three-phase start of the impedance protection function

Table. 6.3.22 - 67. Input signals for three phase start decision of the impedance protection function.

Input status signal	Explanation
ZL1L2	The calculated impedance of the fault loop L1L2 is within the characteristic
ZL2L3	The calculated impedance of the fault loop L2L3 is within the characteristic
ZL3L1	The calculated impedance of the fault loop L3L1 is within the characteristic
IMP21_cIL1_Grl_	The current in phase L1 is sufficient for impedance calculation

Table. 6.3.22 - 68. Inputs needed for three phase start decision

Input status signal	Explanation
IMP21_cIL2_Grl_	The current in phase L2 is sufficient for impedance calculation
IMP21_cIL3_Grl_	The current in phase L3 is sufficient for impedance calculation
ZL1L2	The calculated impedance of the fault loop L1L2 is within the characteristic
Z21L3	The calculated impedance of the fault loop L2L3 is within the characteristic
ZL3L1	The calculated impedance of the fault loop L3L1 is within the characteristic
IMP21_cIL1_Grl_	The current in phase L1 is sufficient for impedance calculation
IMP21_cIL2_Grl_	The current in phase L2 is sufficient for impedance calculation

Detection of “L1L2”, “L2L3”, “L3L1” faults

Figure below explains the detection of a phase-to-phase fault between phases “L1” and “L2”:

- no fault is detected in the previous sequential tests
- the start of the polygon impedance logic in loop “L1L2” detects the lowest reactance and

- “OR” relation of the following logic gates:
  - No zero sequence current above the limit and no start of the function in another phase-to-phase loop, or
  - In the presence of a zero sequence current
    - Start of the polygon impedance logic in loops “L1” and “L2” individually as well, or
    - The voltage is small in the faulty “L1L2” loop and the currents in both phases involved are above the setting limit.

The “L1L2” fault detection resets only if none of the “L1L2” line-to-line, “L1N” or “L2N” loops detect fault any longer.

In all figures:

minLL = Minimum(ZL1L2, ZL2L3, ZL3L1)

Figure. 6.3.22 - 107. L1L2 fault detection in Zone "n" (n=1…5).

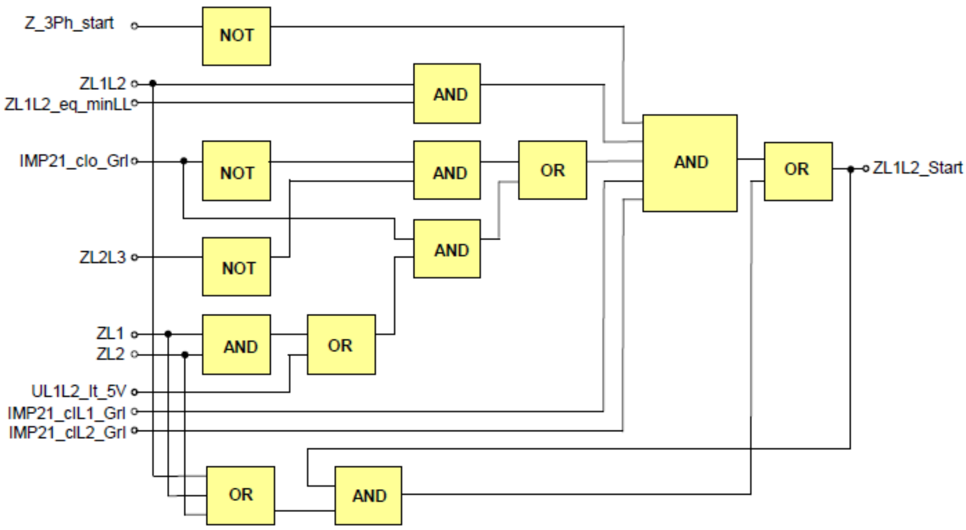


Figure. 6.3.22 - 108. L2L3 fault detection in Zone "n" (n=1…5).

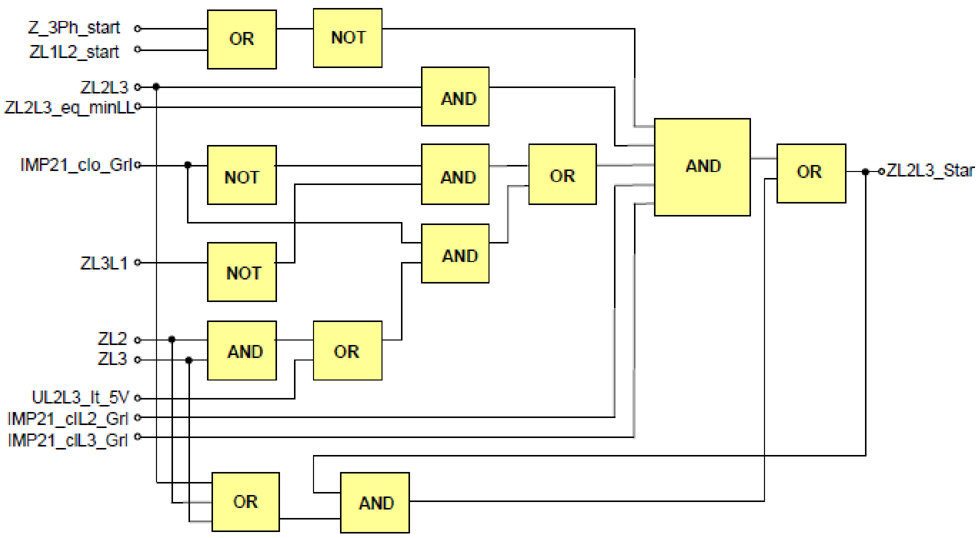


Figure. 6.3.22 - 109. L3L1 fault detection in Zone "n" (n=1…5).

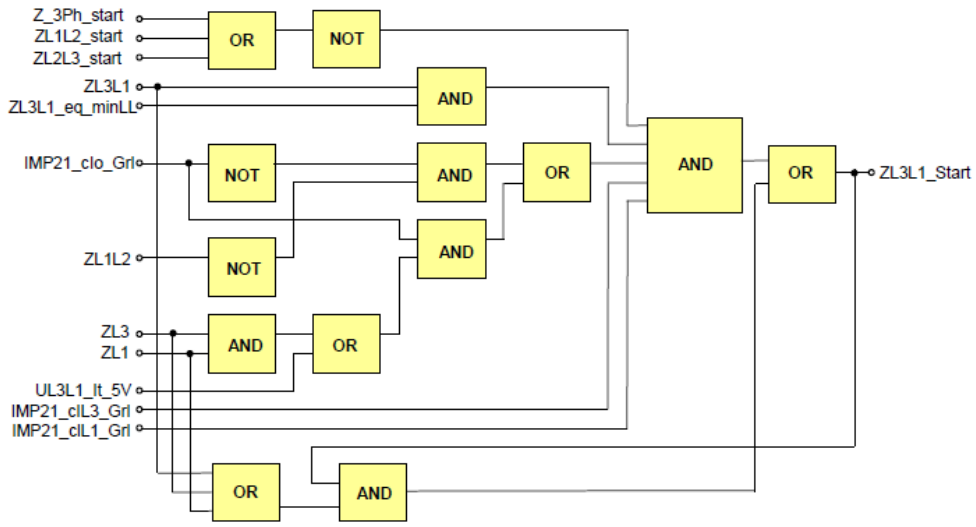


Table. 6.3.22 - 69. Output signals for phase to phase start decision of the impedance protection function.

Output status signals	Explanation
L1L2_Start	L1L2 loop start of the impedance protection function
L2L3_Start	L2L3 loop start of the impedance protection function
L3L1_Start	L3L1 loop start of the impedance protection function

Table. 6.3.22 - 70. Input signals for phase to phase start decision of the impedance protection function.

Input status signal	Explanation
Z_3Ph_Start	Outputs of the previous decisions
ZL1L2_Start	Outputs of the previous decisions
ZL2L3_Start	Outputs of the previous decisions
ZL1L2	The calculated impedance of the fault loop L1L2 is within the characteristic
ZL2L3	The calculated impedance of the fault loop L2L3 is within the characteristic
ZL3L1	The calculated impedance of the fault loop L3L1 is within the characteristic
ZL1L2_equ_minLL	The calculated impedance of the fault loop L1L2 is the smallest one
ZL2L3_equ_minLL	The calculated impedance of the fault loop L2L3 is the smallest one
ZL3L1_equ_minLL	The calculated impedance of the fault loop L3L1 is the smallest one
ZL1	The calculated impedance of the fault loop L1N is within the characteristic
ZL2	The calculated impedance of the fault loop L2N is within the characteristic
ZL3	The calculated impedance of the fault loop L3N is within the characteristic
IMP21_cIL1_Grl	The current in phase L1 is sufficient for impedance calculation

Input status signal	Explanation
IMP21_cIL2_GrI	The current in phase L2 is sufficient for impedance calculation
IMP21_cIL3_GrI	The current in phase L3 is sufficient for impedance calculation
IMP21_clo_GrI_	The zero sequence current component is sufficient for earth fault calculation
UL1L2_Lt_5V	The L1L2 voltage is less than 5 V
UL2L3_Lt_5V	The L2L3 voltage is less than 5 V
UL3L1_Lt_5V	The L3L1 voltage is less than 5 V

Detection of “L1N”, “L2N”, “L3N” faults

Figure below explains the detection of a phase-to-ground fault in phase “L1”:

- No fault is detected in the previous sequential tests
- Start of the impedance logic loop “L1N”
- The minimal impedance is measured in loop “L1N”
- No start of the logic in another phase-to-ground loop
- The zero sequence current above the limit
- The current in the phase involved is above the setting limit
- The minimal impedance of the phase-to-ground loop is less than the minimal impedance in the phase-to-phase loops.

In the figure below:

minLN = Minimum(ZL1N, ZL2N, ZL3N)

Figure. 6.3.22 - 110. L1N fault detection in Zone "n" (n=1…5).

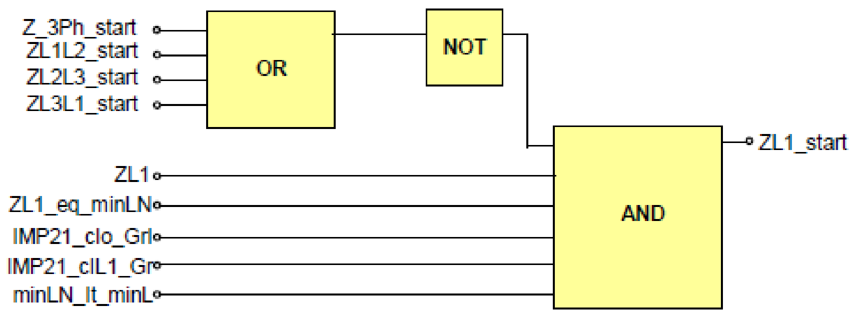


Figure. 6.3.22 - 111. L2N fault detection in Zone "n" (n=1…5)

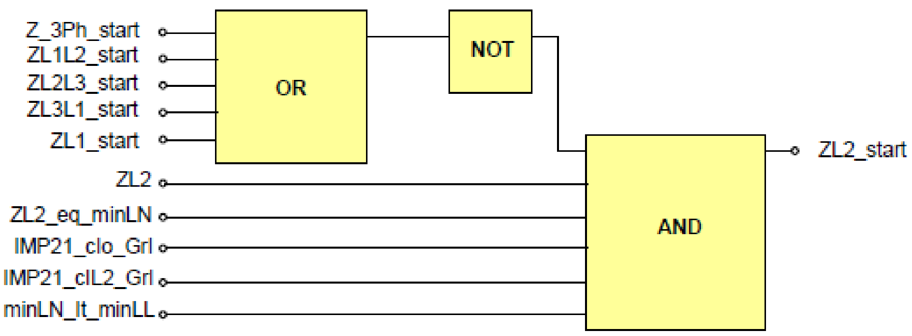


Figure. 6.3.22 - 112. L3N fault detection in Zone "n" (n = 1…5).

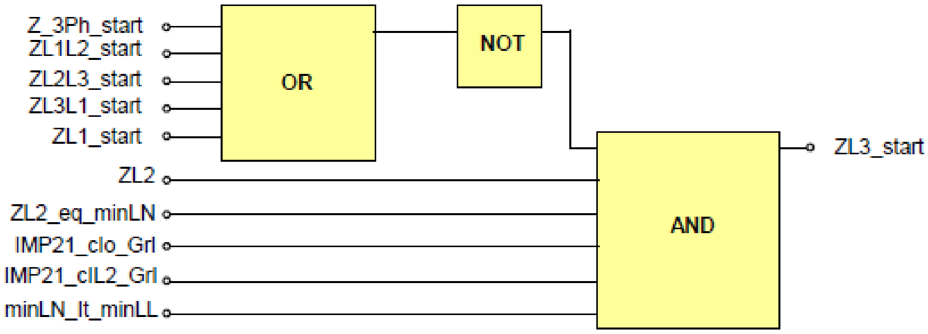


Table. 6.3.22 - 71. LN loop start of the distance protection function.

Output status signals	Zones	Explanation
ZL1_Start_n	n = 1…5	L1N loop start of the impedance protection function
ZL2_Start_n	n = 1…5	L2N loop start of the impedance protection function
ZL3_Start_n	n = 1…5	L3N loop start of the impedance protection function

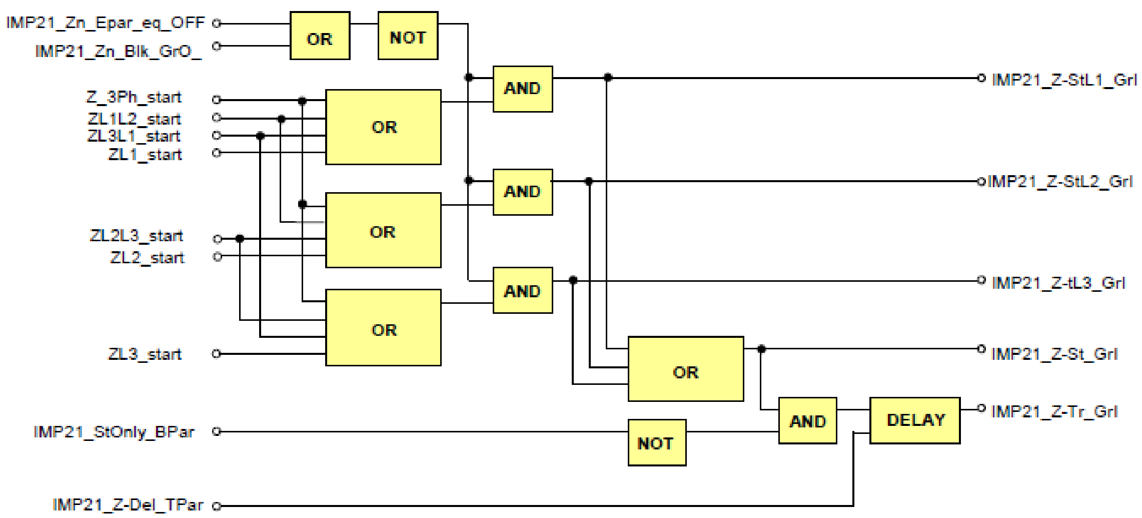
Table. 6.3.22 - 72. Input signals for phase to phase start decision of the impedance protection function.

Input status signal	Zones	Explanation
ZL1L2_Start_n	n = 1…5	Outputs of the previous decisions
ZL2L3_Start_n	n = 1…5	Outputs of the previous decisions
ZL3L1_Start_n	n = 1…5	Outputs of the previous decisions
ZL1_Start_n	n = 1…5	Outputs of the previous decisions
ZL2_Start_n	n = 1…5	Outputs of the previous decisions
ZL1_equ_minLN	n = 1…5	The calculated impedance of the fault loop L1L2 is the smallest one
ZL2_equ_minLN	n = 1…5	The calculated impedance of the fault loop L2L3 is the smallest one
ZL3_equ_minLN	n = 1…5	The calculated impedance of the fault loop L3L1 is the smallest one
ZL1_n	n = 1…5	The calculated impedance of fault loop L1N is within the zone characteristic
ZL2_n	n = 1…5	The calculated impedance of fault loop L3N is within the zone characteristic

Input status signal	Zones	Explanation
ZL3_n	n = 1…5	The calculated impedance of fault loop L3N is within the zone characteristic
DIS21_cIL1_GrI	n = 1…5	The current in phase L1 is sufficient for impedance calculation
DIS21_cIL2_GrI	n = 1…5	The current in phase L2 is sufficient for impedance calculation
DIS21_cIL3_GrI	n = 1…5	The current in phase L3 is sufficient for impedance calculation
DIS21_cIo_GrI	n = 1…5	The zero sequence current component is sufficient for impedance calculation in LN loops

In the figure below is presented the output signal processing principle of the distance protection function.

Figure. 6.3.22 - 113. Output signals of the impedance protection function.



- The operation of the impedance protection may be blocked either by parameter setting (IMP21_Z-_EPar_equ_Off) or by binary input (IMP21_Z-_Blk_GrO_)
- Starting in phase L1 if this phase is involved in the fault (IMP21_Z-StL1_GrI)
- Starting in phase L2 if this phase is involved in the fault (IMP21_Z-StL2_GrI)
- Starting in phase L2 if this phase is involved in the fault (IMP21_ZnStL3_GrI)
- General start if any of the phases is involved in the fault (IMP21_Z-St_GrI)
- A trip command is generated after the timer Delay is expired. This timer is started if the zone is started and if trip command is required too, as it is set, using the parameter IMP21_ StOnly_BPar. The time delay is set by the timer parameter IMP21_Z-Del_TPar.

Table. 6.3.22 - 73. General phase identification of the distance protection function.

Binary output signal	Signal title	Explanation
Impedance Phase identification		

Binary output signal	Signal title	Explanation
DIS21_GenStL1_GrI_	GenStart L1	General start in phase L1
DIS21_GenStL2_GrI_	GenStart L2	General start in phase L2
DIS21_GenStL3_GrI_	GenStart L3	General start in phase L3

The separate phase identification signals for Zones 2-5 are not published.

Current conditions of the impedance protection function

The impedance 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.

Table. 6.3.22 - 74. The binary output status signals of the current conditions module.

Binary output signal	Signal title	Explanation
Impedance function start conditions generated by the I_COND module (these signals are not published)		
IMP21_cIo_GrI_	I0 condition	The zero sequence current component is sufficient for earth fault calculation
IMP21_cIL1_GrI_	I L1 condition	The current in phase L1 is sufficient for impedance calculation
IMP21_cIL2_GrI_	I L2 condition	The current in phase L2 is sufficient for impedance calculation
IMP21_cIL3_GrI_	I L3 condition	The current in phase L3 is sufficient for impedance calculation

The current is considered to be sufficient for impedance calculation if it is above the level set by parameter IMP21_Imin_IPar_.

To decide the presence or absence of the zero sequence current, biased characteristics are applied (see figure below). The minimal setting current IMP21_IoBase_IPar_ (Io Base sens.) and a percentage biasing IMP21_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 - 114. Percentage characteristic for earth fault detection.

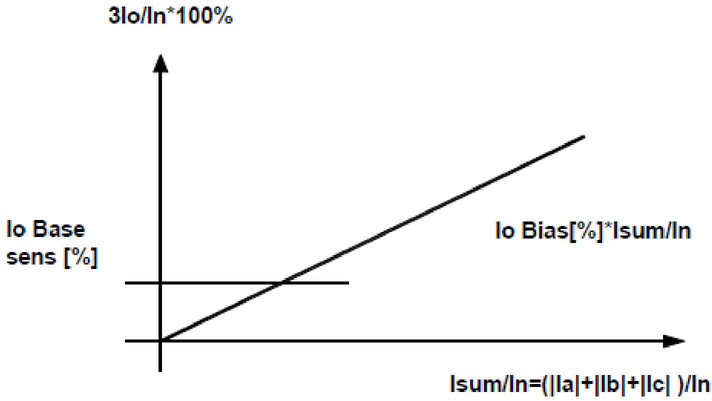


Figure. 6.3.22 - 115. The function block of the impedance protection function with offset characteristic.

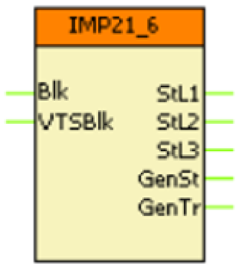


Table. 6.3.22 - 75. Setting parameters of the impedance protection function.

Parameter	Setting value / range	Step	Default	Description
Operation	Off NoCompound FWCompound BWCompound	-	NoCompound	Operating mode selection for the function.
Impedance start only	Activated Deactivated	-	Deactivated	Selection if the function issues either "Start" signal alone or both "Start" and after set time delay "Trip" signal.
IPh Base Sens	10…30 %	1 %	20 %	Minimum current setting for phase currents.
IRes Base Sens	10…50 %	1 %	10 %	Minimum current setting for residual current.
IRes bias	5…30 %	1 %	10 %	Slope of the percentage characteristic for earth fault detection.
PsImpAng	0…90 deg	1 deg	10 deg	Positive impedance angle
OfsImpRch	–150.00…150.00 Ω	0.01 Ω	0.00 Ω	Offset impedance reach
PsImpRch	0.10…250.00 Ω	0.01 Ω	0.00 Ω	Positive impedance reach

Parameter	Setting value / range	Step	Default	Description
Zone1 (Xo-X1)/3X1	0.00…5.00	0.01	0.00	The zero sequence current compensation factor, calculated with X values.
Zone1 (Ro-R1)/3R1	0.00…5.00	0.01	0.00	The zero sequence current compensation factor, calculated with R values.
Time delay	0…60 000 ms	1 ms	500 ms	Operation time delay

6.3.23 Loss of excitation (40)

The loss of excitation protection function can be applied mainly for synchronous generators. On loss of excitation, the flux decreases and the reactive current demand increases relatively slowly. At the end, high reactive current flows from the power system into the machine. To protect the stator coils from the harmful effects of the high currents and to protect the rotor from damages caused by the induced slip-frequency current, a disconnection is required.

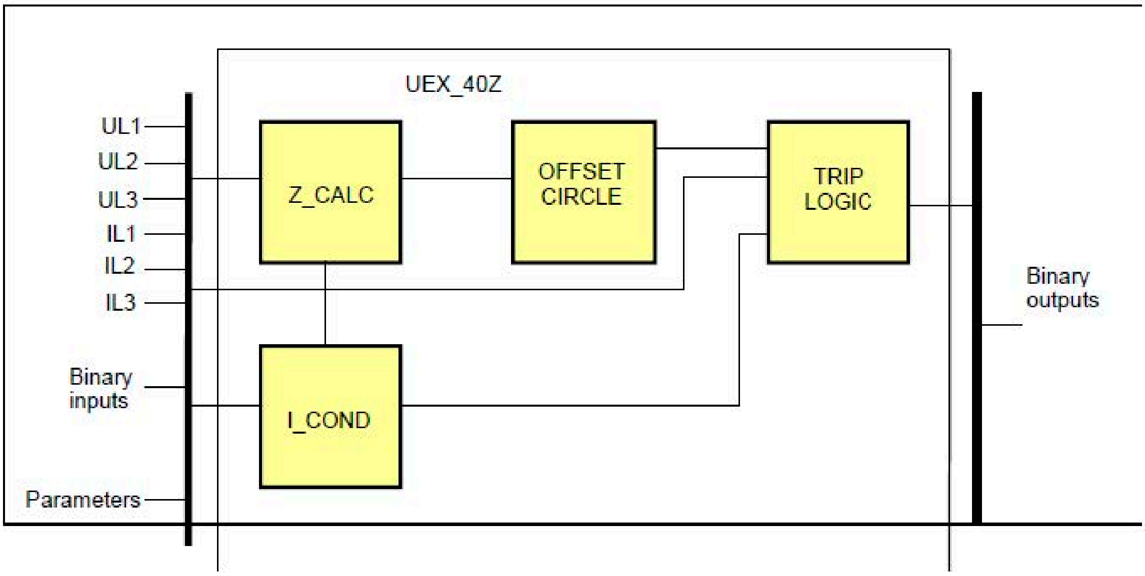
The loss of excitation (loss-of-field) protection function is designed for this purpose.When the excitation is lost, then a relatively high inductive current flows into the generator. With the positive direction from the generator to the network, the calculated impedance based on this current and on the phase voltage is a negative reactive value. As the internal e.m.f. collapses, the locus of the impedance on the impedance plane travels to this negative reactive value. With an appropriate characteristic curve on the impedance plane, the loss of excitation state can be detected. The applied characteristic line is a closed offset circle, the radius and the centre of which is defined by parameter setting.If the calculated impedance gets into the offset circle then the function generates a trip command.The loss of excitation protection function provides two stages, where the parameters of the circles and additionally the delay times can be set independently.The main features of the loss of excitation 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 phase currents being sufficient.
- The operate decision is based on offset circle characteristics.
    - Two independent stages.
- Binary input signals and conditions can influence the operation:
    - Blocking/enabling.
    - VT failure signal.

Structure of loss of excitation protection function

Figure below shows the structure of the loss of excitation protection function with compounded circular characteristic.

Figure. 6.3.23 - 116. Structure of loss of excitation protection function.



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 impedance protection function are as follows:

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

OFFSET CIRCLE compares the calculated impedances with the setting values of the compounded circle 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.

Impedance calculation

The loss of excitation protection 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 table below. Reference source not found.. The result of this calculation s the positive sequence impedance of the measuring loops.

Table. 6.3.23 - 76. Formulas for the calculation of the impedances in the loops.

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

Loop	Calculation of Z
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.

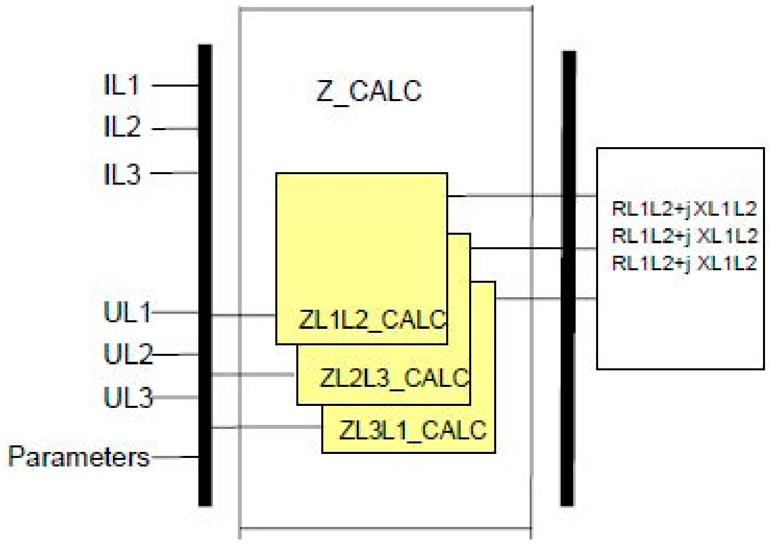
This basic principle is realized in the algorithm by substituting the Fourier fundamental component values of the line-to-line voltages for u and the difference of the Fourier fundamental components of two phase currents:

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

R1 = the positive sequence resistance of the measuring loop
L1 = the positive sequence inductance of the measuring loop
L1, L2, L3 = the three phases.

The applied numerical method is solving the differential equation of the measuring loop, based on the orthogonal components of the Fourier fundamental component vectors. The calculation results complex impedances on the network frequency. Figure below shows the principal scheme of the impedance calculation Z_CALC.

Figure. 6.3.23 - 117. Principal scheme of the impedance calculation Z_CALC.



The inputs are:

- The Fourier components of the three phase voltages

- The Fourier components of the three phase currents
- Parameters.

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

- Impedances of the three phase-phase loops.

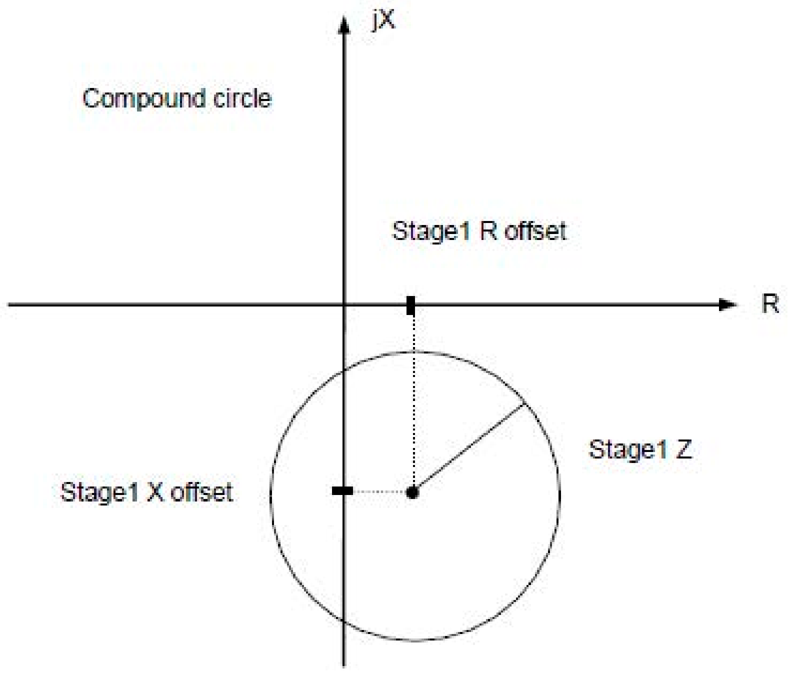
Table. 6.3.23 - 77. The calculated values of the Z_CALC module.

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

Characteristics of loss of excitation protection function (OFFSET CIRCLE)

The operate decision is based on offset circle characteristics. The calculated R1 and X1=ϖL1 co-ordinate values of the three measuring loops define three points on the complex impedance plane. These impedances are the positive sequence impedances in the measuring loops. The protection compares these points with the „offset circle" characteristics of the loss of excitation protection, shown for stage 1 in figure below. For stage 2 the characteristic is the same with independent parameters. Parameter settings decide the size and the position of the circle. The center of the circle can be on the positive R and negative X quadrant of the impedance plane. The R offset and X offset values are defined to be positive in this quadrant.

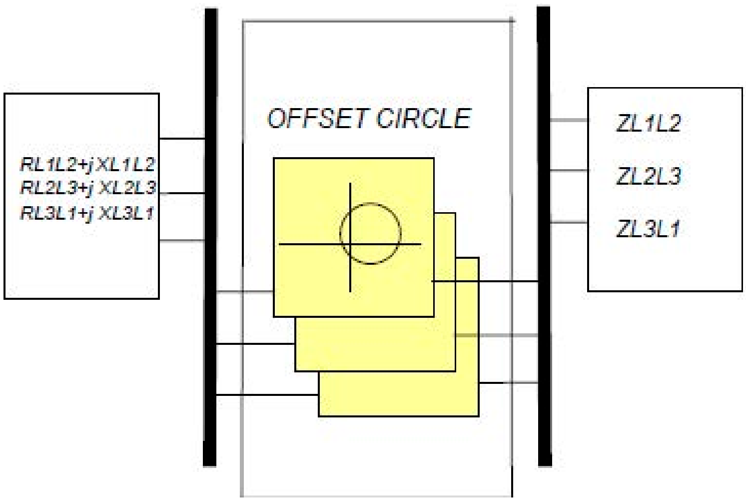
Figure. 6.3.23 - 118. Offset characteristics.



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

The calculated impedance values are compared one by one with the setting values of the „offset circle" characteristics. This procedure is shown schematically in figure below. The procedure is processed for each line-to-line loop. The result is the binary setting of three status variables. This indicates that the calculated impedance is within the processed "offset circle" characteristics.

Figure. 6.3.23 - 119. Principal scheme of the offset circle module.



Input vales

The input values are calculated by the module Z_CALC.

Table. 6.3.23 - 78. Input values.

Input value	Explanation
RL1L2+j XL1L2	Calculated impedance in the measuring loop L1L2
RL2L3+j XL2L3	Calculated impedance in the measuring loop L2L3
RL3L1+j XL3L1	Calculated impedance in the measuring loop L3L1

Output values

Table. 6.3.23 - 79. Output values.

Output value	Explanation
ZL1L2_1	The impedance in the measuring loop L1L2 is inside the characteristics of stage 1
ZL2L3_1	The impedance in the measuring loop L2L3 is inside the characteristics of stage 1
ZL3L1_1	The impedance in the measuring loop L3L1 is inside the characteristics of stage 1
ZL1L2_2	The impedance in the measuring loop L1L2 is inside the characteristics of stage 2
ZL2L3_2	The impedance in the measuring loop L2L3 is inside the characteristics of stage 2
ZL3L1_2	The impedance in the measuring loop L3L1 is inside the characteristics of stage 2

Trip logic and time

Table. 6.3.23 - 80. Binary inputs.

Binary input signals from offset circle module		Explanation
The started states generated by the offset circle module (these signals are not published)		
ZL1L2_1		The impedance in the measuring loop L1L2 is inside the characteristics of stage 1
ZL2L3_1		The impedance in the measuring loop L2L3 is inside the characteristics of stage 1
ZL3L1_1		The impedance in the measuring loop L3L1 is inside the characteristics of stage 1
ZL1L2_2		The impedance in the measuring loop L1L2 is inside the characteristics of stage 2
ZL2L3_2		The impedance in the measuring loop L2L3 is inside the characteristics of stage 2
ZL3L1_2		The impedance in the measuring loop L3L1 is inside the characteristics of stage 2
Impedance function start conditions generated by the I_COND module (these signals are not published)		
UEX_40Z_clL1_GrI_	I L1 condition	The current in phase L1 is sufficient for impedance calculation
UEX_40Z_clL2_GrI_	I L2 condition	The current in phase L2 is sufficient for impedance calculation
UEX_40Z_clL3_GrI_	I L3 condition	The current in phase L3 is sufficient for impedance calculation

Table. 6.3.23 - 81. Binary output status signals.

Binary status signal	Title	Explanation
UEX_40Z_GenSt1_GrI_	General Start 1	General start signal of the first stage
UEX_40Z_GenTr1_GrI_	General Trip 1	General trip signal of the first stage
UEX_40Z_GenSt2_GrI_	General Start 2	General start signal of the second stage
UEX_40Z_GenTr1_GrI_	General Trip 2	General trip signal of the second stage

Table. 6.3.23 - 82. Binary output status signals.

Binary status signal	Title	Explanation
UEX_40Z_Blk_GrO_	Block	Blocking of the underexcitation protection function
UEX_40Z_VTSBlk_GrO_	Block from VTS	Blocking of the underexcitation protection function from the VT supervision function

Current conditions for impedance calculation

The impedance protection function can operate only if the current is sufficient for impedance calculation. This function performs this preliminary decision.

Table. 6.3.23 - 83. Binary output signals.

Binary output signal	Signal title	Explanation
Impedance function start conditions (these signals are not published)		
UEX_40Z_cIL1_GrO_	I L1 condition	The current in phase L1 is sufficient for impedance calculation
UEX_40Z_cIL2_GrO_	I L2 condition	The current in phase L2 is sufficient for impedance calculation
UEX_40Z_cIL3_GrO_	I L3 condition	The current in phase L3 is sufficient for impedance calculation

Figure. 6.3.23 - 120. The function block of the loss of excitation protection function.

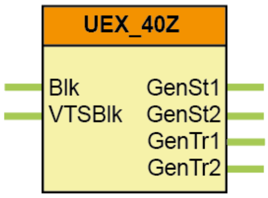


Table. 6.3.23 - 84. Setting parameters of the impedance protection function.

Parameter	Setting value / range	Step	Default	Description
Operation	Off NoCompound FWCompound BWCompound	-	NoCompound	Operating mode selection for the function.
Impedance start only	Activated Deactivated	-	Deactivated	Selection if the function issues either "Start" signal alone or both "Start" and after set time delay "Trip" signal.
IPh Base Sens	10…30 %	1 %	20 %	Minimum current setting for phase currents.
IRes Base Sens	10…50 %	1 %	10 %	Minimum current setting for residual current.
IRes bias	5…30 %	1 %	10 %	Slope of the percentage characteristic for earth fault detection.
PsImpAng	0…90 deg	1 deg	10 deg	Positive impedance angle
OfsImpRch	–150.00…150.00 Ω	0.01 Ω	0.00 Ω	Offset impedance reach
PsImpRch	0.10…250.00 Ω	0.01 Ω	0.00 Ω	Positive impedance reach
Zone1 (Xo-X1)/3X1	0.00…5.00	0.01	0.00	The zero sequence current compensation factor, calculated with X values.

Parameter	Setting value / range	Step	Default	Description
Zone1 (Ro-R1)/3R1	0.00…5.00	0.01	0.00	The zero sequence current compensation factor, calculated with R values.
Time delay	0…60 000 ms	1 ms	500 ms	Operation time delay

6.3.24 Overexcitation (V/H>; 24)

The over excitation protection function is applied to protect generators and unit transformers against high flux values causing saturation of the iron cores and consequently high magnetizing currents.

The problem to be solved is as follows: The flux is the integrated value of the voltage:

$$\Phi(t) = \Phi_0 + \int_0^t u(t)dt$$

In steady state, this integral can be high if the area under the sinusoidal voltage-time function is large. Mathematically this means that in steady state the flux, as the integral of the sinusoidal voltage function, can be expressed as

$$\Phi(t) = k\frac{U}{f}cos\omega t$$

The peak value of the flux increases if the magnitude of the voltage increases, and/or the flux can be high if the duration of a period increases; this means that the frequency of the voltage decreases. That is, the flux is proportional to the peak value (or to the RMS value) of the voltage and inversely proportional to the frequency.

Note: the overexcitation protection function is intended to be applied near the generator, where the voltage is expected to be pure sinusoidal, without any distortion. Therefore, a continuous integration of the voltage and a simple peak detection algorithm can be applied.

The effect of high flux values is the symmetrical saturation of the iron core of the generator or that of the unit transformer. During saturation, the magnetizing current is high and distorted; high current peaks can be detected. The odd harmonic components of the current are of high magnitude and the RMS value of the current also increases. The high peak values of the currents generate high dynamic forces, the high RMS value causes overheating. During saturation, the flux leaves the iron core and high eddy currents are generated in the metallic part of the generator or transformer in which normally no current flows, and which is not designed to withstand overheating.

The frequency can deviate from the rated network frequency during start-up of the generator or at an unwanted disconnection of the load. In this case the generator is not connected to thenetwork and the frequency is not kept at a “constant” value. If the generator is excited in this state and the frequency is below the rated value, then the flux may increase above the tolerated value. Similar problems may occur in distributed generating stations in case of island operation.

The overexcitation protection is designed to prevent this long-term overexcited state.The flux is calculated continuously as the integral of the voltage. In case of the supposed sinusoidal voltage, the shape of the integrated flux will be sinusoidal too, the frequency of which is identical with that of the voltage. The magnitude of the flux can be found by searching for the maximum and the minimum values of the sinusoid.

The magnitude can be calculated if at least one positive and one negative peak value have been found, and the function starts if the calculated flux magnitude is above the setting value. Accordingly, the starting delay of the function depends on the frequency: if the frequency is low, more time is needed to reach the opposite peak value. In case of energizing, the time to find the first peak depends on the starting phase angle of the sinusoidal flux. If the voltage is increased continuously by increasing the excitation of the generator, this time delay cannot be measured.

Operating characteristics

The most harmful effect of the overexcited state is unwanted overheating. As the heating effect of the distorted current is not directly proportional to the flux value, the applied characteristic is of inverse type (so called IEEE type): If the overexcitation increases, the operating time decreases. To meet the requirements of application, a definite-time characteristic is also offered in this protection function as an alternative.The supervised quantity is the calculated U/f value as a percentage of the nominal values (index N):

$$G = \frac{U/f}{U_N/f_N} 100[\%] = \frac{U/U_N}{f/f_N} 100[\%]$$

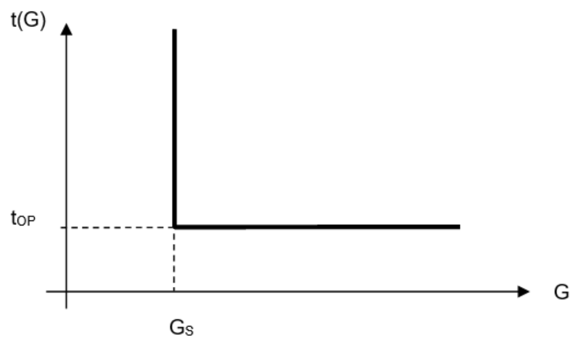
The over-dimensioning of generators in this respect is usually about 5%, that of the transformer about 10%, but for unit transformers this factor can be even higher.

At start-up of the function, the protection generates a warning signal aimed to inform the controller to decrease the excitation. If the time delay determined by the parameter values of the selected characteristics expires, the function generates a trip command to decrease or to switch off the excitation and the generator.

Definite time characteristics

Operate time

Figure. 6.3.24 - 121. Overexcitation independent time characteristic.



where:

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

t_{OP} (seconds) = the theoretical operating time $G>G_S$, fix, according to the parameter setting (VPH24_MinDel_TPar_, Min. Time Delay)

G = the measured value of the characteristic quantity; this is the U/f peak value as a percentage of the rated U_N/f_N value

G_S = the setting value of the characteristic quantity (VPH24_EmaxCont_IPar_, Start U/f LowSet); this is the U_{set}/f_{set} peak value as a percentage of the rated U_N/f_N value

Reset time

$t(G) = t_{Drop\text{-}off}$ (when $G<0.95*G_S$)

where:

$t_{drop\text{-}off}$ (seconds) = the drop-off time if $G<0.95*G_S$, fix value

IEEE standard dependent time characteristics

Operating time

"IEEE square law"

$$t = \frac{0.18 * TMS}{\left(\frac{U/f}{U_N/f_N} - \frac{U_{set}/f_{set}}{U_N/f_N}\right)^2} = \frac{0.18 * TMS}{(G - G_S)^2}$$

where:

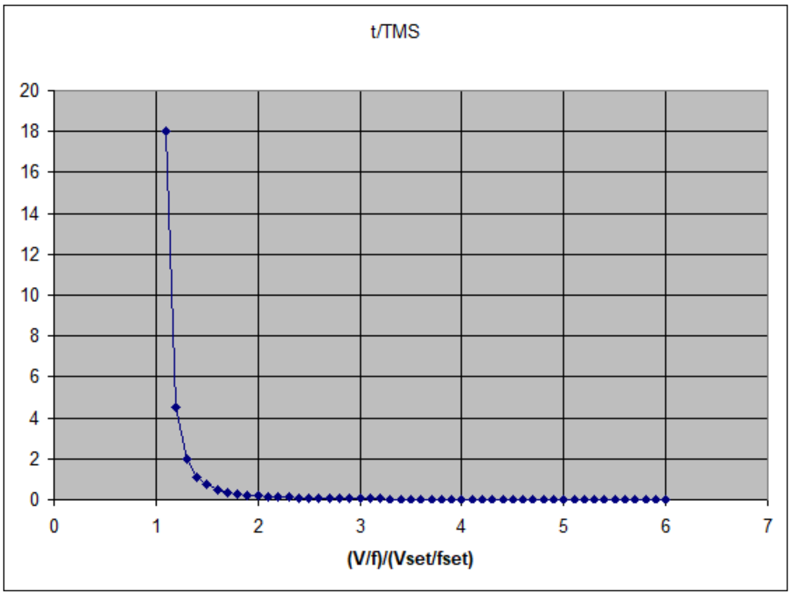
TMS = 1…60, time multiplier setting

U/f = flux value calculated at the measured voltage and frequency

U_N/f_N = flux at rated voltage and rated frequency

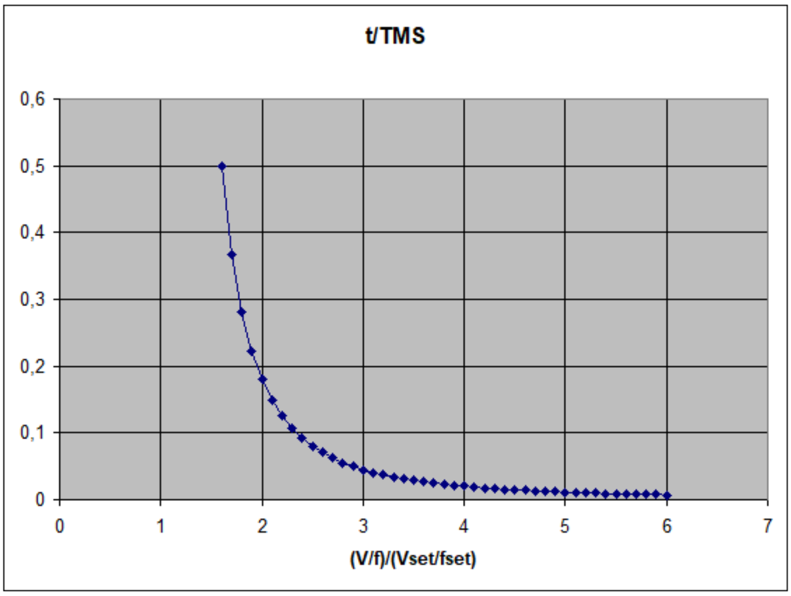
U_{set}/f_{set} = flux setting value.

Figure. 6.3.24 - 122. IEEE standard dependent time characteristics.



The maximum delay time is limited by the parameter VPH24_MaxDel_TPar_ (Max.Time Delay). This time delay is valid if the flux is above the preset value VPH24_EmaxCont_IPar_ (Start U/f LowSet).

Figure. 6.3.24 - 123. IEEE standard dependent time characteristics (enlarged).



This inverse type characteristic is also combined with a minimum time delay, the value of which is set by user parameter VPH24_MinDel_TPar_ (Min. Time Delay). This time delay is valid if the flux is above the setting value VPH24_Emax_IPar_ (Start U/f HighSet).

Reset time

If the calculated flux is below the drop-off flux value (when *s*G < 0.95*G), then thecalculated flux value decreases linearly to zero. The time to reach zero is defined by the parameter VPH24_CoolDel_TPar_ (Cooling Time).

Analogue input of the function

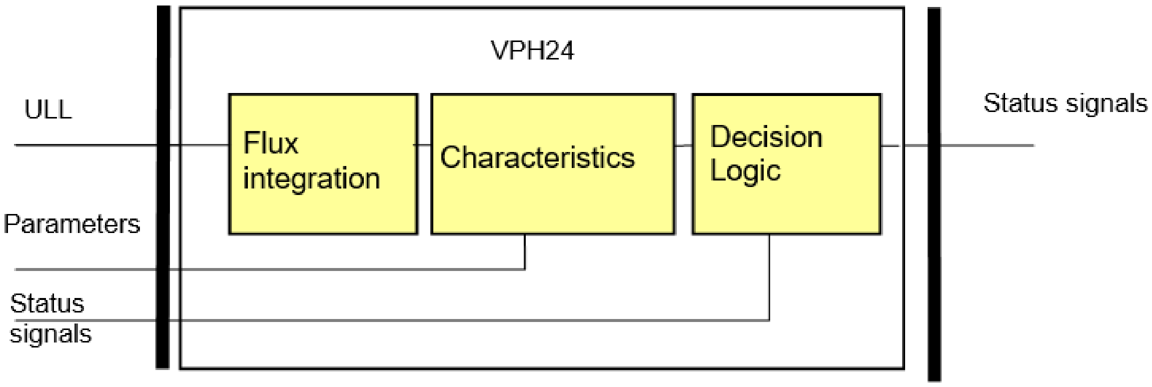
Overexcitation is a typically symmetrical phenomenon. There are other dedicated protection functions against asymmetry. Accordingly, the processing of a single voltage is sufficient. In a network with isolated neutral, the phase voltage is not exactly defined due to the uncertain zero sequence voltage component. Therefore, line-to-line voltages are calculated based on the measured phase voltages, and one of them is assigned to overfluxing protection.

As overexcitation is a phenomenon which is typical if the generator or the generator transformer unit is not connected to the network, the voltage drop does not need any compensation. If the voltage is measured at the supply side of the unit transformer, then the voltage is higher then the voltage of the magnetization branch of the transformer’s equivalent circuit. Thus the calculated flux cannot be less then the real flux value. The protection operates with increased security.

Structure of the overexcitation protection function

Figure below shows the structure of the overexcitation protection (VPH24) algorithm.

Figure. 6.3.24 - 124. Structure of the overexcitation protection function.



The inputs are

- The sampled values of a line-to-line voltage (ULL)
- Parameters
- Status signals.

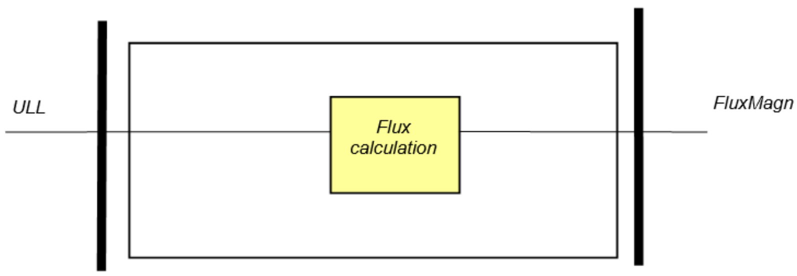
The outputs are

- The binary output status signals.

The software modules of the overexcitation protection function:

- Flux saturation
  This module integrates the voltage to obtain the flux time-function and determines the magnitude of the flux. The inputs are the sampled values of a line-to-line voltage (ULL). The output is the magnitude of the flux (FluxMagn), internal signal.

Figure. 6.3.24 - 125. Principal scheme of the flux calculation.



- Characteristics
  This module calculates the required time delay based on the magnitude of the flux and the parameter settings.
- Decision logic
  The decision logic module combines the status signals to generate the trip command of the function.

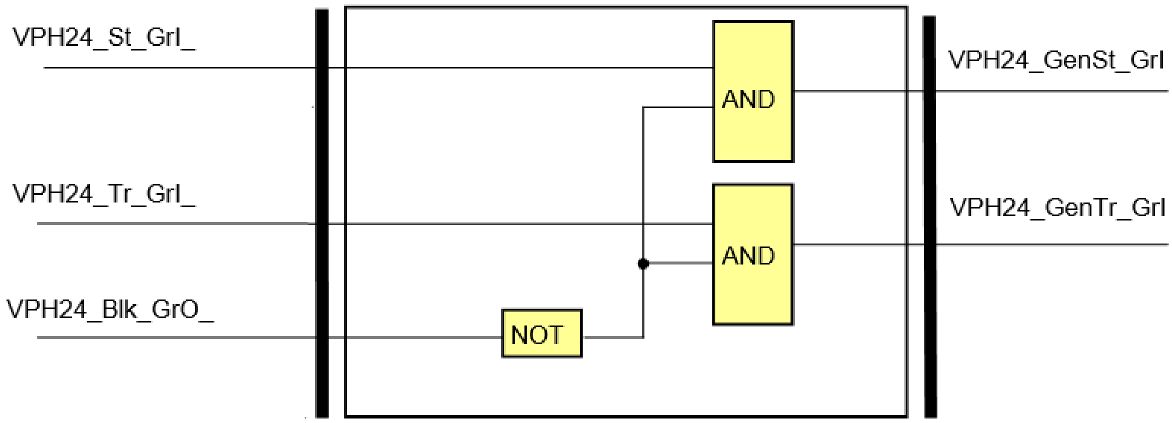


Table. 6.3.24 - 85. Binary status signals.

Binary output signals	Signal title	Explanation
VPH24_GenSt_GrI_	General Start	General starting of the function
VPH24_GenTr_GrI_	General Trip	General trip command of the function
Binary status signal	**Explanation**	
VPH24_Blk_GrO_	Output status defined by the user to disable the overexcitation protection function.	
VPH24_St_GrI_	Starting of the function	
VPH24_Tr_GrI_	Trip command of the function	

Figure. 6.3.24 - 126. The function block of the overexcitation protection function.

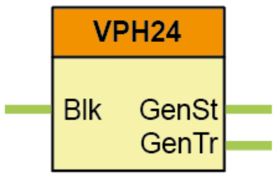


Table. 6.3.24 - 86. Setting parameters of the overexcitation protection function.

Parameter	Setting value / range	Step	Default	Description
Operation	Off Definite time IEEE	-	Definite time	Operating mode selection for the function. Operation can be either disabled “Off” or definite time or IEEE inverse characteristics.
Start U/f	80…140 %	1 %	110 %	Pick-up setting of the function
Time multiplier	1…100	1	10	Time multiplier for inverse time characteristics

Parameter	Setting value / range	Step	Default	Description
Min Time Delay	0.5…60 s	0.01 s	10 s	Minimum time delay for inverse time characteristics or delay for the definite time characteristics.
Max Time Delay	300…8 000 s	0.01 s	3 000 s	Maximum time delay for inverse time characteristics.
Cooling time	60…8 000 s	0.01 s	1 000 s	Reset time delay for inverse time characteristics.

6.3.25 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.

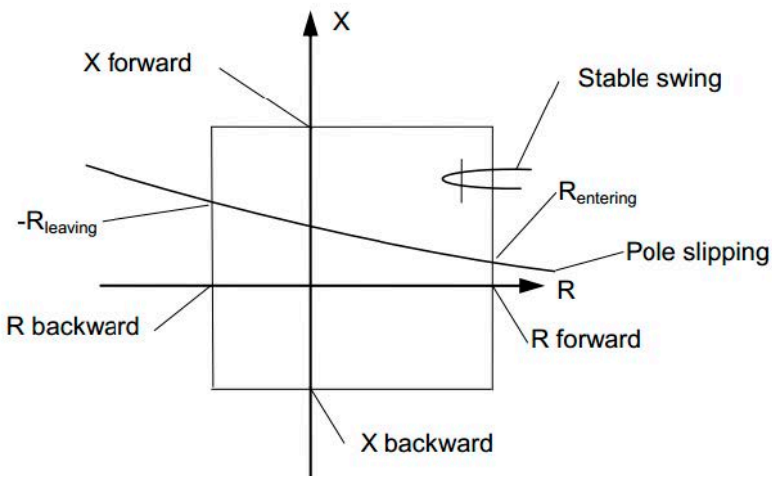
The pole slipping protection function is designed for this purpose.

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. 6.3.25 - 127. 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 –$R_{leaving}$) 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

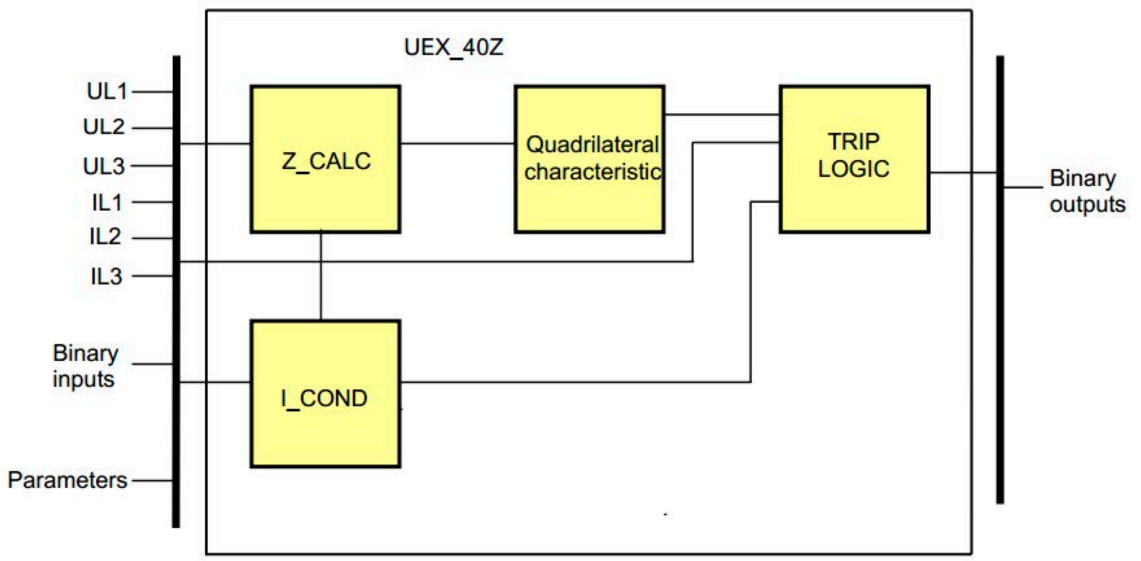
The main features of the pole slipping protection function are as follows:

- 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. 6.3.25 - 128. 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. 6.3.25 - 87. 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:

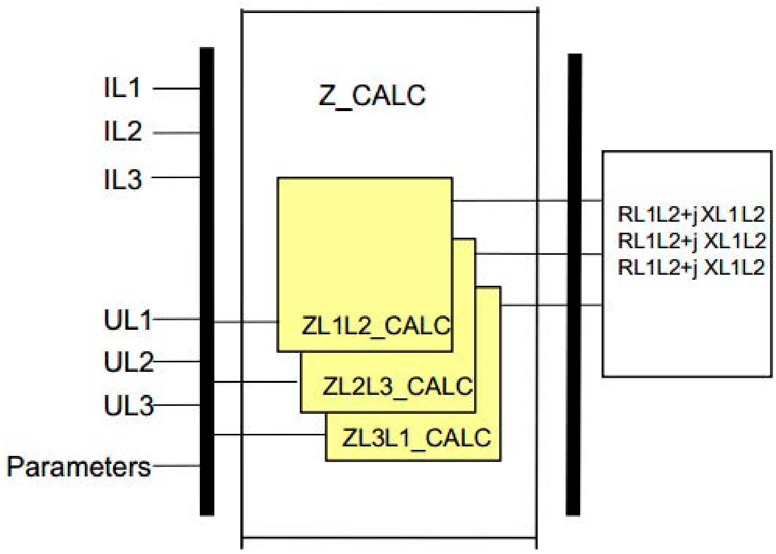
$$u_{L2} - u_{L3} = R_1(i_{L2} - i_{L3}) + L_1\frac{d(i_{L2} - i_{L3})}{dt}$$

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. 6.3.25 - 129. 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. 6.3.25 - 88. 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.

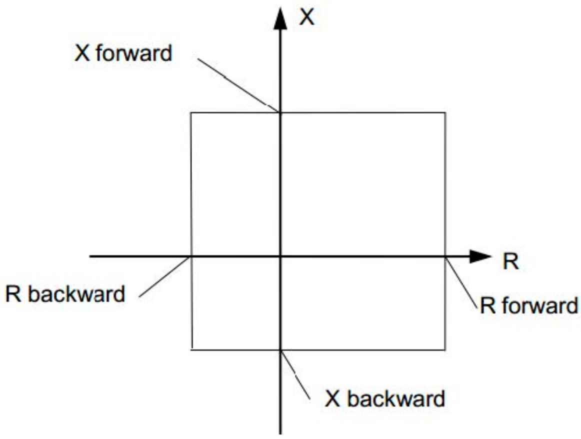
The characteristics of the pole slip protection function (Quadrilateral characteristics)

The method is an impedance-based comparison.

The operate decision is based on quadrilateral characteristics.

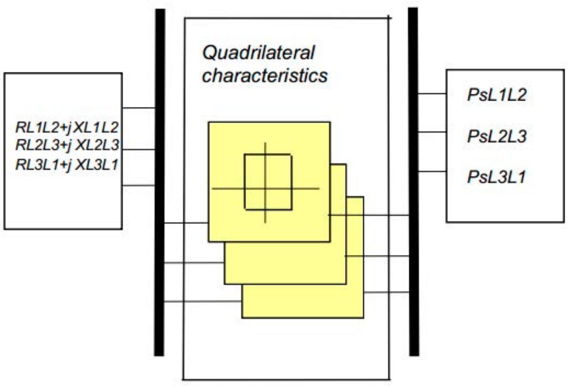
The calculated R1 and X1= L1 co-ordinate values of the three measuring loops define three points on the complex impedance plane. These impedances are the positive sequence impedances. The protection compares these points with the quadrilateral characteristics of the pole slip protection, shown in the 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. 6.3.25 - 130. 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. 6.3.25 - 131. Principal scheme of the quadrilateral characteristic decision.



Input values

The input values are calculated by the module Z_CALC.

Table. 6.3.25 - 89. 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. 6.3.25 - 90. 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. 6.3.25 - 91. 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. 6.3.25 - 92. 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. 6.3.25 - 93. Trip pulse parameter setting.

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

Table. 6.3.25 - 94. 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. 6.3.25 - 95. 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. 6.3.25 - 96. 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. 6.3.25 - 132. The function block of the pole slip function.

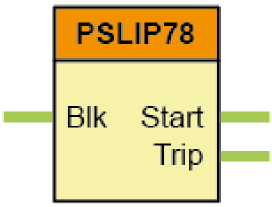


Table. 6.3.25 - 97. Binary I/O signals.

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

6.3.26 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. 6.3.26 - 98. 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.

Parameter	Setting value / range	Step	Default	Description
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.

6.4 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 - 133. The function block of the common function block.

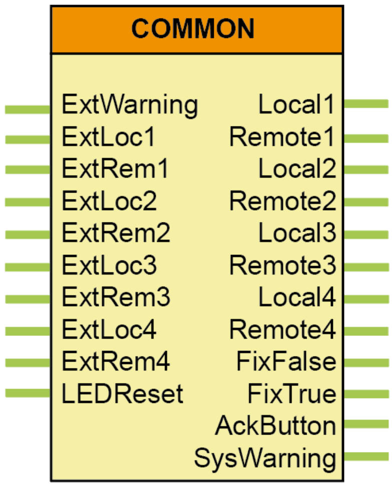


Table. 6.4.1 - 99. The binary output status signals.

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

Binary output status signal	Title	Explanation
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 - 100. 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
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.

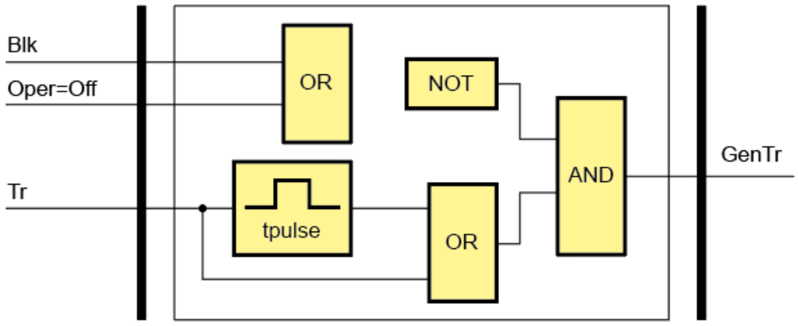
Table. 6.4.1 - 101. Setting parameters.

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.

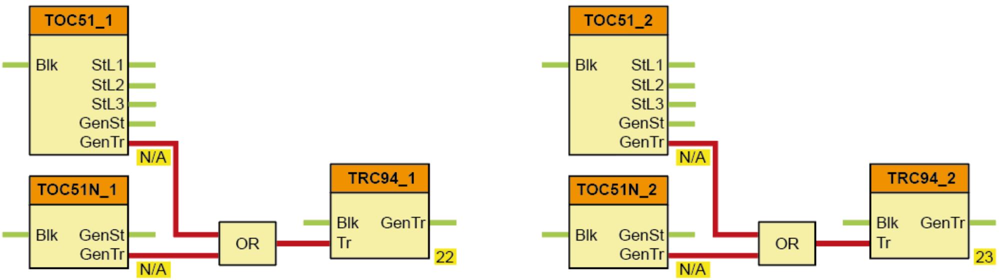
Figure. 6.4.2 - 134. Operation logic of the trip logic function.



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.

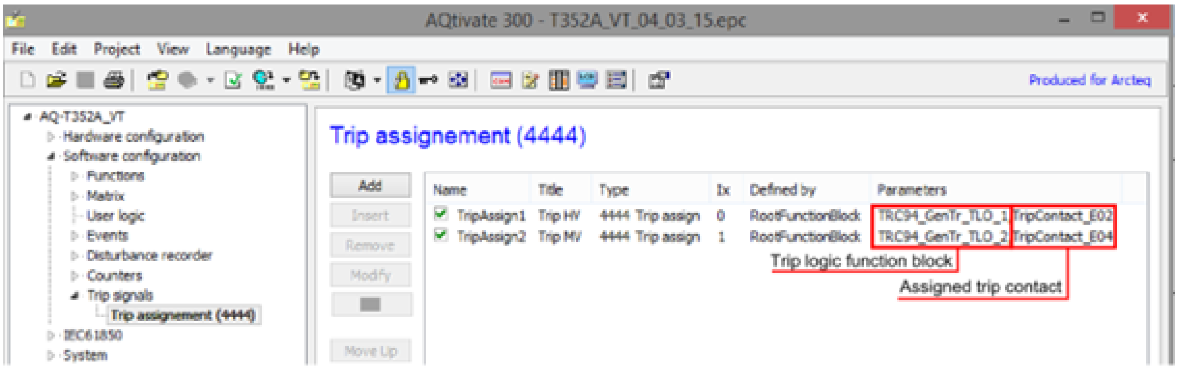
Application example

Figure. 6.4.2 - 135. Example picture where two I> TOC51 and I0> TOC51N trip signals are connected to two trip logic function blocks.



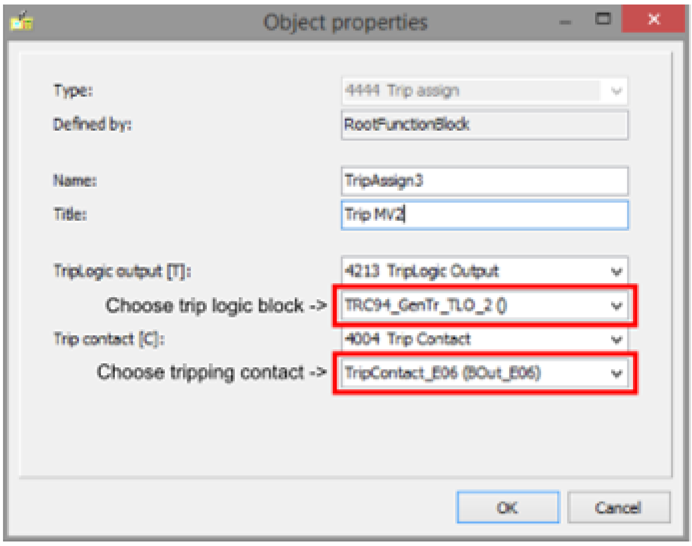
In this example we have a transformer protection supervising phase and residual currentson both sides of the transformer. So in this case the protection function trips have been connected to their individual trip logic blocks (for high voltage side and low voltage side). After connecting the trip signals 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 - 136. 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 - 137. 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 - 102. 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.

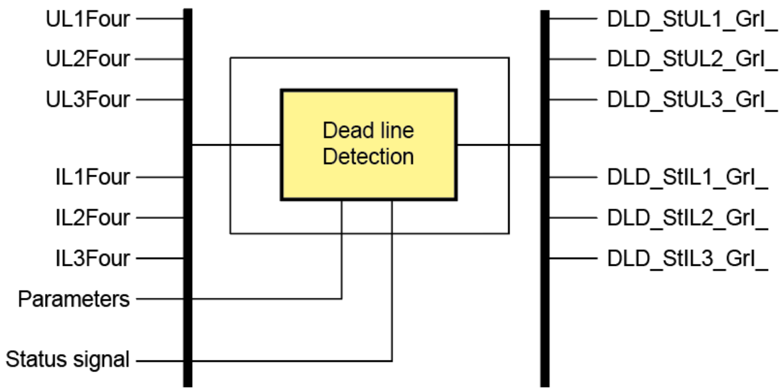
Criteria of "Dead line" state: all three phase voltages are below the voltage setting value AND all three currents are below the current setting value.

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.

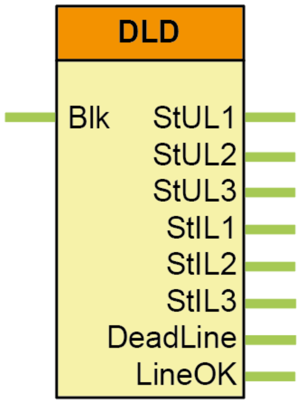
In the figure below is presented the operating logic of the dead line detection function.

Figure. 6.4.3 - 138. 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 - 139. 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 - 103. 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 - 104. The binary output status signals.

Binary output signal	Signal title	Explanation
DLD function		
DLD_StUL1_Grl_	Start UL1	The voltage of phase L1 is above the setting limit
DLD_StUL2_Grl_	Start UL2	The voltage of phase L2 is above the setting limit
DLD_StUL3_Grl_	Start UL3	The voltage of phase L3 is above the setting limit
DLD_StIL1_Grl_	Start IL1	The current of phase L1 is above the setting limit
DLD_StIL2_Grl_	Start IL2	The current of phase L2 is above the setting limit
DLD_StIL3_Grl_	Start IL3	The current of phase L3 is above the setting limit
DLD_DeadLine_Grl_	DeadLine condition	The requirements of "DeadLine condition" are fulfilled
DLD_LineOK_Grl_	LineOK condition	The requirements of "Live line condition" (LineOK) are fulfilled

Table. 6.4.3 - 105. 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.
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.

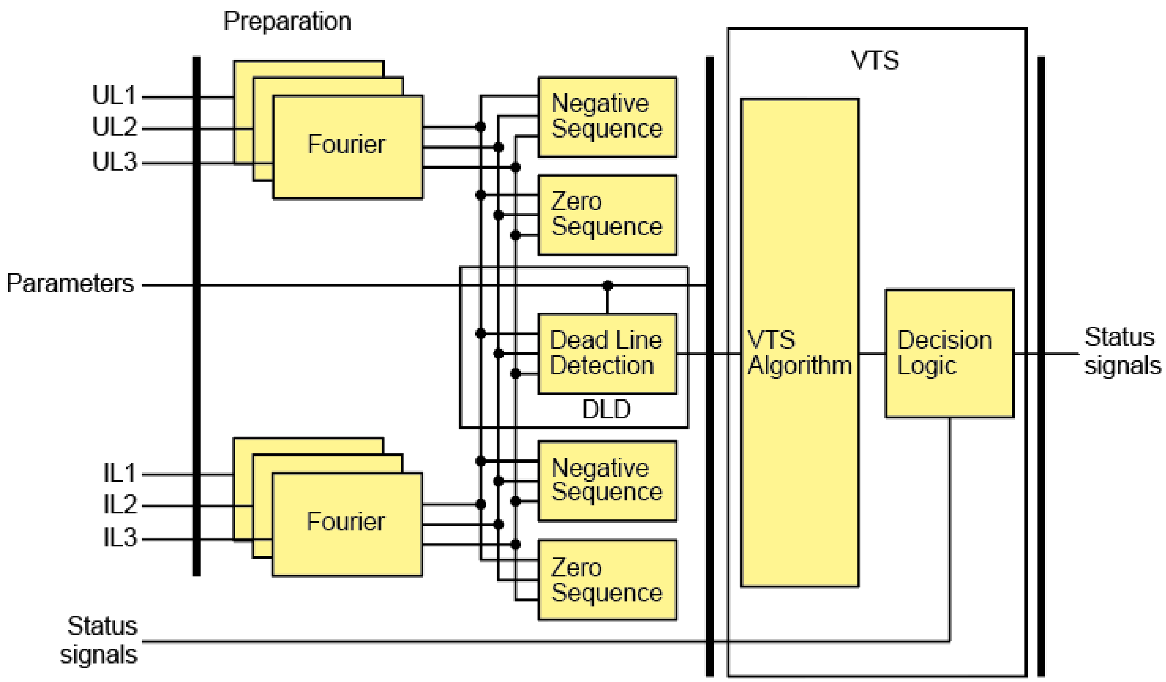
The voltage transformer supervision function can be used in three different modes of application:

- 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:

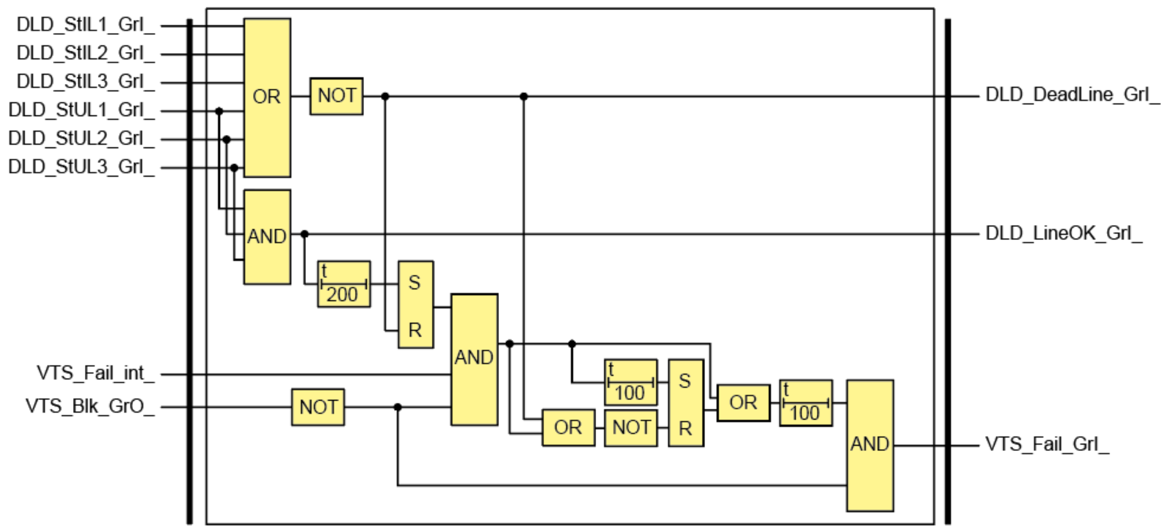
- If the "Live line" state is valid, then the function resets after approx. 200 ms of time delay.
- If the "Dead line" state is started and the "VTS Failure" signal has been continuous for at least 100 ms, then the "VTS failure" signal does not reset; it is generated continuously even when the line is 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 - 140. 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.

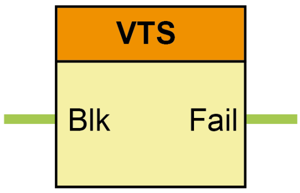
Figure. 6.4.4 - 141. Decision logic of the voltage transformer supervision function.



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 - 142. 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 - 106. 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 - 107. 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.

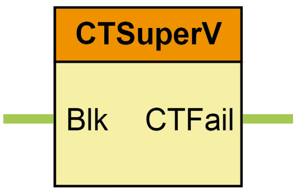
The function block selects maximum and minimum phase currents (fundamental Fourier components). If the difference between them is above the setting limit, the function generates a start signal. For function to be operational the highest measured phase current shall be above 10 % of the rated current 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 - 143. 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 - 108. The binary input and output status signals.

Binary status signal	Title	Explanation
CTSuperV_Blk_GrO_	Block	Blocking of the function

Binary status signal	Title	Explanation
CTSuperV_CtFail_GrI_	CtFail	CT failure signal

Table. 6.4.5 - 109. Setting parameters.

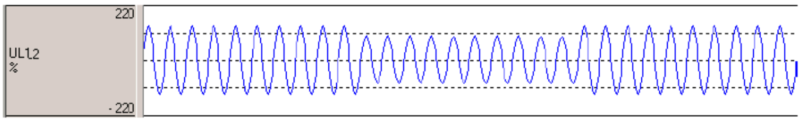
Parameter	Setting value/range	Step	Default	Description
Operation	On Off	-	On	Operating mode selection for the function. Operation can be either disabled "Off" or enabled "On".
IPhase Diff	50…90 %	1 %	80 %	Phase current difference setting.
Time delay	100…60 000 ms	1 ms	1 000 ms	CT supervision time delay.

6.4.6 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:

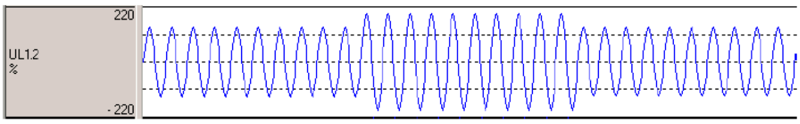
- Voltage sag, when the RMS value of the measured voltage is below a level defined by a dedicated parameter and at the same time above a minimum level specified by another parameter setting. For the evaluation, the duration of the voltage sag should be between a minimum and a maximum time value defined by parameters.

  Figure. 6.4.6 - 144. Voltage sag.

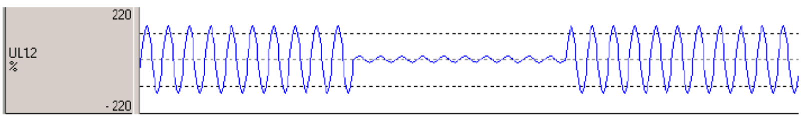
- Voltage swell, when the RMS value of the measured voltage is above a level defined by a dedicated parameter. For the evaluation, the duration of the voltage swell should be between a minimum and a maximum time value defined by parameters.

  Figure. 6.4.6 - 145. 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. 6.4.6 - 146. 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:

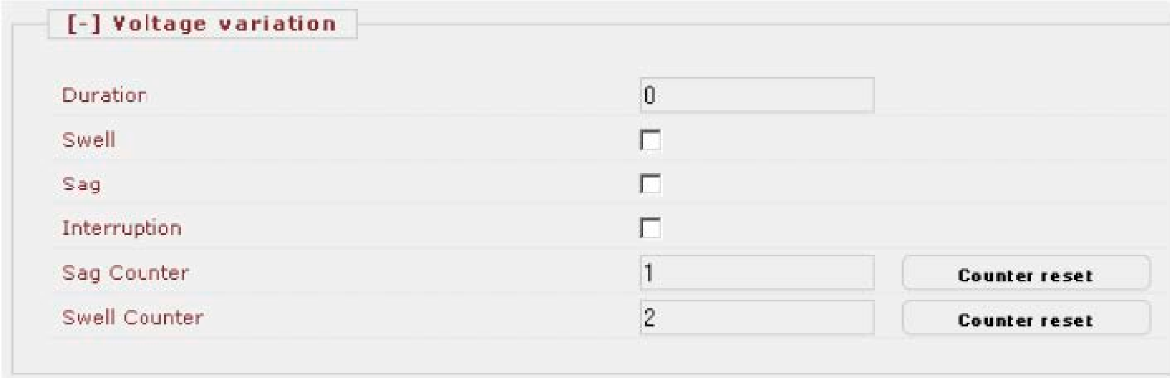
- Sag detection
- Swell detection
- Interruption detection
- Counters.

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. 6.4.6 - 147. 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. 6.4.6 - 148. Example sag and swell.

6.4.7 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.

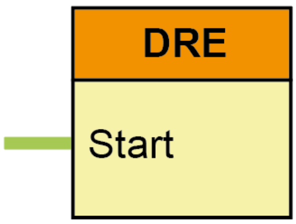
The records are stored in standard COMTRADE format:

- 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. 6.4.7 - 149. 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. 6.4.7 - 110. 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. 6.4.7 - 111. 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.

6.4.8 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. 6.4.8 - 112. 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	

6.4.9 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. 6.4.9 - 113. 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

6.4.10 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.

6.4.11 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 System integration

The AQ G3x7 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 G357 generator 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.

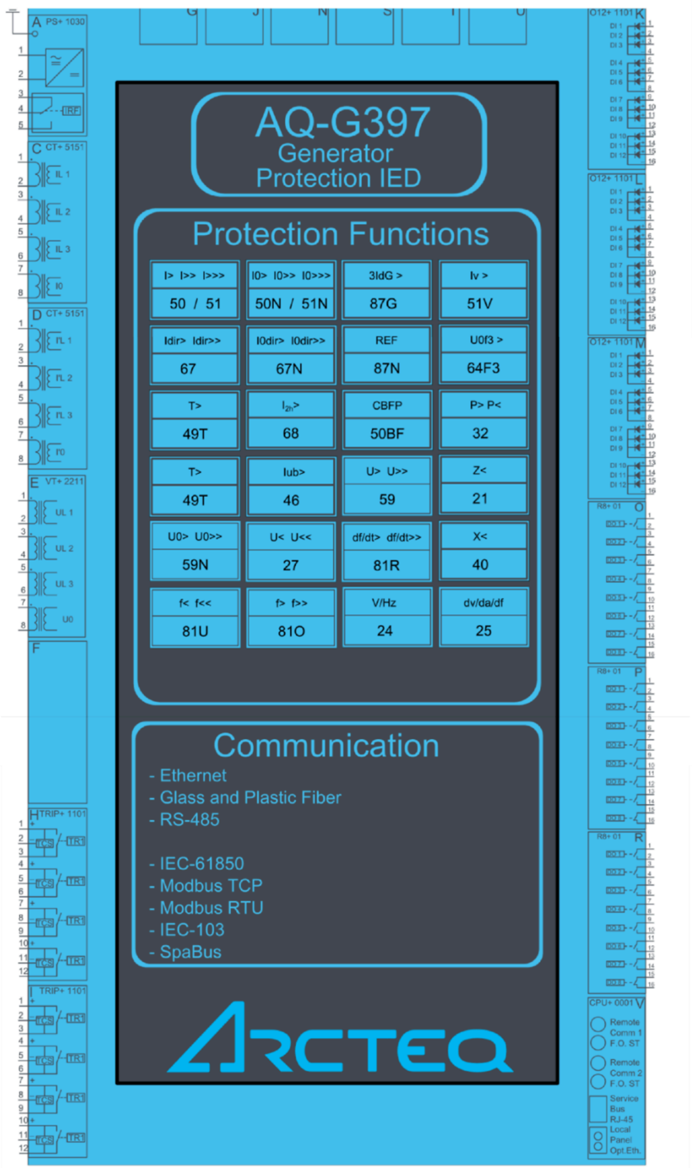
For IRIG-B time synchronization binary input module O12 channel 1 can be used.

8 Connections

8.1 Block diagram

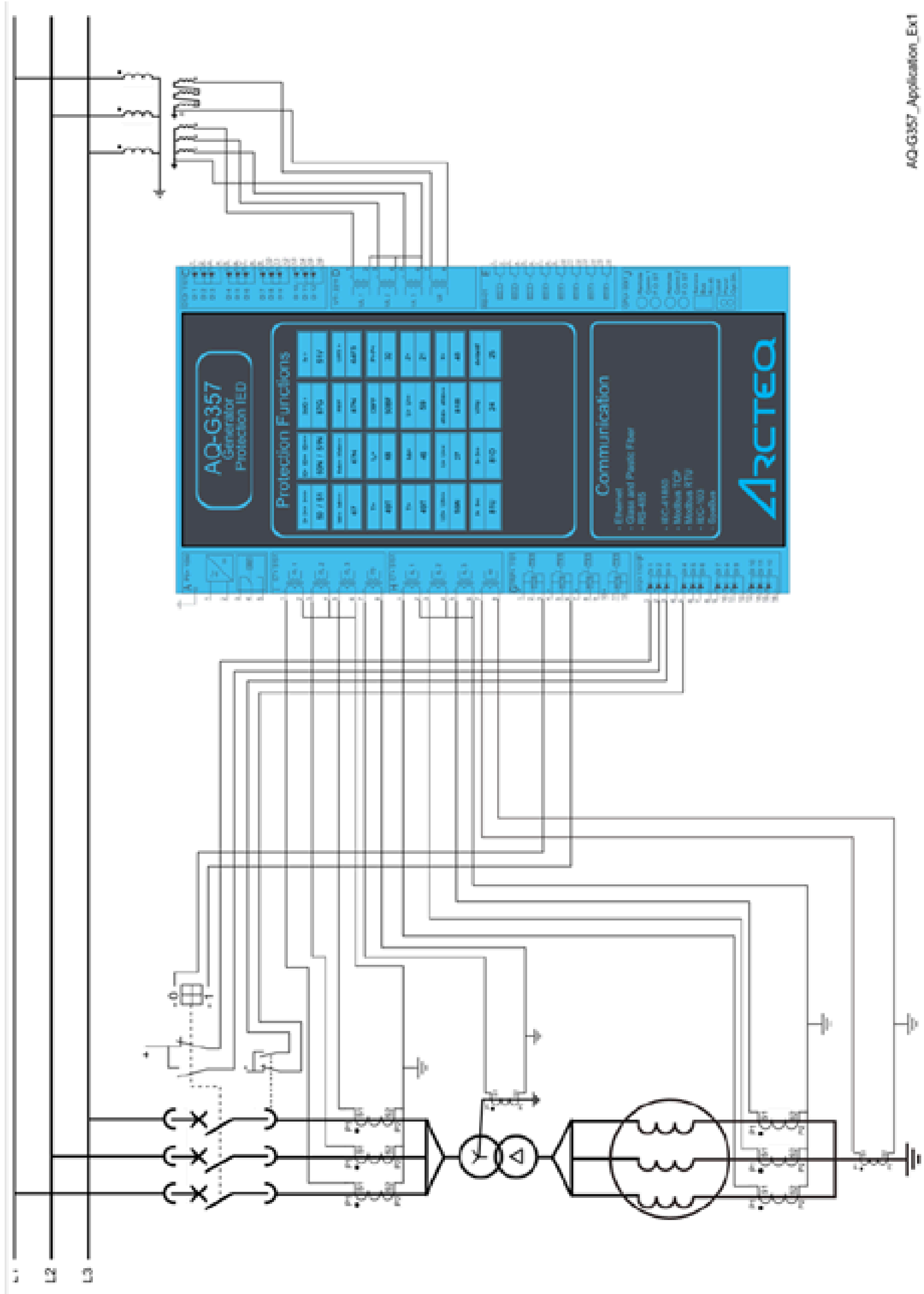
Block diagram of AQ-G397 with typical options

Figure. 8.1 - 150. Block diagram of AQ-G397 with typical options installed.



8.2 Connection example

Figure. 8.2 - 151. Connection example of AQ-G357 generator protection IED.

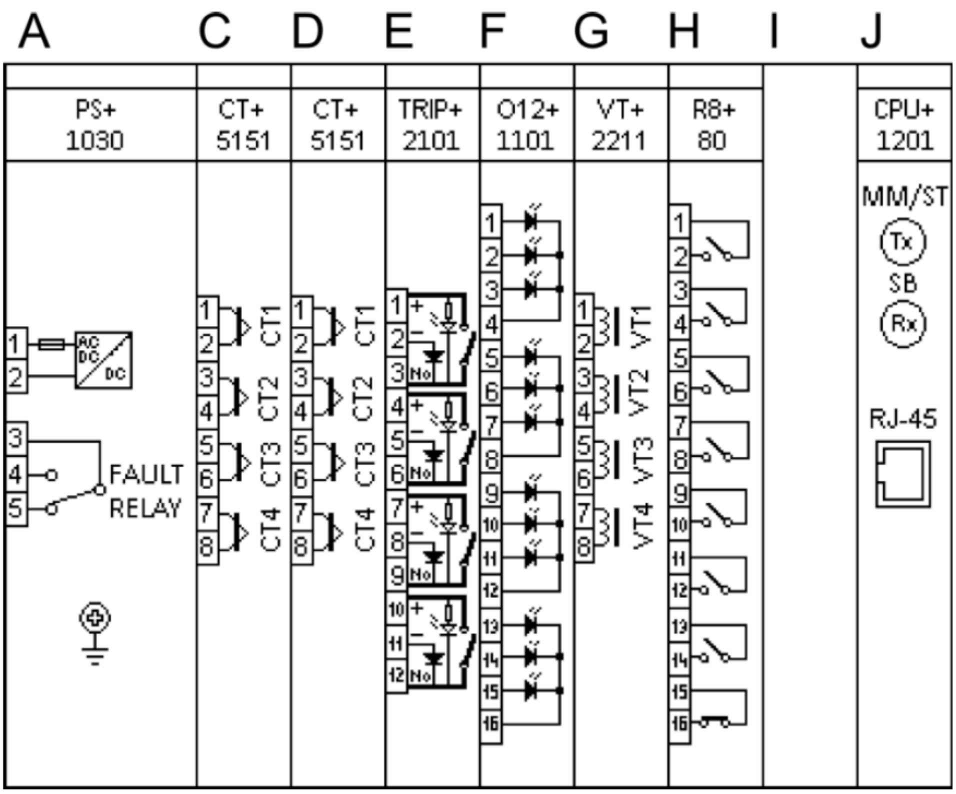


9 Construction and installation

9.1 Construction

The Arcteq AQ-G357 generator protection IED consists of hardware modules. Due to modular structure 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 the AQ-G357 is shown in the figure below. Visit https://configurator.arcteq.fi/ to see all of the available options.

Figure. 9.1 - 152. An example module arrangement configuration for the AQ-G357 IED.



For available configurations refer to order code.

9.2 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:

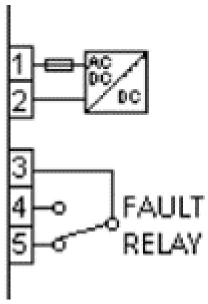
- Station bus (100Base-FX Ethernet).
- Redundant Station bus (100Base-FX Ethernet).
- Process bus (100Base-FX Ethernet).
- EOB (Ethernet over Board) user interface.
- Optional 100Base-TX port via RJ-45 connector.

Other communication:

- R422/RS485/RS232 interfaces.
- Plastic or glass fiber interfaces to support legacy protocols.
- Process-bus communication controller on COM+ card.

9.3 Power supply module

Figure. 9.3 - 153. Connector allocation of the 30 W power supply unit.



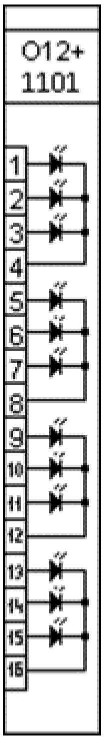
The power supply module converts primary AC and/or DC voltage to required system voltages. Redundant power supply cards extend system availability in case of the outage of any power source and can be ordered separately if required.

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.

9.4 Binary input module(s)

Figure. 9.4 - 154. The binary input module O12+ 1101.



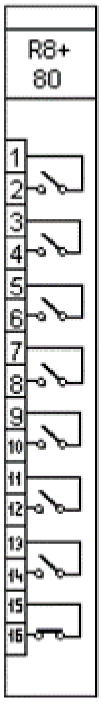
The inputs are galvanic isolated and the module converts high-voltage signals to the voltagelevel and format of the internal circuits. This module is also used as an external IRIG-B synchronization input. Dedicated synchronization input (input channel 1) is used for this purpose.

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.

9.5 Binary output module(s)

Figure. 9.5 - 155. The binary output module R8+ 80.



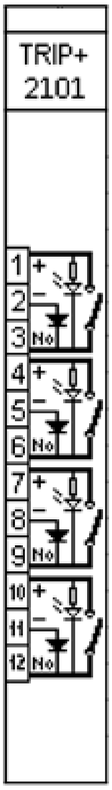
The signaling output modules can be ordered as 8 relay outputs with dry contacts.

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

9.6 Tripping module

Figure. 9.6 - 156. The tripping module TRIP+ 2101.



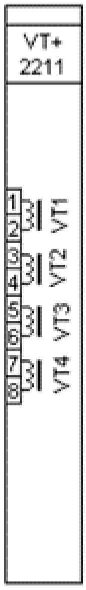
The tripping module applies direct control of a circuit breaker. The module provides fast operation and is rated for heavy duty controlling.

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.

9.7 Voltage measurement module

Figure. 9.7 - 157. 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.

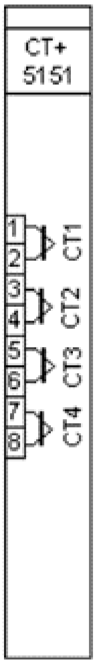
For capacitive voltage measurement of the synchrocheck reference, the voltage measurement module can be ordered with reduced burden in channel VT4. In this module the burden is < 50 mVA.

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: 0.5° Ux 25 % of rated voltage.

9.8 Current measurement module

Figure. 9.8 - 158. 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.

9.9 Installation and dimensions

Figure. 9.9 - 159. Dimensions of AQ-x35x IED.

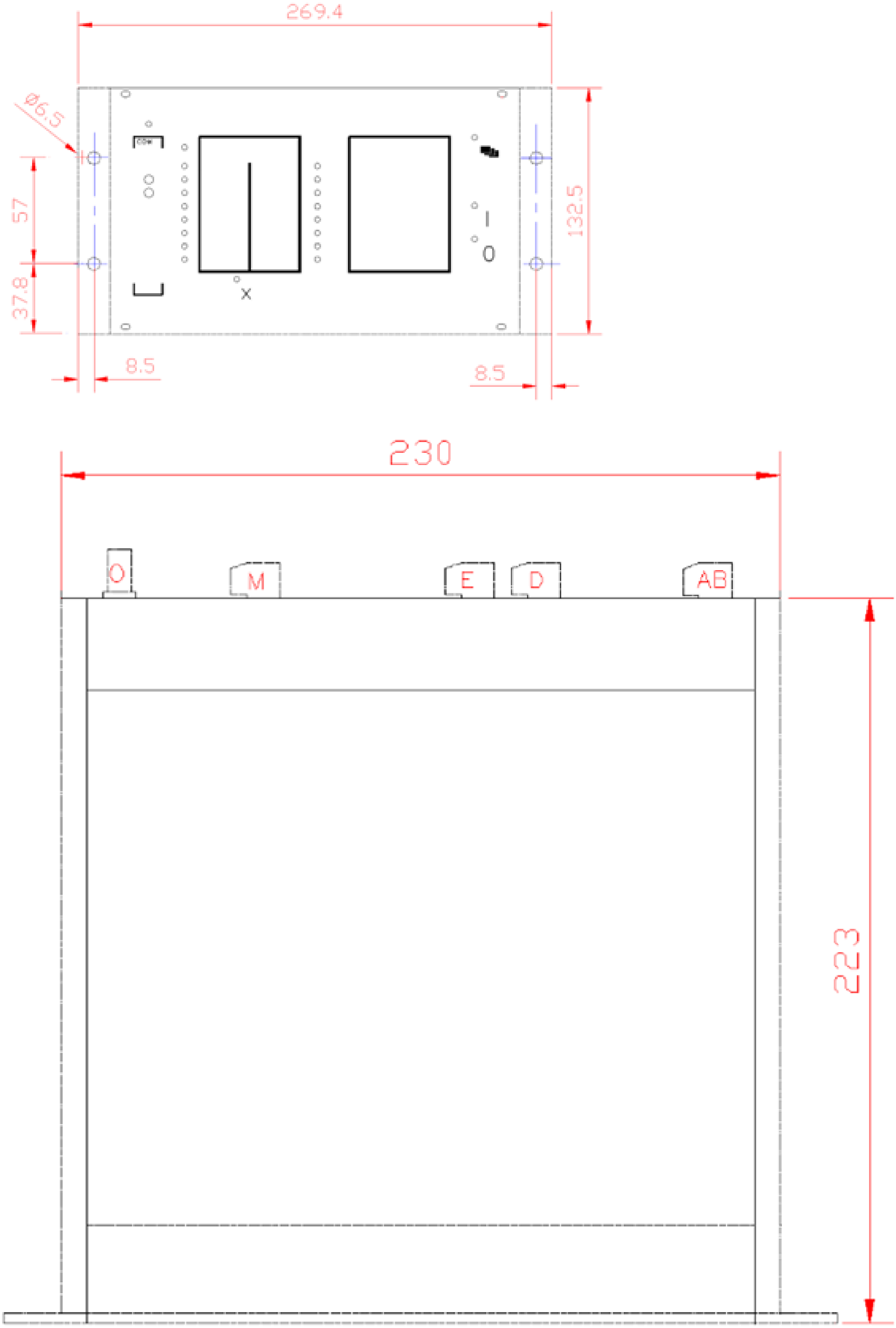
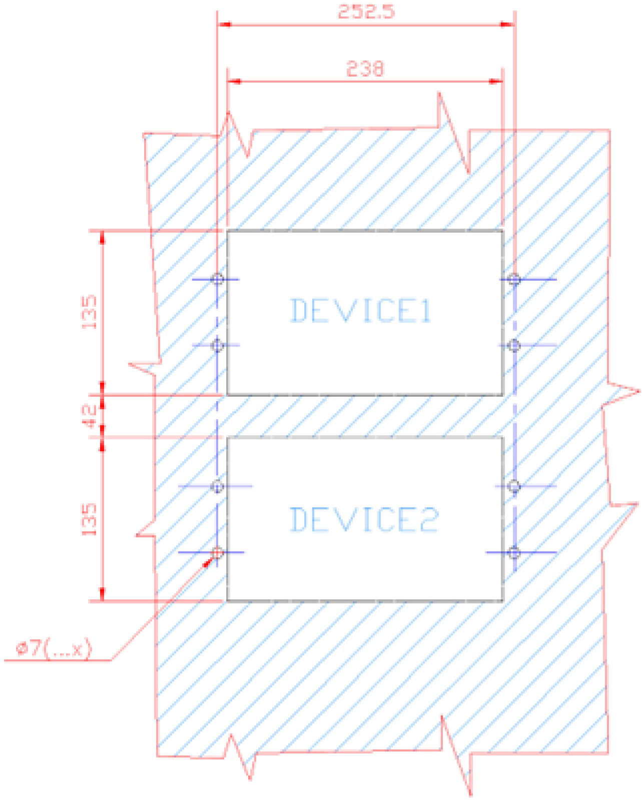


Figure. 9.9 - 160. Panel cut-out and spacing of AQ-x35x IED.



10 Technical data

10.1 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°

Negative sequence overcurrent protection function (46)

Pick-up starting inaccuracy at In	< 2 %
Operate time inaccuracy	±5% or ±15ms whichever is greater
Operate time inaccuracy in minimum time range	±35ms
Reset ratio	0,95
Reset time	<2% or ±35ms whichever is greater
Transient overreach	< 2%
Overshot time Dependent time charact. Definite time charact.	25ms 45ms
Pick-up time	25-30ms

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

Overexcitation/volts per hertz protection V/Hz, (24)

Frequency range	10…70Hz
Voltage range	10…170V secondary
Voltage measurement inaccuracy	<1% (0.5 – 1.2xUn)

Frequency measurement inaccuracy	<1% (0.8 – 1.2xfn)

Generator/Motor differential protection IdG> (87G)

Operating characteristic	Biased 2 breakpoints and unrestrained decision
Reset ratio	0.95
Characteristic inaccuracy	<2%
Operate time	Typically 30ms (restrained) Typically 20ms (unrestrained)
Reset time	Typically 25ms

Voltage restrained or controller overcurrent protection Iv> (51V)

Pick-up current inaccuracy	< 2%
Operation time inaccuracy	±5% or ±15ms
Reset ratio	0.95
Transient overreach	2 %

Reverse power / directional overpower protection (32)

Effective operating range	I> 5% In
Function inaccuracy	<3%

Directional underpower protection (32)

Effective operating range	I> 5% In
Function inaccuracy	<3%

Loss of field protection function X< (40Z)

Current effective range	20 - 2000% of In
Voltage effective range	2 - 110% of Un
Impedance effective range In= 1A In=5A	0.1 - 200 Ohm 0.1 – 40 Ohm
Impedance calculation angular inaccuracy	±3°
Instant operate time	Typically 25ms
Operate time inaccuracy	±3% or 15ms
Minimum operate time	<20ms
Reset time	16 – 25ms

Reset ratio	1.1

Pole Slip protection function (78)

Pole Slip protection function (78)		
Function	Range	Accuracy
Rated current In	1/5A, parameter setting	
Rated voltage Un	100/200V, parameter setting	
Current effective range	20-2000% of In	±1% of In
Voltage effective range	2-110% of Un	±1% of Un
Impedance effective range In=1A In=5A	0.1-200 Ohm 0.1-40 Ohm	±5%
Zone static accuracy	48Hz-52Hz 49.5-50.5Hz	±5% ±2%
Operate time	Typically 25ms	±3 ms
Minimum operate time	<20ms	
Reset time	16-25ms	

Underimpedance protection function Z< (21)

Current effective range	20 - 2000% of In
Voltage effective range	2 - 110% of Un
Impedance effective range In= 1A In=5A	0.1 - 200 Ohm 0.1 – 40 Ohm
Zone static inaccuracy 48 – 52Hz 49.5 – 50.5Hz	±5% ±2%
Zone angular inaccuracy	±3°
Operate time	Typically 25ms
Operate time inaccuracy	±3% or 15ms
Minimum operate time	<20ms
Reset time	16 – 25ms
Reset ratio	1.1

Inrush current detection function INR2, (68)

Current inaccuracy	<2 %

Reset ratio	0,95
Operating time	Approx. 20 ms

10.2 Control functions

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

10.3 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

10.4 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 °
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 ° 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)

10.5 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

11 Ordering information

Visit https://configurator.arcteq.fi/ to build a hardware configuration, define an ordering code and get a module layout image.

12 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