INSTRUCTION MANUAL

AQ L3x7 – Line protection IED

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Date	November 2010
Changes	- The first revision.
Revision	**1.01**
Date	January 2011
Changes	- HW construction and application drawings revised
Revision	**1.02**
Date	February 2011
Changes	- Directional earthfault function (67N) revised - Synchrocheck chapter revised - Voltage measurement module revised - CPU module description added - Binary input module description revised - IRIG-B information added - Voltage Sag and swell function added - Updated ordering information and type designation - Technical data revised
Revision	**1.03**
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Changes	- MHO characteristics added, synch check parameter updates, technical data updated, order code updated - Technical data of frequency protection updated
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Changes	- L397 descriptions added - Frequency specifications updated
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Revision	1.07
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Changes	- Added parameters for phase-to-phase and phase-to-ground fault detection separately (distance)
Revision	**1.08**
Date	17.12.2019
Changes	- Updated construction and installation chapter

Read these instructions carefully and inspect the equipment to become familiar with it before trying to install, operate, service or maintain it.

Electrical equipment should be installed, operated, serviced, and maintained only by qualified personnel. Local safety regulations should be followed. No responsibility is assumed by Arcteq for any consequences arising out of the use of this material.

We reserve right to changes without further notice.

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1 ABBREVIATIONS

CB – Circuit breaker

CBFP – Circuit breaker failure protection

CT – Current transformer

CPU – Central Processing Unit

EMC – Electromagnetic compatibility

HMI – Human Machine Interface

HW – Hardware

IED – Intelligent Electronic Device

IO – Input Output

LED – Light emitting diode

LV – Low voltage

MV – Medium voltage

NC – Normally closed

NO – Normally open

RMS – Root mean square

SF – System failure

TMS – Time multiplier setting

TRMS – True RMS

VAC – Voltage Alternating Current

VDC – Voltage Direct Current

SW – Software

uP - Microprocessor

2 GENERAL

The AQ-L3x7 line protection IED is a member of the AQ-300 product line. The AQ-300 protection product line in respect of hardware and software is a modular device. The hardware modules are assembled and configured according to the application IO requirements and the software determines the available functions. This manual describes the specific application of the AQ-L3x7 line protection IED.

Arcteq line protection IED can be ordered in two mechanical sizes. The AQ-L357 comes in half of 19 inch rack arrangement and the AQ-L397 comes in full 19 inch rack arrangement allowing for larger quantity of IO cards. The functionality is the same in both units.

The AQ-L3x7 line protection IED is applicable as a main and/or back up protection for medium voltage, sub-transmission and high voltage and extra high voltage transmission lines and can be freely configured for either single pole or three pole tripping schemes.

3 SOFTWARE SETUP OF THE IED

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

Table 3-1 Available protection functions

Function Name	IEC	ANSI	Description
DIS21	Z<	21	5-zone distance protection
SCH85	-	85	Teleprotection
WEI	-	-	Weak end infeed protection
DIS21	$\Delta Z/\Delta t$	78	Out of step
DIS21	-	68	Power swing blocking
IOC50	I >>>	50	Three-phase instantaneous overcurrent protection
TOC50_low TOC50_high	I> I>>	51	Three-phase time overcurrent protection
IOC50N	I0 >>>	50N	Residual instantaneous overcurrent protection
TOC51N_low TOC51N_high	I0> I0>>	51N	Residual time overcurrent protection
TOC67_low TOC67_high	IDir > IDir>>	67	Directional three-phase overcurrent protection
TOC67N_low TOC67N_high	I0Dir > I0Dir >>	67N	Directional residual overcurrent protection
INR2	I_{2h} >	68	Inrush detection and blocking
VCB60	I_{ub} >	46	Current unbalance protection
TTR49L	T >	49L	Line thermal protection
TOV59_low TOV59_high	U > U >>	59	Definite time overvoltage protection
TUV27_low TUV27_high	U < U <<	27	Definite time undervoltage protection
TOV59N_low TOV59N_high	U0> U0>>	59N	Residual voltage protection
TOF81_1 TOF81_2 TOF81_3 TOF81_4	f > f >> f >>> f >>	81O	Overfrequency protection
TUF81_1 TUF81_2 TUF81_3 TUF81_4	f < f << f <<< f <<<<	81U	Underfrequency protection
FRC81_1 FRC81_2 FRC81_3 FRC81_4	df/dt	81R	Rate of change of frequency protection
BRF50MV	CBFP	50BF	Breaker failure protection
PSLIP78	-	78	Pole slip protection (option)

Table 3-2 Available control and monitoring functions

Name	IEC	ANSI	Description
TRC94	-	94	Phase-selective trip logic
DLD	-	-	Dead line detection
VTS	-	60	Voltage transformer supervision
SYN25	SYNC	25	Synchro-check function Δf, ΔU, $\Delta \varphi$
REC79MV	0 -> 1	79	Autoreclosing function
SOTF	-	-	Switch on to fault logic
DREC	-	-	Disturbance recorder

3.1 Measurements

3.1.1 Current measurements 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.

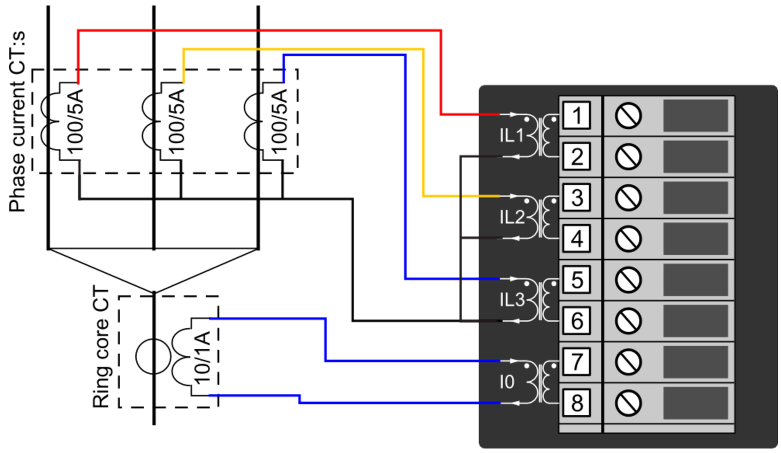


Figure 3-1 Example connection

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.	

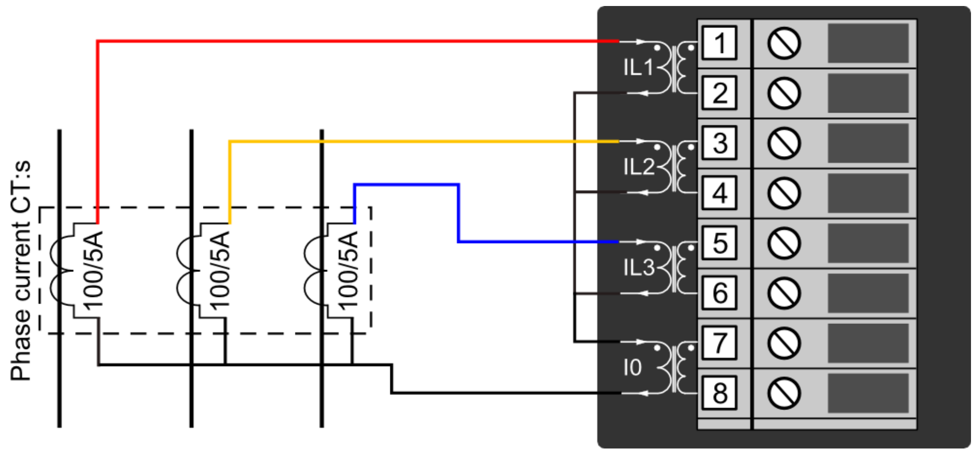


Figure 3-2 Example connection with phase currents connected into summing "Holmgren" connection into the I0 residual input.

Phase current CT: CT primary 100A	Ring core CT in Input I0: I0CT primary 100A

CT secondary 5A	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 3-3 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 3-4 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 3-5 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

NOTE1: 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”.

NOTE2: 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.)

3.1.2 Voltage measurements 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.

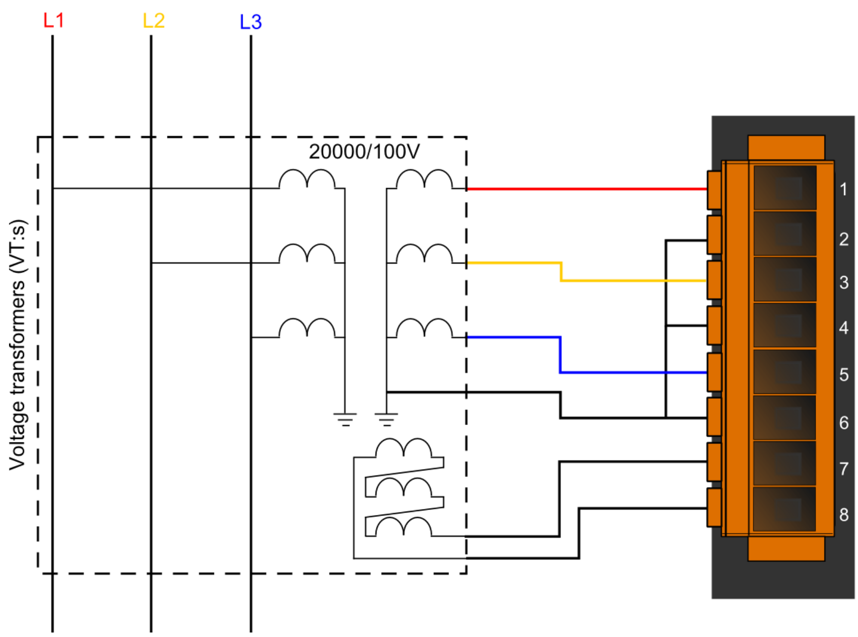


Figure 3-3 Phase to neutral connection. Connection U1-3

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.

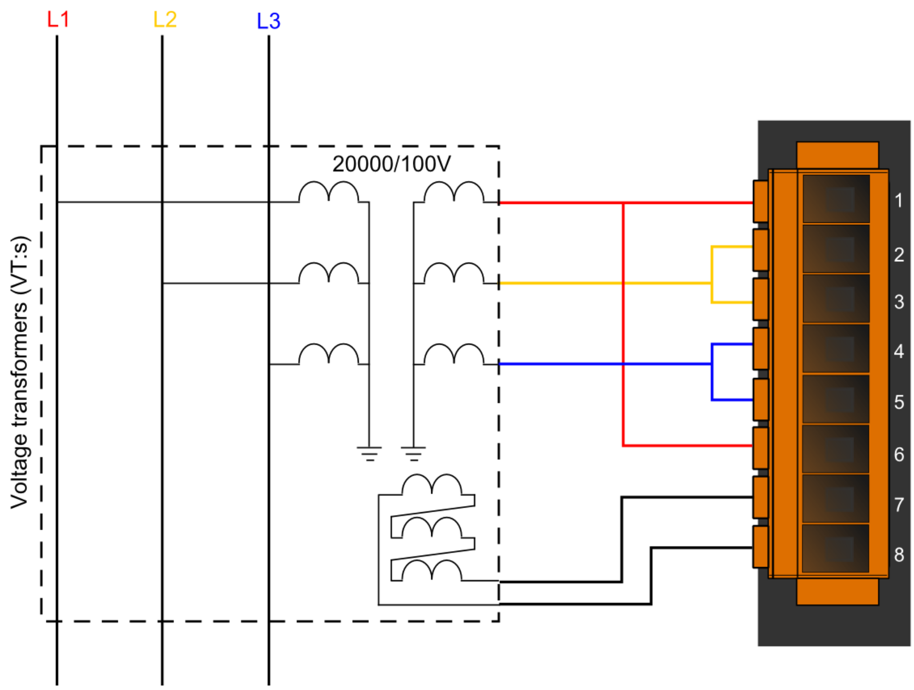


Figure 3-4 Phase-to-phase connection.

Ph-N Voltage: Rated Primary U1-3: 20kV Range: Type 100	Residual voltage: Rated Primary U4: 11.54kV (=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 3-6 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)			
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_Ch13Dir_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 3-7 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 3-8 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

NOTE: 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 3-9 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
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

NOTE1: 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”.

NOTE2: 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.

3.1.3 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.

3.1.3.1 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.

3.1.3.2 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.

NOTE: the scaling values are entered as parameter setting for the “Voltage transformer input” function block and for the “Current transformer input” function block.

3.1.3.3 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 3-10 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.

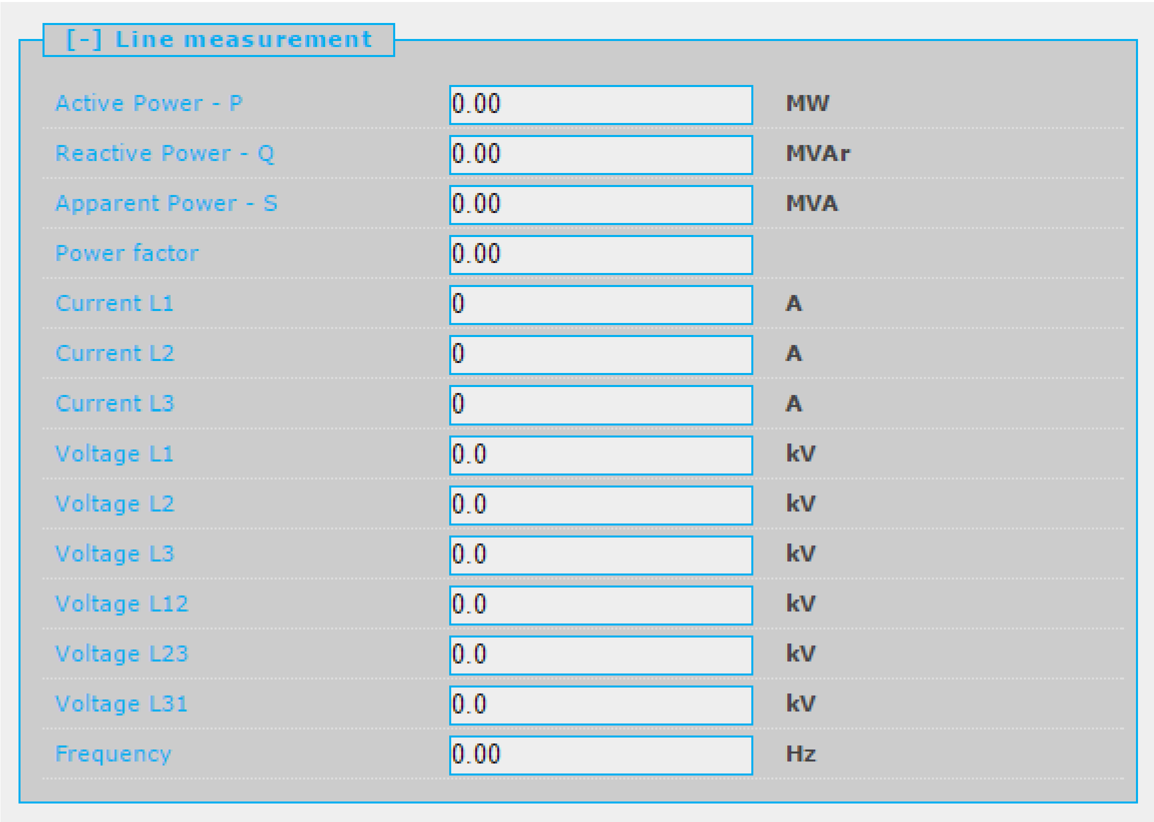


Figure 3-5 Measured values in a configuration for compensated networks

The available quantities are described in the configuration description documents.

3.1.3.4 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 3-11 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 ActivePower	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.

3.1.3.5 “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, Figure 1-2 shows that the current becomes higher than the value reported in “report1” PLUS the Deadband value, this results “report2”, etc.

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 3-12 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	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 current						
MXU_fDeadB_FPar_	Deadband value - f	Hz	0.01	1	0.01	0.02
Range value for the current						
MXU_fRange_FPar_	Range value - f	Hz	0.05	10	0.01	5

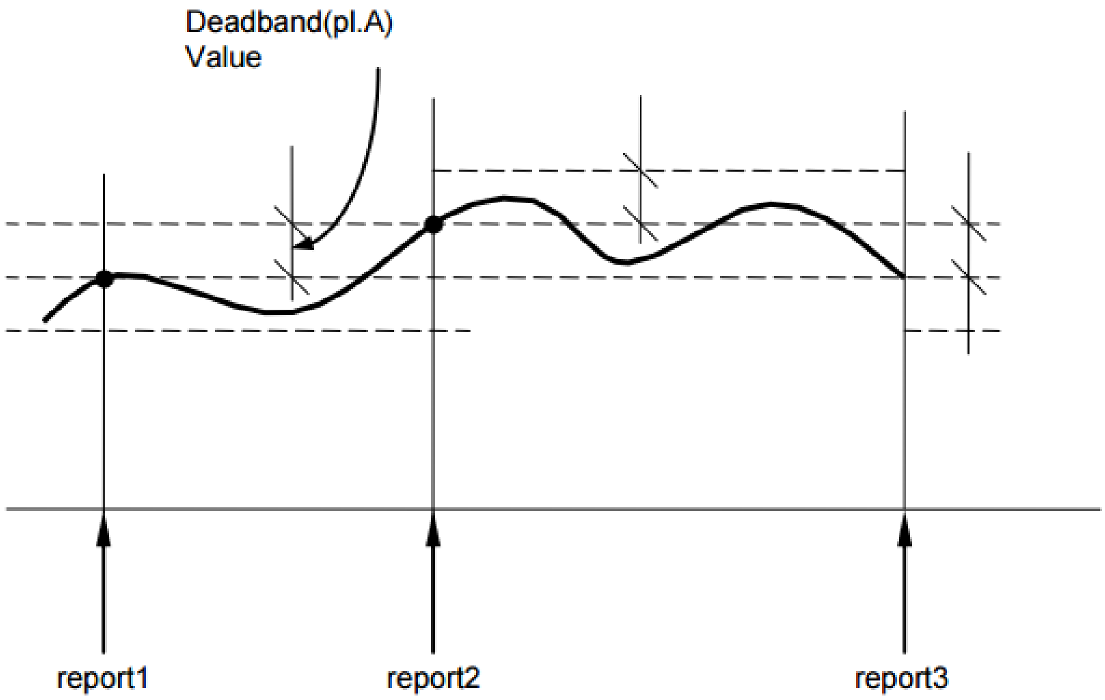


Figure 3-6 Reporting if "Amplitude" mode is selected

3.1.3.6 "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, Figure 1-3 shows that the integral of the current in time becomes higher than the Deadband value multiplied by 1sec, this results "report2", etc.

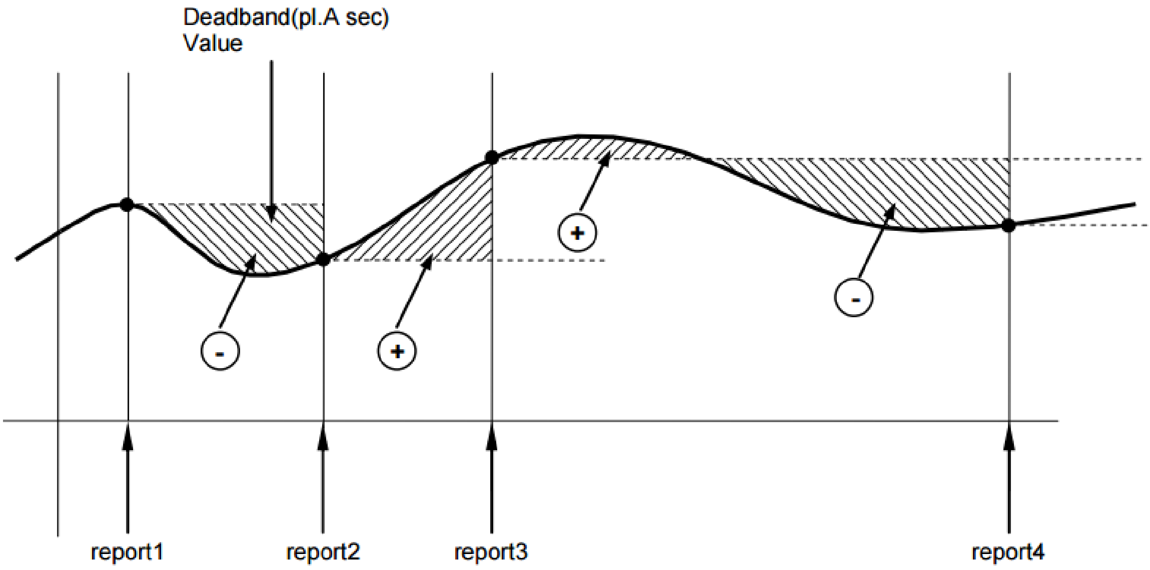


Figure 3-7 Reporting if "Integrated" mode is selected

3.1.3.7 Periodic reporting

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

Table 3-13 The integer parameters of the line measurement function

Parameter name	Title	Unit	Min	Max	Step	Default
Reporting time period for the active power						
MXU_PIntPer_IPar_	Report period P	sec	0	3600	1	0
Reporting time period for the reactive power						
MXU_QIntPer_IPar_	Report period Q	sec	0	3600	1	0
Reporting time period for the apparent power						
MXU_SIntPer_IPar_	Report period S	sec	0	3600	1	0
Reporting time period for the voltage						
MXU_UIntPer_IPar_	Report period U	sec	0	3600	1	0
Reporting time period for the current						
MXU_IIntPer_IPar_	Report period I	sec	0	3600	1	0
Reporting time period for the frequency						
MXU_fIntPer_IPar_	Report period f	sec	0	3600	1	0

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". See Table 3-11.

3.2 Protection Functions

3.2.1 Distance protection Z< (21)

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

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

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

The directional decision is dynamically based on:

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

Binary input signals and conditions can influence the operation:

- Blocking/enabling
- VT failure signal

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

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

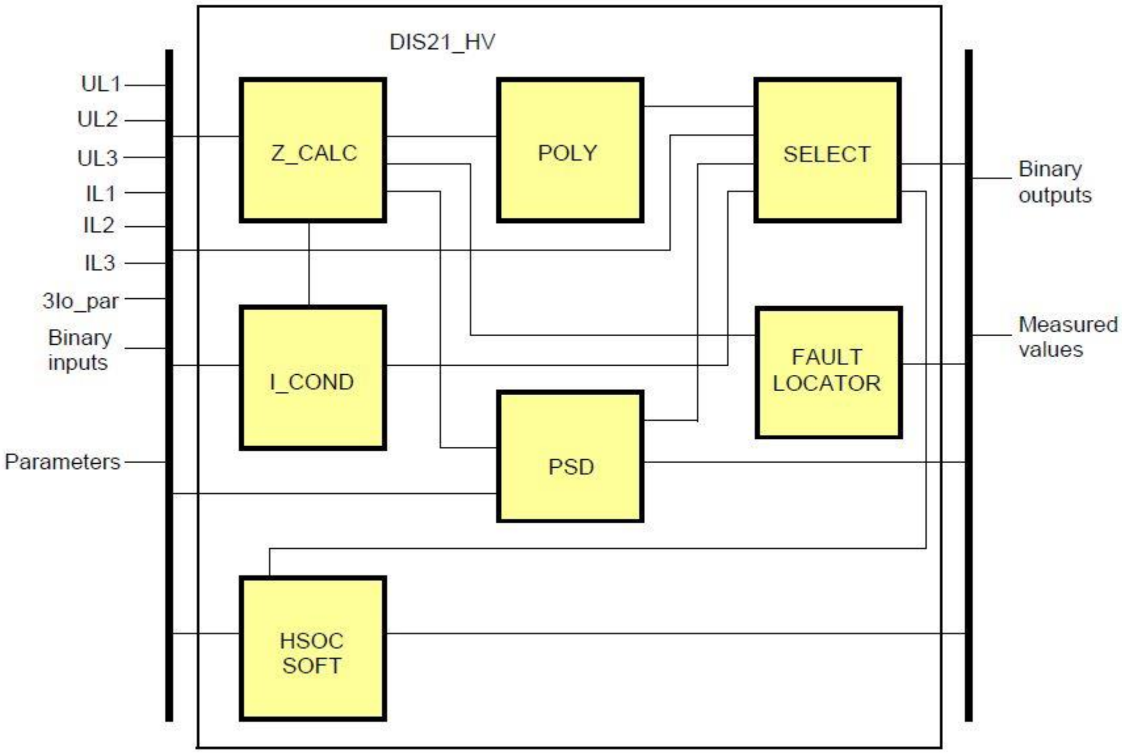


Figure 3-8: Structure of the distance protection

The **inputs** are:

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

The **outputs** are:

- Binary output status signals,
- Measured values for displaying.

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

- **Z_CALC** calculates the impedances (R+jX) of the six measuring current loops:
    - three phase-phase loops,
    - three phase-ground loops.

- **POLY** compares the calculated impedances with the setting values of the five polygon characteristics. The result is the decision for all six measuring loops and for all five polygons if the impedance is within the polygon.
- **SELECT** is the phase selection algorithm for all five zones to decide which decision is caused by a faulty loop and to exclude the false decisions in healthy loops.
- **I_COND** calculates the current conditions necessary for the phase selection logic.
- **PSD** is the module that detects power swings and generates out-of-step trip command, influencing the distance protection function.
- **FAULT LOCATOR** calculates the distance to fault after the trip command.
- **HSOC SOTF** is a high-speed overcurrent protection function for the switch-onto-fault logic.

The following description explains the details of the individual components.

Principle of the impedance calculation

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

Table 3-14 Impedance calculation formulas

Fault	Calculation of Z	Other possible calculation
L1L2L3(N)	$Z_{L2L3}=\frac{U_{L2}-U_{L3}}{I_{L2}-I_{L3}}$	Z_{L1L2} , Z_{L2L3} , Z_{L3L1} Z_{L1N} , Z_{L2N} , Z_{L3N}
L1L2	$Z_{L1L2}=\frac{U_{L1}-U_{L2}}{I_{L1}-I_{L2}}$	
L2L3	$Z_{L2L3}=\frac{U_{L2}-U_{L3}}{I_{L2}-I_{L3}}$	
L3L1	$Z_{L3L1}=\frac{U_{L3}-U_{L1}}{I_{L3}-I_{L1}}$	
L1L2N	$Z_{L1L2}=\frac{U_{L1}-U_{L2}}{I_{L1}-I_{L2}}$	Z_{L1N} , Z_{L2N}
L2L3N	$Z_{L2L3}=\frac{U_{L2}-U_{L3}}{I_{L2}-I_{L3}}$	Z_{L2N} , Z_{L3N}
L3L1N	$Z_{L3L1}=\frac{U_{L3}-U_{L1}}{I_{L3}-I_{L1}}$	Z_{L3N} , Z_{L1N}
L1N	$Z_{L1N}=\frac{U_{L1}}{I_{L1}+3I_oK_N}$	
L2N	$Z_{L2N}=\frac{U_{L2}}{I_{L2}+3I_oK_N}$	
L3N	$Z_{L3N}=\frac{U_{L3}}{I_{L3}+3I_oK_N}$	

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

Equation 3-1 Earth fault compensation factor

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

Equation presents the earth fault compensation factor.

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

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

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

General method of calculation of the impedances of the fault loops

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

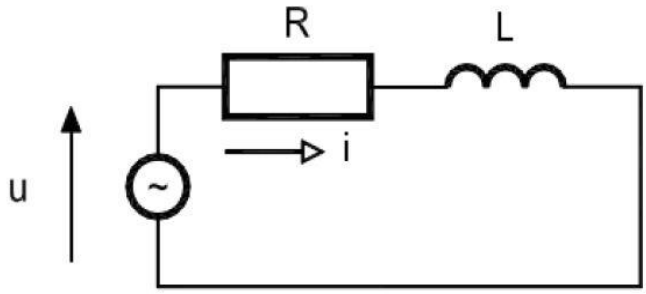


Figure 3-9: Equivalent circuit of the fault loop.

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

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

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

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

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

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

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

Where

R_1	is the positive sequence resistance of the line or cable section between the fault location and the relay location
L_1	is the positive sequence inductance of the line or cable section between the fault location and the relay location
L1	is the faulty phase
$3i_o = iL1 + iL2 + iL3$	is the sampled value of the zero sequence current of the protected line
$3i_{op} = iL1_p + iL2_p + iL3_p$	is the sampled value of the zero sequence current in parallel line

And

$$\alpha_R = \frac{R_o - R_1}{3R_1}$$

$$\alpha_L = \frac{L_o - L_1}{3L_1} = \frac{X_o - X_1}{3X_1}$$

$$\beta_R = \frac{R_m}{3R_1}$$

$$\beta_L = \frac{L_m}{3L_1} = \frac{X_m}{3X_1}$$

R_m	is the real part of the mutual impedance between the protected and the parallel line
L_m	is the mutual inductance between the protected and the parallel line

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

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

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

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

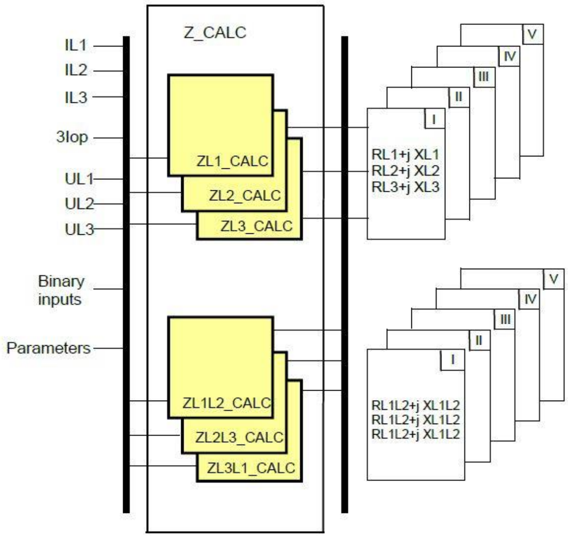


Figure 3-10: Impedance calculation principal scheme

The **inputs** are the sampled values and Fourier components of:

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

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

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

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

Z_CALC includes six practically identical software modules for impedance calculation:

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

Table 3-15 Calculated values of the impedance module.

Measured value	Dim.	Explanation
RL1+j XL1	ohm	Measured positive sequence impedance in the L1N loop, using the zero sequence current compensation factor for zone 1
RL2+j XL2	ohm	Measured positive sequence impedance in the L2N loop, using the zero sequence current compensation factor for zone 1
RL3+j XL3	ohm	Measured positive sequence impedance in the L3N loop, using the zero sequence current compensation factor for zone 1
RL1L2+j XL1L2	ohm	Measured positive sequence impedance in the L1L2 loop
RL2L3+j XL2L3	ohm	Measured positive sequence impedance in the L2L3 loop
RL3L1+j XL3L1	ohm	Measured positive sequence impedance in the L3L1 loop

Internal logic of the impedance calculation

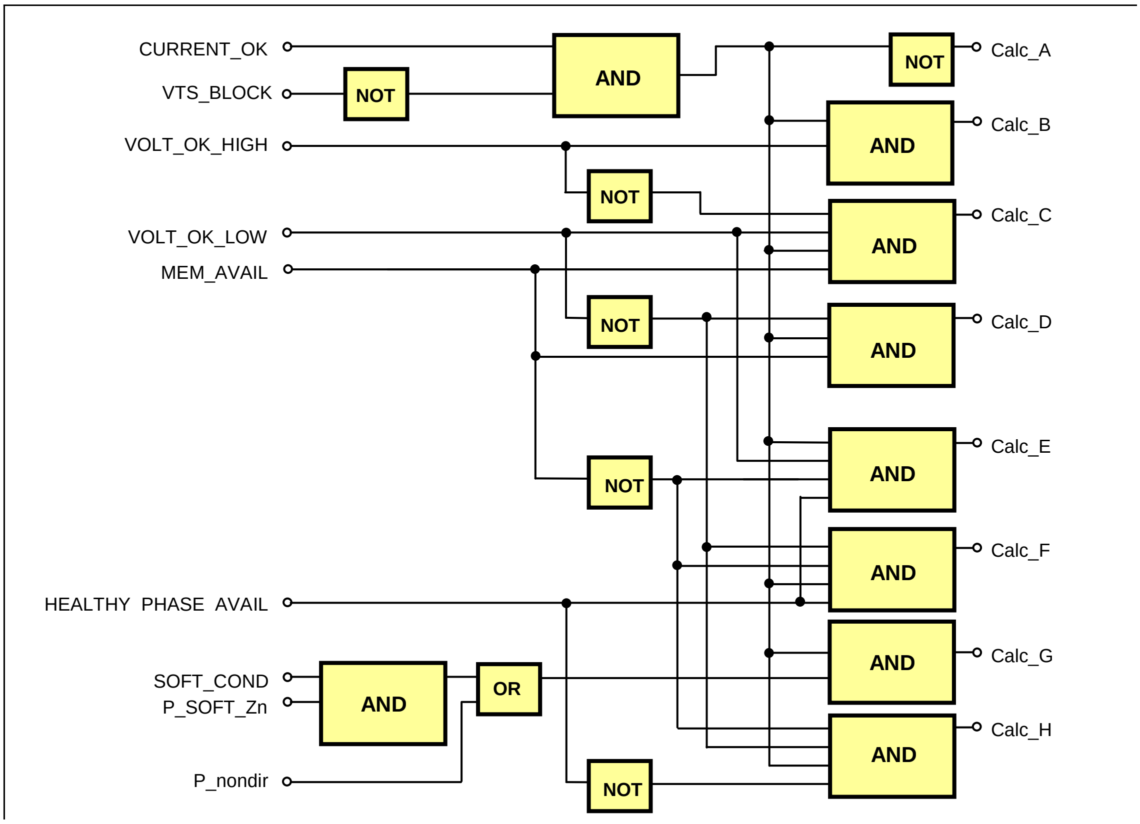


Figure 3-11: Impedance calculation internal logic.

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

Table 3-16 Internal logic parameters of the impedance calculation.

Parameter	Explanation
P_SOTF_Zn	This logic parameter is true if the “switch-onto-fault” logic is enabled for Zone_n, (where n=1…5), i.e., DIS21_SOTFMd_EPar_ (SOTF Zone) is selected for “Zone n” (where n=1…5).
P_nondir	This logic parameter is true if no directionality is programmed, i.e., the DIS21_Zn_EPar_(Operation Zone1) parameter (where n=1…5) is set to “*NonDirectional*” for the individual zones.

Table 3-17 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 current (3Io) should be above Iphase/4. This status signal is generated within the *Z_CALC* module based on the parameter DIS21_Imin_IPar_ (I minimum) and in case of phase-ground loops on parameters DIS21_IoBase_IPar_ (Io Base sens.) and DIS21_IoBias_IPar_ (Io Bias)
VTS Block	Binary blocking signal due to error in the voltage measurement
VOLT_OK_HIGH	The voltage is suitable for the calculation if the most recent ten sampled values include a sample above the defined limit (35% of the nominal loop voltage). This status signal is generated within the *Z_CALC* module.
VOLT_OK_LOW	The voltage can be applied for the calculation of the impedance if the three most recent sampled three values include a sample above the defined lower limit (5% of the nominal loop voltage), but in this case the direction is to be decided using the voltage samples stored in the memory because the secondary swings of the capacitive voltage divider distort the sampled voltage values. Below this level, the direction is decided based on the sign either of the real part of the impedance or that of the imaginary part of the impedance, whichever is higher. This status signal is generated within the *Z_CALC* module.
MEM_AVAIL	This status signal is true if the voltage memory is filled up with available samples above the defined limit for 80 ms. This status signal is generated within the *Z_CALC* module.
HEALTHY_PHASE_ AVAIL	This status signal is true if there are healthy phase voltages (in case of asymmetrical faults) that can be applied to directional decision. This status signal is generated within the *Z_CALC* module.
SOTF_COND	This status signal is true if the algorithm detected switch-onto-fault conditions, and the binary input signal DIS21_SOTFCond_GrO_ (SOTF COND.) is programmed by the user to logic “1”, using the graphic equation editor.

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

Table 3-18 Calculation methods applied in the impedance calculation module

Calculation method	Explanation
Calc(A)	No current is available, the impedances are supposed to be higher than the possible maximum setting values R=1000000 mohm, X=1000000 mohm
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)	The currents are suitable but the voltages are in the range of the CVT swings and there are no healthy voltages stored in the memory but because of asymmetrical faults, there are healthy voltages. Therefore, during the first 35 ms the directional decision is based on healthy voltages R, X=f(u, i) direction = f(Uhealthy, i) /in the first 35 ms/ R, X=f(u, i) direction = f(u, i) /after 35 ms/
Calc(F)	The currents are suitable but the voltages are too low, there are no pre-fault voltages stored in the memory but because of asymmetrical faults, there are healthy voltages. Therefore, the directional decision is based on healthy voltages R, X=f(u, i) direction = f(Uhealthy, i)
Calc(G)	If no directional decision is required or in case of prescribed SOTF logic the fault was caused by a switching, then the decision is based on the absolute value of the impedance (forward fault is supposed) R=abs(R), X=abs(X)
Calc(H)	If the decision is not possible (no voltage, no pre-fault voltage, no healthy phase voltage but directional decision is required), then the impedance is set to a value above the possible impedance setting R=1000500 mohm, X=1000500 mohm

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:

$$R=1000000, X=1000000.$$

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):

The currents are suitable but the voltages are in the range of the CVT swings, there are no pre-fault voltages stored in the memory but because of asymmetrical faults, there are healthy phase voltages. Therefore, during the first 35 ms the directional decision is based on healthy voltages

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

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

This directional decision is based on a special voltage compensation method (Bresler). The product of the Fourier components of the phase currents and the highest zone impedance setting value is composed. These compensated voltage values are first subtracted from the corresponding phase voltages. If the phase sequence of theses resulting voltages is (L1,L3, L2), the fault is in the forward direction. The reverse direction is decided based on the compensated voltages added to the corresponding phase voltages. If this resulting phase sequence is (L1,L3, L2), the fault is in the backward direction. If both phase sequences are (L1, L2, L3), the direction of the fault is undefined.

Calculation method Calc(F):

The currents are suitable but the voltages are too low, there are no pre-fault voltages stored in the memory but because of asymmetrical faults, there are healthy voltages. Therefore, the directional decision is based on healthy voltages

R, X=f(u, i) direction = f(Uhealthy, i)

The directional decision is described in calculation method Calc(E).

Calculation method Calc(G):

If no directional decision is required or in case of prescribed SOTF logic and the fault was caused by a switching, then the decision is based on the absolute value of the impedance (forward fault is supposed)

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

Calculation method Calc(H):

If the voltage is not sufficient for a directional decision and no stored voltage samples are available, and if the “switch-onto-fault” logic is not enabled, then the impedance is set to a high value:

R=1000500, X=1000500

Polygon characteristics

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

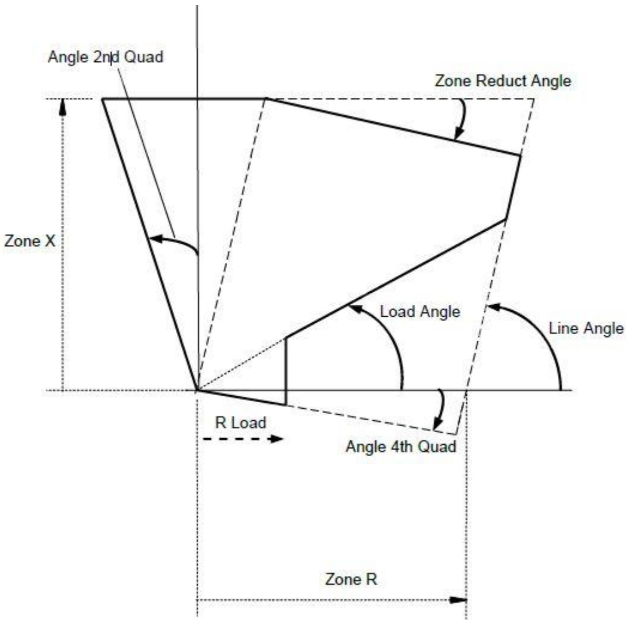
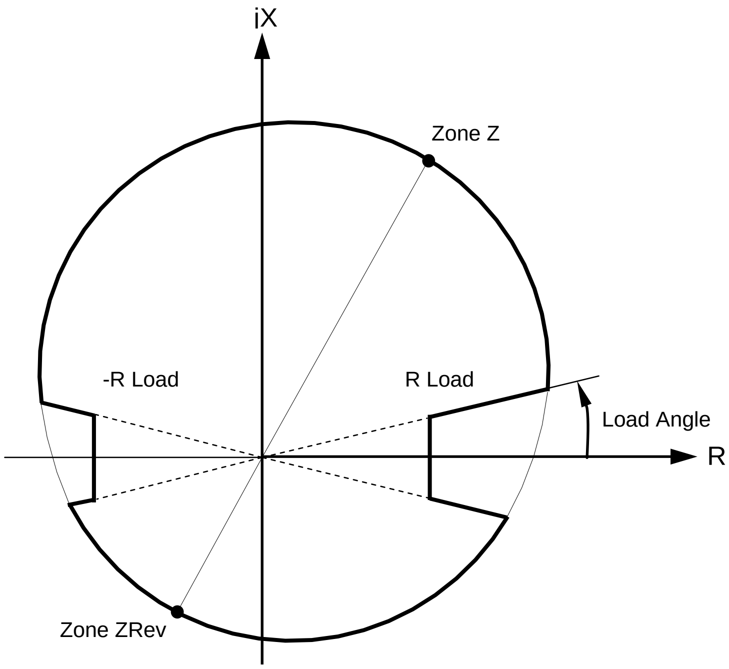


Figure 3-12: The characteristics of the distance protection in complex plane.

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

MHO characteristics

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



Note: For Zone 1: Zone 1 ZRev=0

Figure 3-13: The MHO characteristics of the distance protection function on the complex plane

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

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

Polygon and MHO characteristics logic

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

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

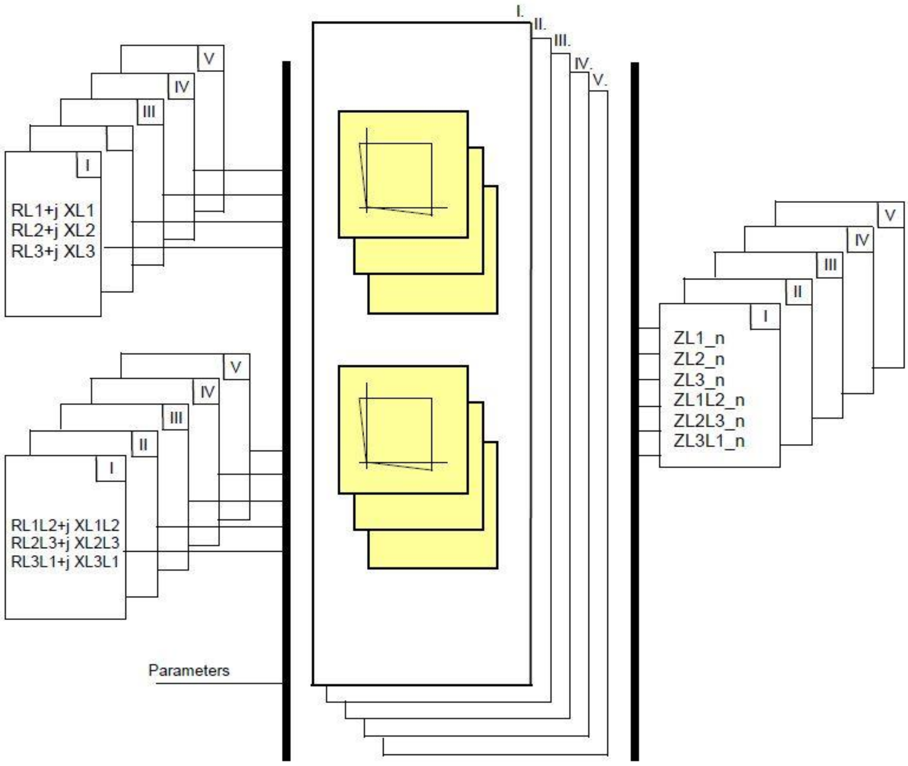


Figure 3-14: Polygon characteristics logic

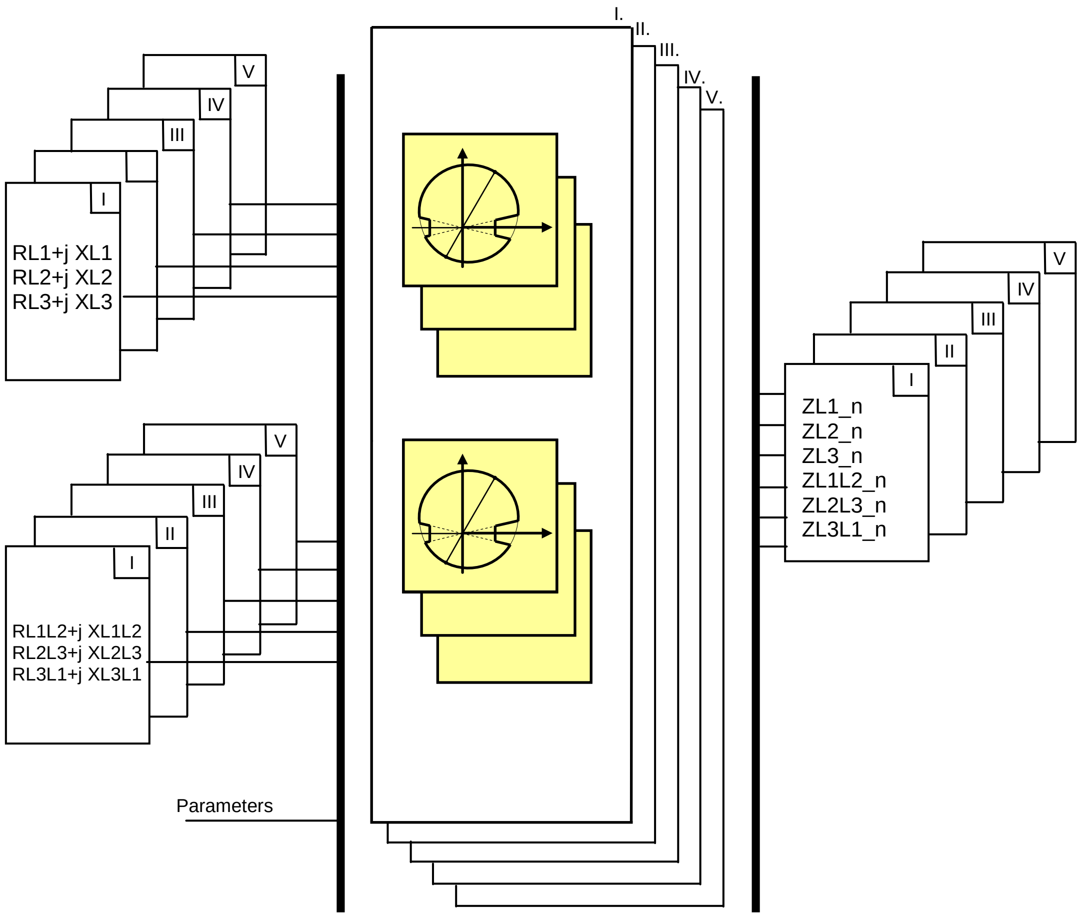


Figure 3-15: MHO characteristics Logic

Table 3-19 Input impedances for the characteristics logic.

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

Table 3-20 Output signals of the characteristics logic.

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

The phase selection logic and timing

In case of fault, 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.

Three phase fault detection

The 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 of the polygon impedance logic have stated 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.

In and in the subsequent figures "n = 1…5" means that the logic is repeated for all five zones.

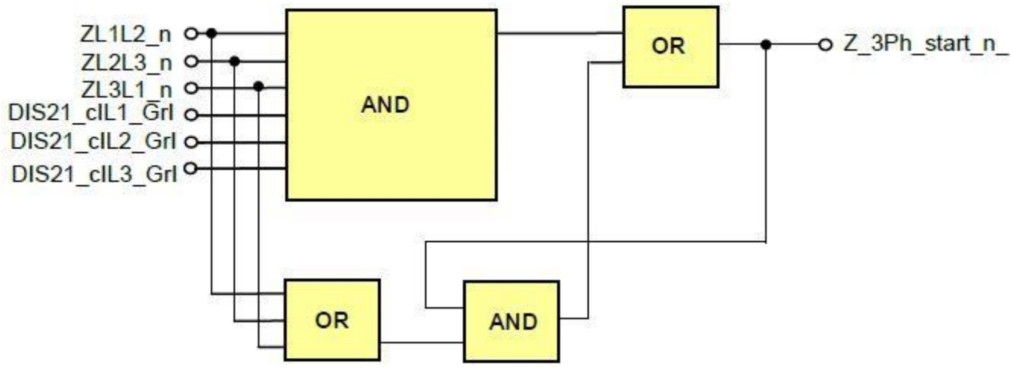


Figure 3-16: Three-phase fault detection in Zone "n"(1...5)

Table 3-21: Inputs needed to decide the three-phase start of the distance protection function

Input status signals	Zones	Explanation
ZL1L2_n	n=1…5	The calculated impedance of fault loop L1L2 is within the zone characteristic
ZL2L3_n	n=1…5	The calculated impedance of fault loop L2L3 is within the zone characteristic
ZL3L1_n	n=1…5	The calculated impedance of fault loop L3L1 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

Table 3-22: Three-phase start of the distance protection function

Output status signals	Zones	Explanation
Z_3Ph_start_n	n=1…5	Three-phase start of the distance protection function in zone "n"

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" and loop "L1L2" detects the lowest reactance, and
- "OR" relation of the following logic states:
    - no zero sequence current above the limit and no start of the polygon logic 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.

minLL = Minimum(ZL1L2, ZL2L3, ZL3L1)

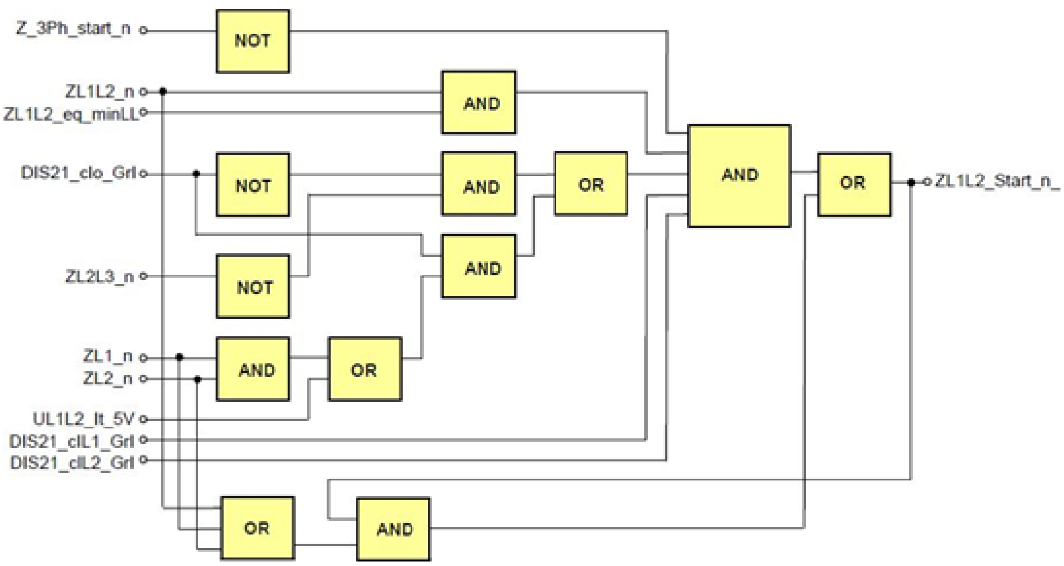


Figure 3-17: L1L2 fault detection in Zone "n" (n=1...5)

Figures below show a similar logic for loops “L2L3” and “L3L1”, respectively.

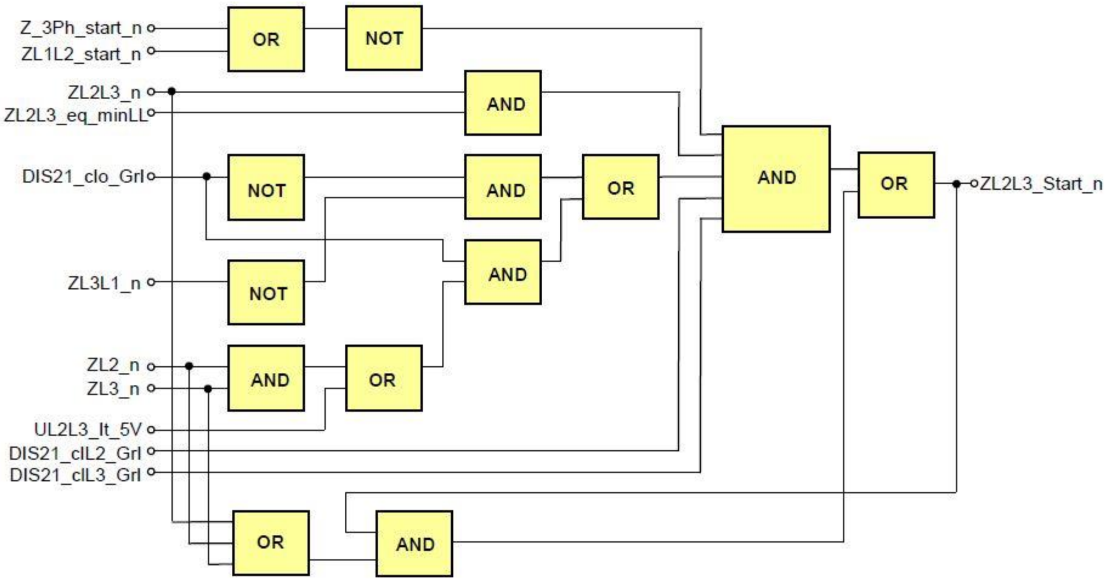


Figure 3-18: L2L3 fault detection in Zone “n” (n=1...5)

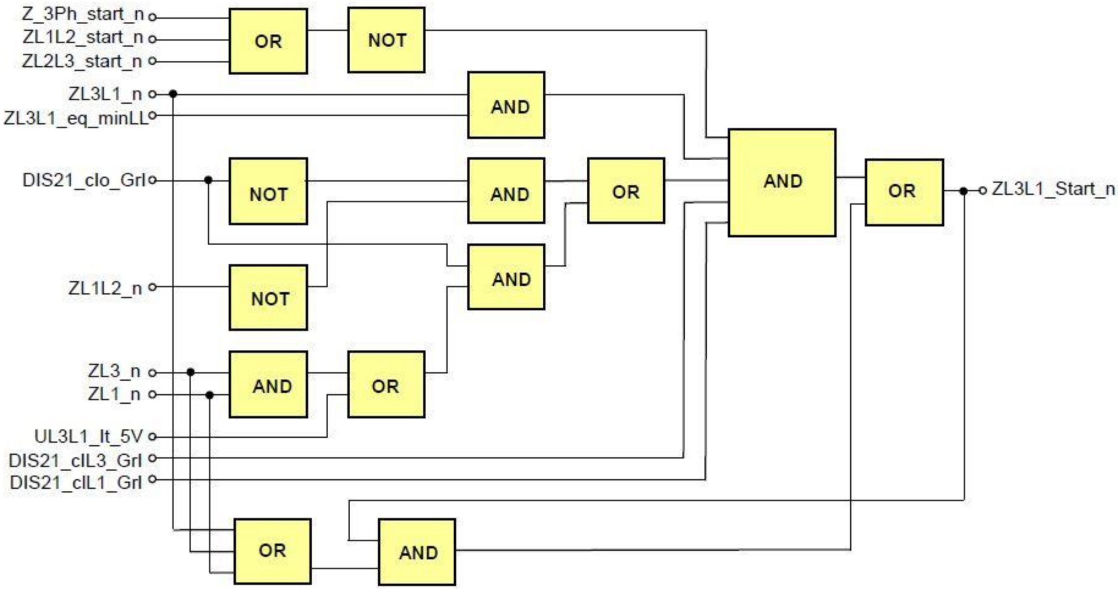


Figure 3-19: L3L1 fault detection in Zone “n” (n=1...5)

Table 3-23 LL loop start of the distance protection function.

Output status signals	Zones	Explanation
L1L2_Start_n	n=1…5	L1L2 loop start of the distance protection function in zone “n”
L2L3_Start_n	n=1…5	L2L3 loop start of the distance protection function in zone “n”
L3L1_Start_n	n=1…5	L3L1 loop start of the distance protection function in zone “n”

Table 3-24 Input signals for the LL loop start decision for the distance protection function.

Input status signals	Zones	Explanation
Z_3Ph_start_n	n=1…5	Outputs of the previous decisions
ZL1L2_Start_n	n=1…5	Outputs of the previous decisions
ZL2L3_Start_n	n=1…5	Outputs of the previous decisions
ZL1L2_n	n=1…5	The calculated impedance of fault loop L1L2 is within the zone characteristic
ZL2L3_n	n=1…5	The calculated impedance of fault loop L2L3 is within the zone characteristic
ZL3L1_n	n=1…5	The calculated impedance of fault loop L3L1 is within the zone characteristic
ZL1L2_equ_min LL	n=1…5	The calculated impedance of fault loop L1L2 is the smallest one
ZL2L3_ equ_minLL	n=1…5	The calculated impedance of fault loop L2L3 is the smallest one
ZL3L1_ equ_minLL	n=1…5	The calculated impedance of 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 L2N is within the zone characteristic
ZL3_n	n=1…5	The calculated impedance of fault loop L3N is within the zone characteristic
DIS21_cIL1_Grl		The current in phase L1 is sufficient for impedance calculation
DIS21_cIL2_Grl		The current in phase L1 is sufficient for impedance calculation
DIS21_cIL3_Grl		The current in phase L1 is sufficient for impedance calculation
DIS21_clo_Grl_		The zero sequent current component is sufficient for earth fault calculation
UL1L2_Lt_5V		The L1L2 voltage is less than 5V
UL3L3_Lt_5V		The L2L3 voltage is less than 5V
UL3L2_Lt_5V		The L3L1 voltage is less than 5V

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 polygon impedance logic in loop "L1N",
- the minimal impedance is measured in loop "L1N",
- no start of the polygon 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 loops is less then the minimal impedance in the phase-to-phase loops.

minLN = Minimum(ZL1N, ZL2N, ZL3N)

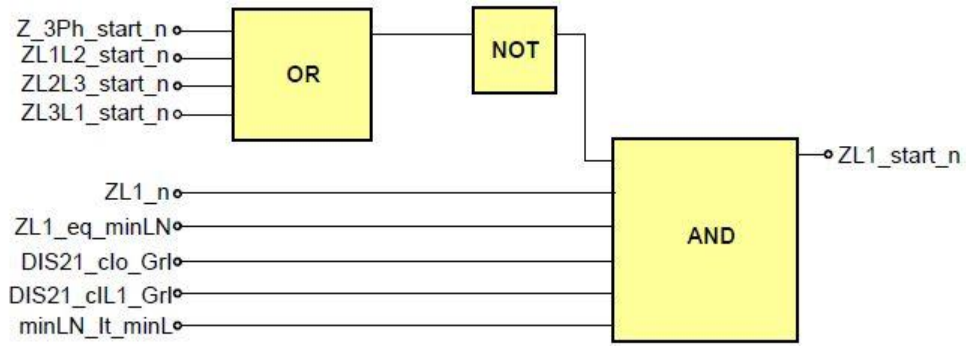


Figure 3-20: L1N fault detection in Zone "n" (n=1...5)

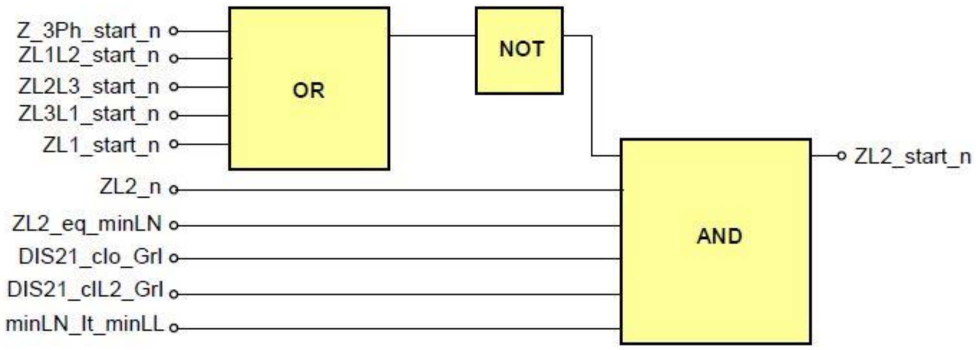


Figure 3-21: L2N fault detection in Zone "n" (n=1...5)

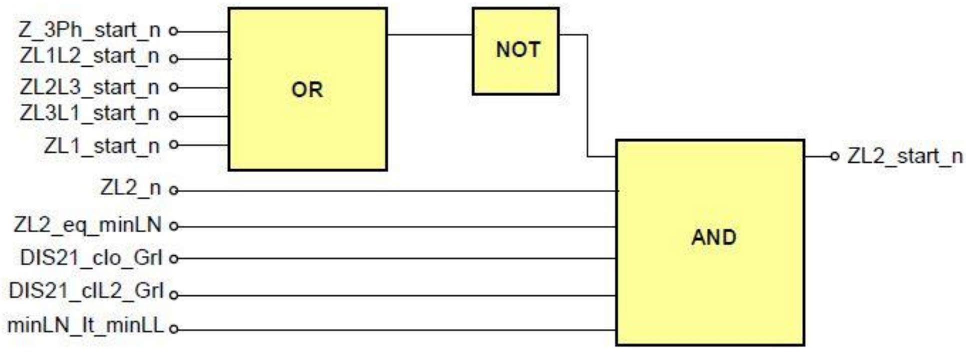


Figure 3-22: L3N fault detection in Zone "n" (n=1...5)

Table 3-25 LN loop start of the distance protection function.

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

Table 3-26 Input signals for the LN loop start decision for the distance protection function.

Input status signals	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 fault loop L1L2 is the smallest one
ZL2_ equ_minLN	n=1…5	The calculated impedance of fault loop L2L3 is the smallest one
ZL3_ equ_minLN	n=1…5	The calculated impedance of 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 L2N is within the zone characteristic
ZL3_n	n=1…5	The calculated impedance of fault loop L3N is within the zone 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 L1 is sufficient for impedance calculation
DIS21_cIL3_Grl	n=1…5	The current in phase L1 is sufficient for impedance calculation
DIS21_cIo_Grl	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.

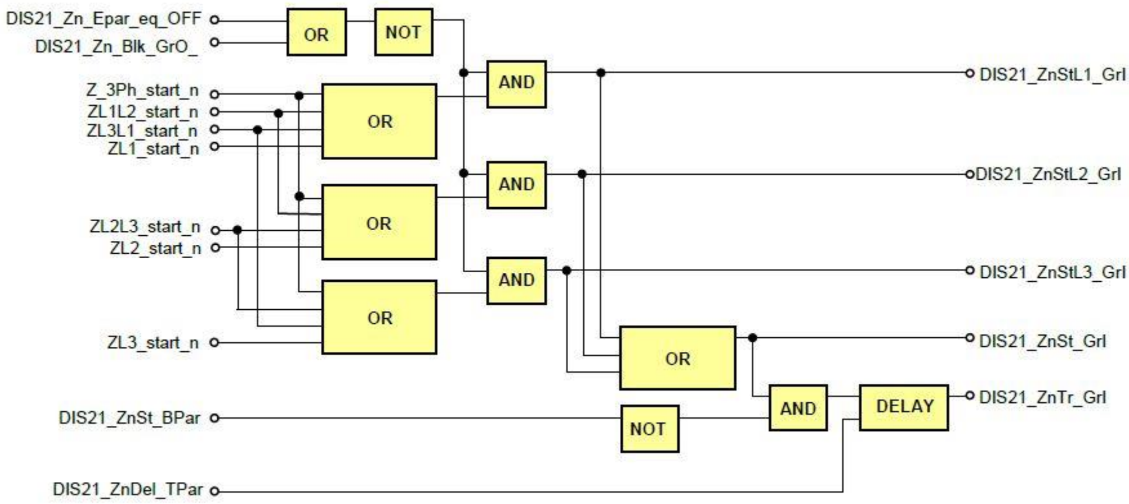


Figure 3-23: Output signals of the distance protection function Zone “n” (n=1...5).

- The operation of the distance protection may not be blocked either by parameter setting (DIS21_Zn_EPar_equ_Off) or by binary input (DIS21_Zn_Blk_GrO_)
- Starting in phase L1 if this phase is involved in the fault (DIS21_ZnStL1_GrI),
- Starting in phase L2 if this phase is involved in the fault (DIS21_ZnStL2_GrI),
- Starting in phase L2 if this phase is involved in the fault (DIS21_ZnStL3_GrI),
- General start if any of the phases is involved in the fault (DIS21_ZnSt_GrI),
- A trip command is generated after the timer Zn_Delay has expired. This timer is started if the zone is started and it is not assigned to “Start signal only”, using the parameter DIS21_ZnStBPar. The time delay is set by the timer parameter DIS21_ZnDel_TPar.

Figure below shows the method of post-processing the binary output signals to generate general start signals for the phases individually and separately for zones 2 to 5.

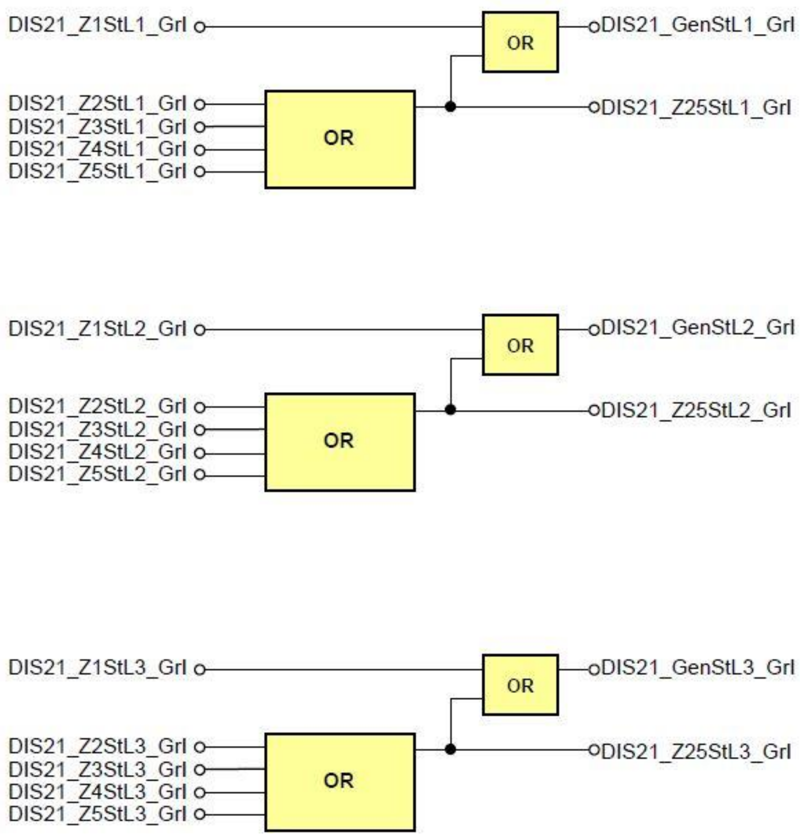


Figure 3-24: General start in the phase loops separately for Zones 2 to 5.

Table 3-27 General phase identification of the distance protection function.

Binary output signals	Signal title	Explanation
Distance Phase identification		
DIS21_GenStL1_Grl_	GenStart L1	General start in phase L1
DIS21_GenStL2_Grl_	GenStart L2	General start in phase L2
DIS21_GenStL3_Grl_	GenStart L3	General start in phase L3

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

Current conditions of the distance protection function

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

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

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

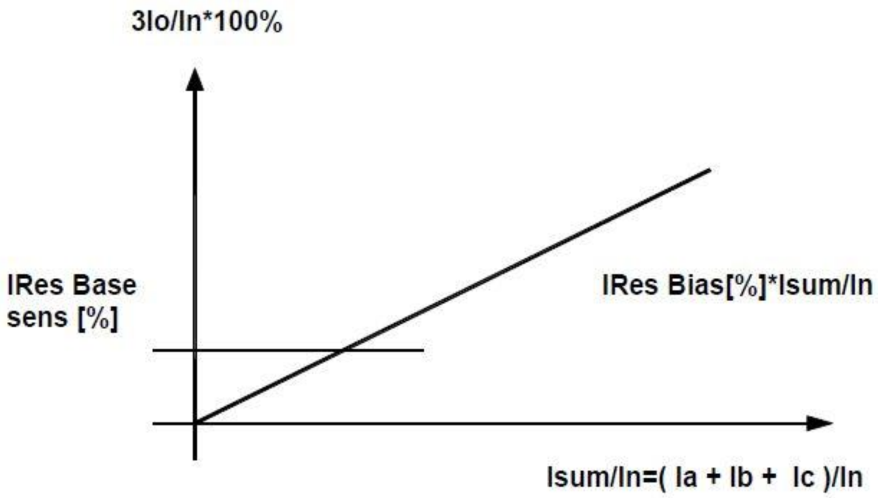


Figure 3-25: Percentage characteristic for earth-fault detection.

Power swing block and out-of step detection

Power swings can be stable or they can result in an out-of-step operation. Accordingly, the power swing detection function can block the distance protection function in case of stable swings, or it can generate a trip command if the system operates out of step.

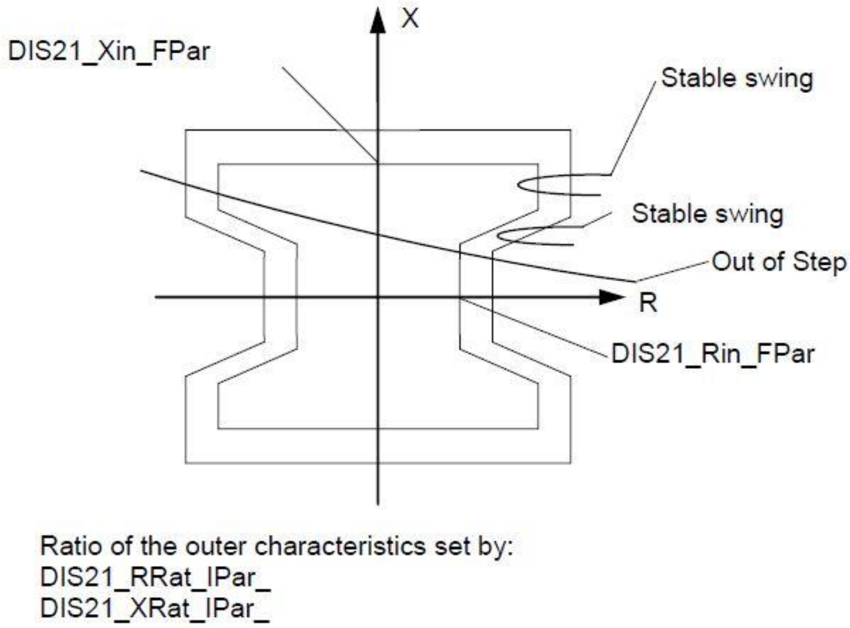


Figure 3-26: Characteristics of the Power swing blocking and out-of-step detection function.

Table 3-28 The binary output status signals of the power swing detection function.

Binary output signals	Signal title	Explanation
Distance function power swing signals generated by the PSD module		
DIS21_PSDDet_GrI_	PSD Detect	Signal for power swing detection
DIS21_OutTr_GrI_	OutOfStep Trip	Signal for out-of-step tripping condition
DIS21_PSDslow_GrI_	VerySlow Swing	Signal for very slow power swing detection

All these binary signals presented in the table can be programmed by the user.

The binary inputs are signals influencing the operation of the distance protection function. These signals are the results configuration by the user. E.g., the DIS21_PSDBlk_GrO_ signal can be programmed using these inputs to block the distance protection function.

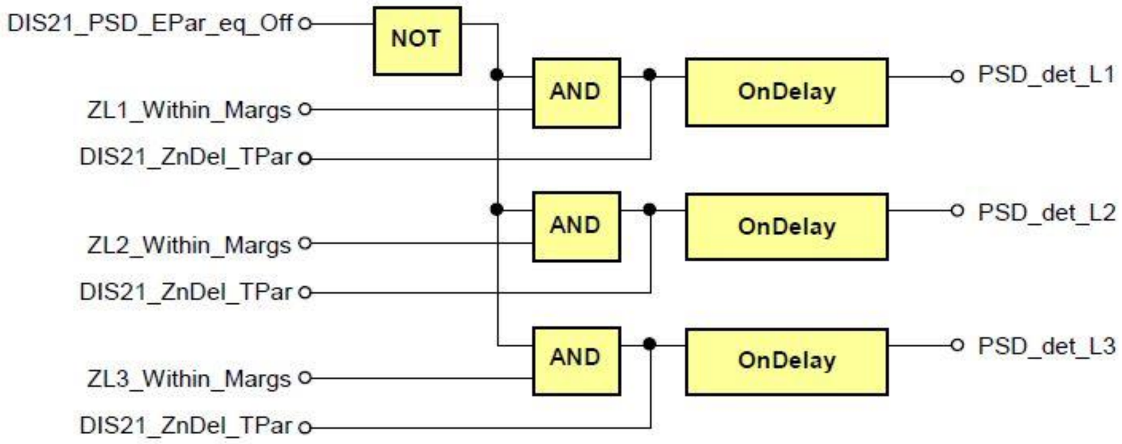


Figure 3-27: Power swing detection in the individual phases.

Figure above shows that power swing is detected in the individual phases if the measured impedance (Phase-to-ground loop for Zone1) is within the margins of the PSD characteristics for the time span, given with parameter DIS21_PSDDel_TPar_.

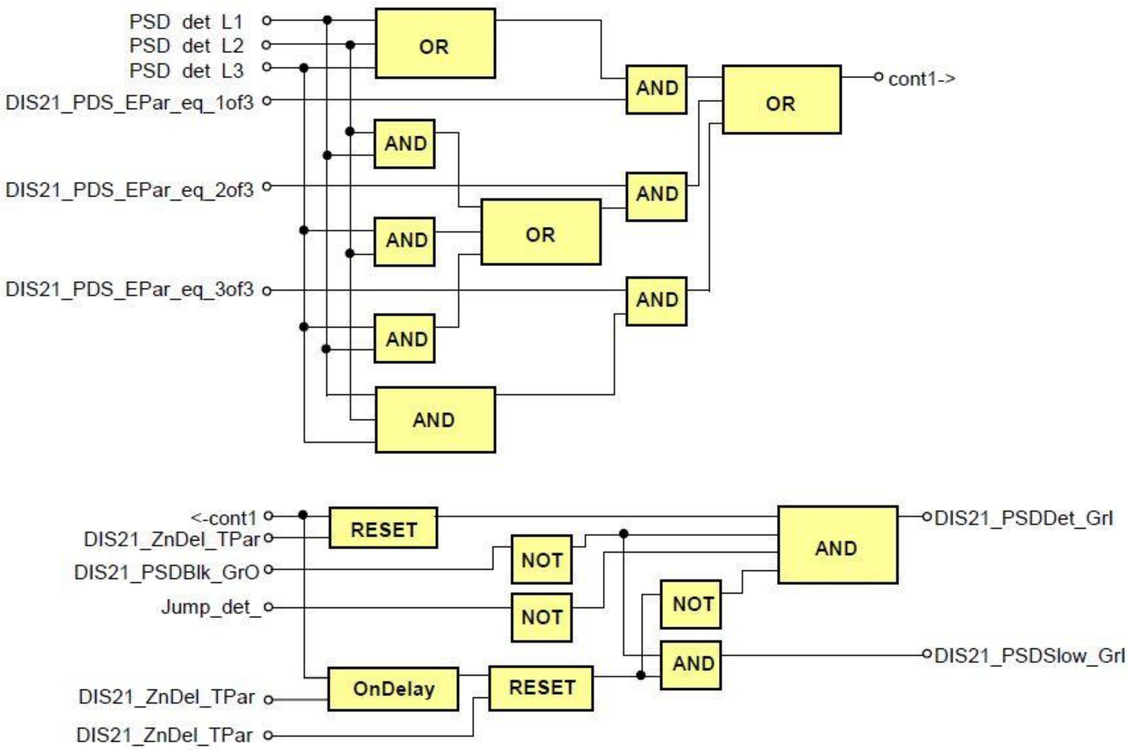


Figure 3-28: Power swing detection and slow power swing detection.

According to figure above, the power swings in the individual phases result in a power swing state only if the combination of the phases corresponds to the parameter setting DIS21_PSD_EPar (which can be 1 out of 3, 2 out of 3, 3 out of 3).

The function can be blocked using the enumerated parameter DIS21_PSD_EPar_ if it is set to “Off”. The function can be blocked using the user-programmable graphic output status DIS21_PSDBlk_GrO_.

This part of the function has two output status signals:

- DIS21_PSDDet_GrI_ to detect power swings. For instance, the user has the possibility to block one or more distance protection zones during power swings using the DIS21_Zn_Blk_GrO_ output status of the equation editor.
- DIS21_PSDslow_GrI_ to detect slow power swings. This status has signaling purposes only.

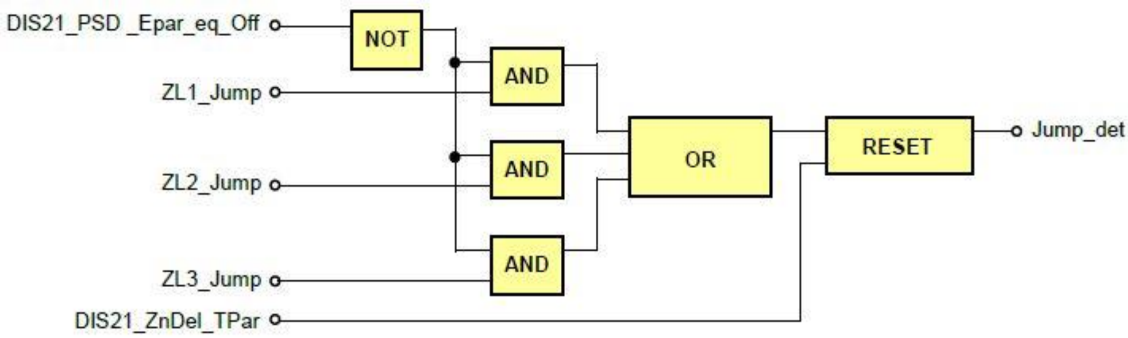


Figure 3-29: Impedance jump detection.

Figure above shows that if impedance jump is detected (i.e., the change of the reactance and resistance values between two consecutive samples is greater than ¼ of the PSD margin setting) in any of the phases, then the “Jump_det” condition is true for the “reset” time.

The impedance jump is an internal signal. If during power swings the impedance “jumps”, this means a fault during the swings and the power swing state must be terminated.

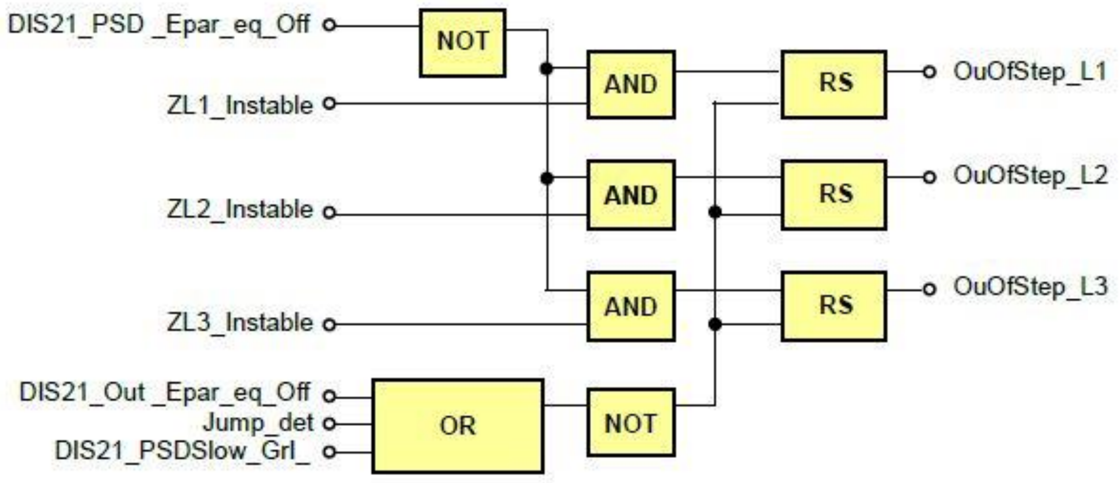


Figure 3-30: Out-of-step condition detection in the individual phases.

If the swings are instable, the sign of the resistive component of the impedance at entrance is opposite to the sign of the resistance calculated at leaving the characteristics. Figure 23 shows that "Out-of-step condition" is detected in the individual phases if instable state is measured (i.e., the sign of the resistive component is opposite if the impedance enters and if it exits the PSD characteristics). The function can be disabled using the enumerated parameter DIS21_PSD_EPar_ if it is set to "Off". This function also resets if the out-of-step function is disabled by the parameter DIS21_Out_EPar_ by setting it to "Off", or an impedance jump is detected ("Jump_det") according to figure 22 or a slow swing is detected (see "DIS21_PSDslow_Grl_" on figure 21 above).

In this case, the algorithm can generate the out-of-step tripping condition DIS21_OutTr_Grl_. The duration of this impulse is determined by the parameter DIS21_OutPs_TPar_.

The "very slow swing" condition DIS21_PSDslow_Grl_ is generated if the duration of measuring the impedance within the rectangle is longer then the parameter setting DIS21_PSDSlow_TPar_.

All these binary signals can serve as binary inputs for the equations, to be programmed by the user.

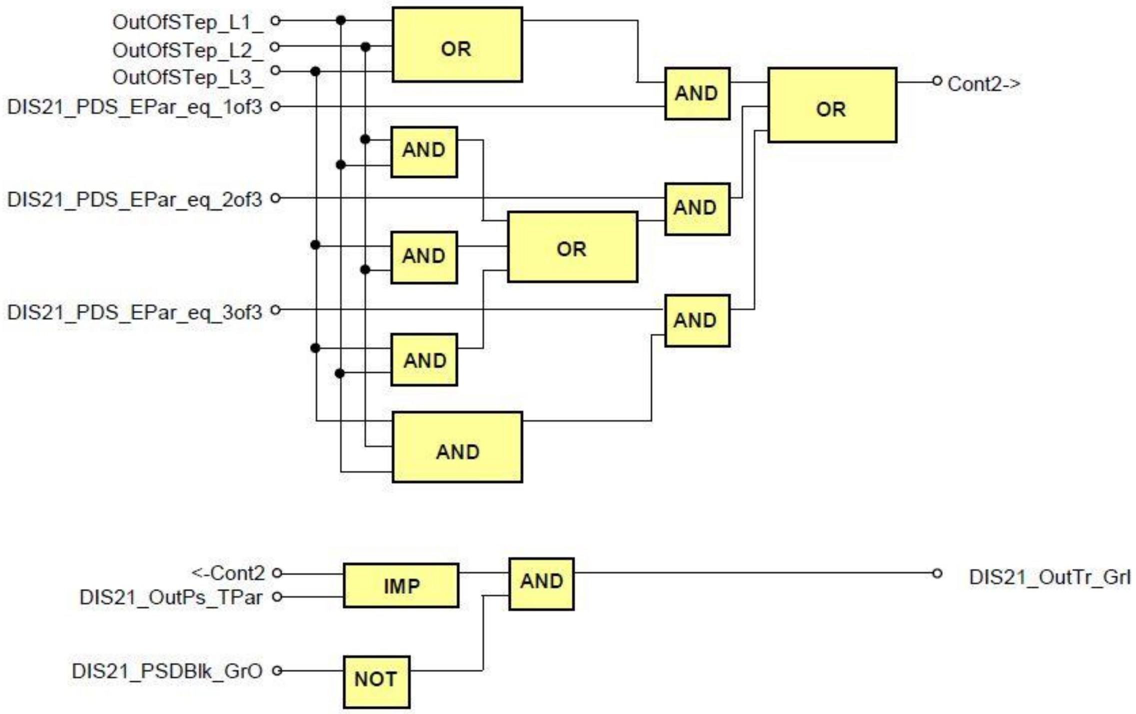


Figure 3-31: Out-of-step trip command generation.

According to figure 24, the out-of-step conditions in the individual phases can result in an out-of-step trip command impulse only if the combination of the phases corresponds to the parameter setting DIS21_PSD_EPar (which can be 1 out of 3, 2 out of 3, 3 out of 3). The duration of the trip command can be set using the parameter DIS21_OutPs_TPar_.

The distance-to-fault calculation

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

Table 3-29. Setting parameters of the distance to fault calculation

Parameter name	Title	Dim.	Min	Max	Default
DIS21_Lgth_FPar_	Line Length	km	0.1	1000	100
DIS21_LReact_FPar_	Line Reactance	ohm	0.01	150	10

The high-speed overcurrent protection function and the switch-onto-fault logic

The switch-onto-fault protection function can generate an immediate trip command if the function is enabled and switch-onto-fault condition is detected. The condition of the operation can be the starting signal of any distance protection zone as it is selected by a dedicated parameter, or it can be the operation of the high-speed overcurrent protection function.

The high-speed overcurrent protection function operates if a sampled value of the phase current is above the setting value.

The binary output status signals of SOTF function are presented in table below.

Table 3-30 The binary output signals of the SOTF function.

Binary output signals	Signal title	Explanation
SOTF function		
DIS21_SOTFTr_GrI_	SOTF Trip	The distance protection function generated a trip command caused by switching onto fault

The binary input is a signal influencing the operation of the distance protection function configured by the user.

Table 3-31 Binary input signals of the SOTF logic.

Binary input signals	Signal title	Explanation
DIS21_SOTFCond_GrO_	SOTF COND.	Status signal indicating switching-onto-fault condition

Table 3-32 Operating mode selection of the SOTF function.

Parameter name	Title	Selection range	Default
Parameter for selecting one of the zones or “high speed overcurrent protection” for the “switch-onto-fault” function:			
DIS21_SOTFMd_EPar _	SOTF Zone	Off,Zone1,Zone2,Zone 3,Zone4,Zone5,HSOC	Zone1

Table 3-33 Setting parameters of the SOTF logic

Parameter name	Title	Unit	Min	Max	Step	Default
Definition of the overcurrent setting for the switch-onto-fault function, for the case where the DIS21_SOTFMd_EPar_ (SOTF Zone) parameter is set to “HSOC”:						
DIS21_SOTFOC_IPar_	SOTF Current	%	10	1000	1	200

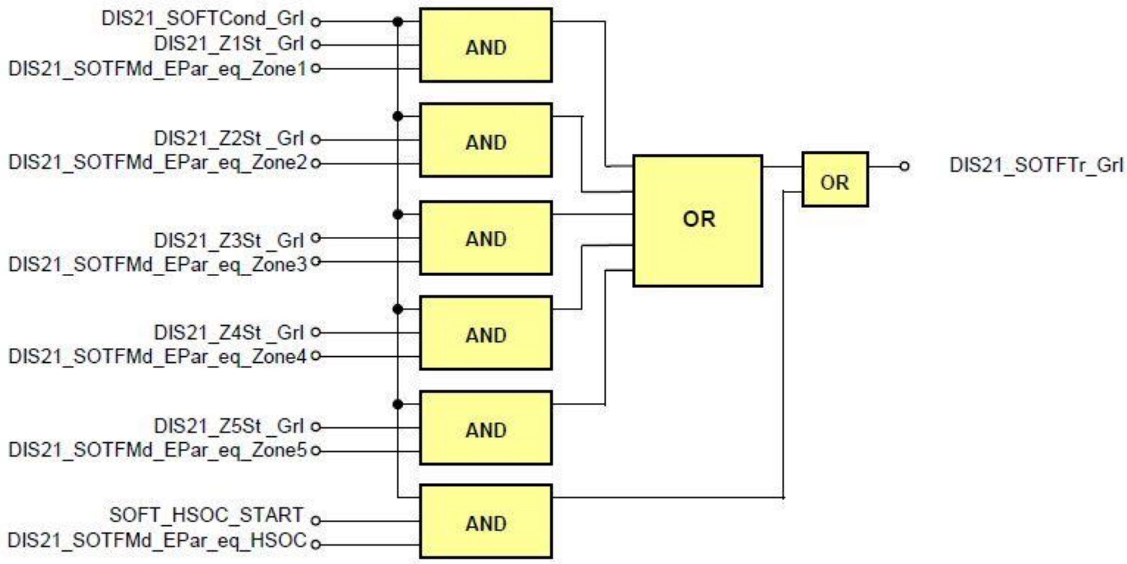


Figure 3-32: The internal logic of the SOTF function.

Table 3-34 Input signals of the SOTF logic

Binary input signals	Signal title	Explanation
DIS21_Z1St_GrI		Started state of the distance protection Zone1
DIS21_Z2St_GrI		Started state of the distance protection Zone2
DIS21_Z3St_GrI		Started state of the distance protection Zone3
DIS21_Z4St_GrI		Started state of the distance protection Zone4
DIS21_Z5St_GrI		Started state of the distance protection Zone5
SOTF_HSOC_START		Started state of the HSOC function

On-line measured values of the distance protection function

Table 3-35 Measured magnitudes of the distance protection function.

Name	Title	Explanation
DIS21_HTXkm_OLM_	Fault location	Measured distance to fault in kilometers
DIS21_HTXohm_OLM_	Fault react.	Measured reactance to fault
DIS21_L1N_R_OLM_	L1N loop R	Measured positive sequence resistance in L1N loop
DIS21_L1N_X_OLM_	L1N loop X	Measured positive sequence reactance in L1N loop
DIS21_L2N_R_OLM_	L2N loop R	Measured positive sequence resistance in L2N loop
DIS21_L2N_X_OLM_	L2N loop X	Measured positive sequence reactance in L2N loop
DIS21_L3N_R_OLM_	L3N loop R	Measured positive sequence resistance in L3N loop
DIS21_L3N_X_OLM_	L3N loop X	Measured positive sequence reactance in L3N loop
DIS21_L12_R_OLM_	L12 loop R	Measured positive sequence resistance in L12 loop
DIS21_L12_X_OLM_	L12 loop X	Measured positive sequence reactance in L12 loop
DIS21_L23_R_OLM_	L23 loop R	Measured positive sequence resistance in L23 loop
DIS21_L23_X_OLM_	L23 loop X	Measured positive sequence reactance in L23 loop
DIS21_L31_R_OLM_	L31 loop R	Measured positive sequence resistance in L31 loop
DIS21_L31_X_OLM_	L31 loop X	Measured positive sequence reactance in L31 loop

Table 3-36 Calculated analogue values of the distance protection function.

Measured value	Dim.	Explanation
ZL1 = RL1+j XL1	ohm	Measured positive sequence impedance in the L1N loop, using the zero sequence current compensation factor for zone 1
ZL2 = RL2+j XL2	ohm	Measured positive sequence impedance in the L2N loop, using the zero sequence current compensation factor for zone 1
ZL3 = RL3+j XL3	ohm	Measured positive sequence impedance in the L3N loop, using the zero sequence current compensation factor for zone 1
ZL1L2 = RL1L2+j XL1L2	ohm	Measured positive sequence impedance in the L1L2 loop
ZL2L3 = RL2L3+j XL2L3	ohm	Measured positive sequence impedance in the L2L3 loop
ZL3L1 = RL3L1+j XL3L1	ohm	Measured positive sequence impedance in the L3L1 loop
Fault location	km	Measured distance to fault
Fault react.	ohm	Measured impedance in the fault loop

The symbol of the function block in the AQtivate 300 software

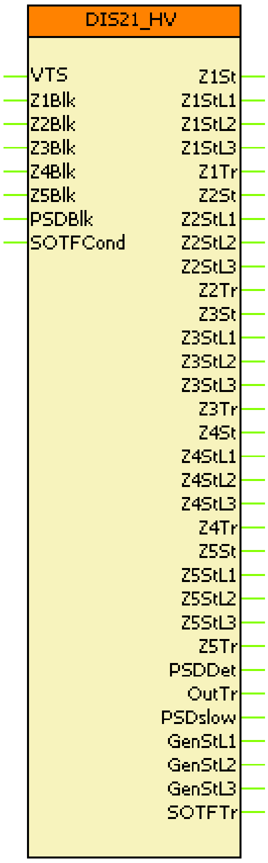


Figure 3-33: The function block of the distance protection function with polygon characteristic

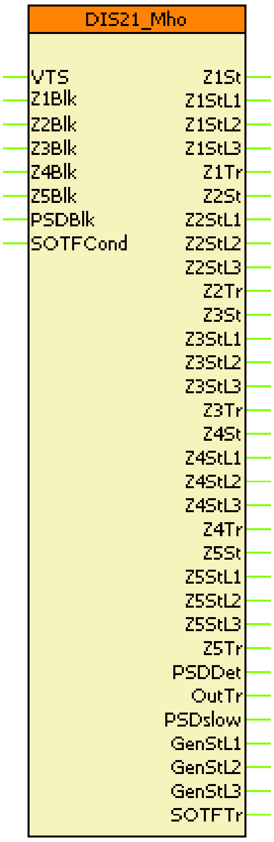


Figure 3-34: The function block of the distance protection function with MHO characteristic

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

Table 3-37: The binary input signals of the distance protection function

Binary input signals	Signal title	Explanation
DIS21_VTS_GrO_	Block from VTS	Blocking signal due to error in the voltage measurement
DIS21_Z1Blk_GrO_	Block Z1	Blocking of Zone 1
DIS21_Z2Blk_GrO_	Block Z2	Blocking of Zone 2
DIS21_Z3Blk_GrO_	Block Z3	Blocking of Zone 3
DIS21_Z4Blk_GrO_	Block Z4	Blocking of Zone 4
DIS21_Z5Blk_GrO_	Block Z5	Blocking of Zone 5
DIS21_PSDBlk_GrO_	Block PSD	Blocking signal for power swing detection
DIS21_SOTFCond_GrO_	SOTF COND.	Status signal indicating switching-onto-fault condition

Table 3-38: The binary output status signals of the distance protection function

Binary output signals	Signal title	Explanation
Distance Zone 1		
DIS21_Z1St_GrI_	Start Z1	General start of Zone1
DIS21_Z1StL1_GrI_	Z1 Start L1	Start in phase L1 of Zone1
DIS21_Z1StL2_GrI_	Z1 Start L2	Start in phase L2 of Zone1
DIS21_Z1StL3_GrI_	Z1 Start L3	Start in phase L3 of Zone1
DIS21_Z1Tr_GrI_	Trip Z1	Trip command generated in Zone1
Distance Zone 2		
DIS21_Z2St_GrI_	Start Z2	General start of Zone2
DIS21_Z2StL1_GrI_	Z2 Start L1	Start in phase L1 of Zone2
DIS21_Z2StL2_GrI_	Z2 Start L2	Start in phase L2 of Zone2
DIS21_Z2StL3_GrI_	Z2 Start L3	Start in phase L3 of Zone2
DIS21_Z2Tr_GrI_	Trip Z2	Trip command generated in Zone2
Distance Zone 3		
DIS21_Z3St_GrI_	Start Z3	General start of Zone3
DIS21_Z3StL1_GrI_	Z3 Start L1	Start in phase L1 of Zone3
DIS21_Z3StL2_GrI_	Z3 Start L2	Start in phase L2 of Zone3
DIS21_Z3StL3_GrI_	Z3 Start L3	Start in phase L3 of Zone3
DIS21_Z3Tr_GrI_	Trip Z3	Trip command generated in Zone3
Distance Zone 4		
DIS21_Z4St_GrI_	Start Z4	General start of Zone4
DIS21_Z4StL1_GrI_	Z4 Start L1	Start in phase L1 of Zone4
DIS21_Z4StL2_GrI_	Z4 Start L2	Start in phase L2 of Zone4
DIS21_Z4StL3_GrI_	Z4 Start L3	Start in phase L3 of Zone4
DIS21_Z4Tr_GrI_	Trip Z4	Trip command generated in Zone4
Distance Zone 5		
DIS21_Z5St_GrI_	Start Z5	General start of Zone5
DIS21_Z5StL1_GrI_	Z5 Start L1	Start in phase L1 of Zone5
DIS21_Z5StL2_GrI_	Z5 Start L2	Start in phase L2 of Zone5
DIS21_Z5StL3_GrI_	Z5 Start L3	Start in phase L3 of Zone5
DIS21_Z5Tr_GrI_	Trip Z5	Trip command generated in Zone5
Distance Phase identification		
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
SOTF function		
DIS21_SOTFTr_GrI_	SOTF Trip	The distance protection function generated a trip command caused by switching onto fault
Distance function power swing signals generated by the PSD module		
DIS21_PSDDet_GrI_	PSD Detect	Signal for power swing detection
DIS21_OutTr_GrI_	OutOfStep Trip	Signal for out-of-step tripping condition
DIS21_PSDslow_GrI_	VerySlow Swing	Signal for very slow power swing detection

Table 3-39 Basic setting parameters of the distance protection function.

Parameter	Setting value, range and step	Description
Operation Zone1	Off, Forward, Backward	Operating direction selection for the distance Zone1. Default setting is Forward.
Operation Zone2	Off, Forward, Backward Offset (only in MHO)	Operating direction selection for the distance Zone2. Default setting is Forward.
Operation Zone3	Off, Forward, Backward Offset (only in MHO)	Operating direction selection for the distance Zone3. Default setting is Forward.
Operation Zone4	Off, Forward, Backward Offset (only in MHO)	Operating direction selection for the distance Zone4. Default setting is Forward.
Operation Zone5	Off, Forward, Backward Offset (only in MHO)	Operating direction selection for the distance Zone5. Default setting is Backward.
Operation PSD	Off, 1 out of 3, 2 out of 3, 3 out of 3	Operating mode setting for the power swing blocking detection. Default setting is 1 out of 3 phases.
Oper OutOfStep	Off, On	Out of step functionality enabling/disabling. Default setting is Off.
SOTF Zone	Off, Zone1, Zone2, Zone3, Zone4, Zone5, HSOC	Switch on to fault function input selection. For the input can be selected any of the distance protection Zones or high speed non directional overcurrent function. Default setting is Zone1.

Table 3-40 Zone behavioural setting parameters of the distance protection function.

Parameter	Setting value, range and step	Description
Zone1 Start Only	0 1	Selection if the Zone1 initiates starting signal only or start and trip signals. Selection “0” Zone1 to generate both start and trip commands. Default setting is “0”.
Zone2 Start Only	0 1	Selection if the Zone2 initiates starting signal only or start and trip signals. Selection “0” Zone2 to generate both start and trip commands. Default setting is “0”.
Zone3 Start Only	0 1	Selection if the Zone3 initiates starting signal only or start and trip signals. Selection “0” Zone3 to generate both start and trip commands. Default setting is “0”.
Zone4 Start Only	0 1	Selection if the Zone4 initiates starting signal only or start and trip signals. Selection “0” Zone4 to generate both start and trip commands. Default setting is “0”.
Zone5 Start Only	0 1	Selection if the Zone5 initiates starting signal only or start and trip signals. Selection “0” Zone5 to generate both start and trip commands. Default setting is “0”.

3-41: Setting parameters to block individual zones by the Power Swing Detection (PSD) function

Parameter	Setting value, range and step	Description
PSD Block Z1	0 1	1 for Zone1 to be blocked by PSD. Default setting is “0”.
PSD Block Z2	0 1	1 for Zone2 to be blocked by PSD. Default setting is “0”.
PSD Block Z3	0 1	1 for Zone3 to be blocked by PSD. Default setting is “0”.
PSD Block Z4	0 1	1 for Zone4 to be blocked by PSD. Default setting is “0”.
PSD Block Z5	0 1	1 for Zone5 to be blocked by PSD. Default setting is “0”.

Table 3-42 General setting parameters of the distance protection function with polygonal characteristics.

Parameter	Setting value, range and step	Description
IPh Base Sens	10%…30% by step of 1 %	Setting of minimum current for enabling impedance calculation. Default setting is 20 %.
IRes Base Sens	10%...50% by step of 1%	Setting of basic zero sequence current characteristic for enabling impedance calculation in phase-to-earth loops. Default setting is 10 %.
IRes Bias	5%...30% by step of 1%	Setting of biasing zero sequence current characteristic for enabling impedance calculation in phase-to-earth loops. Default setting is 10 %.
Angle 4th Quad	0 deg…30 deg by step of 1 deg.	Setting of the polygon characteristic angle in the 4th quadrant of the impedance plane. Default setting is 15 deg from the resistive axle.
Angle 2nd Quad	0 deg…30 deg by step of 1 deg.	Setting of the polygon characteristic angle in the 2nd quadrant of the impedance plane. Default setting is 15 deg from the reactive axle.
Zone Reduct Angle	0 deg…40 deg by step of 1 deg.	Setting of the polygon characteristic's zone reduction angle on the impedance plane for the load compensation. Default setting is 0 deg.
Load Angle	0 deg…45 deg by step of 1 deg.	Setting of the load encroachment angle of the polygon characteristic. Default setting is 30 deg.
Line Angle	45 deg…90 deg by step of 1 deg.	Setting of the line angle. Default setting is 75 deg.
PSD R_out/R_in	120%…160% by step of 1%.	Resistive reach setting of the ratio of the characteristics for power swing detection. Default setting is 130 %.
PSD X_out/X_in	120%…160% by step of 1%.	Reactive reach setting of the ratio of the characteristics for power swing detection. Default setting is 130 %.
SOTF Current	10%…1000% by step of 1%.	High speed overcurrent setting for the switch-onto-fault function, where the input signal is set to "HSOC". Default setting is 200 %.

Table 3-43: General setting parameters of the distance protection function with MHO characteristics.

Parameter	Setting value, range and step	Description
IPh Base Sens	10%…30% by step of 1 %	Setting of minimum current for enabling impedance calculation. Default setting is 20 %.
IRes Base Sens	10%...50% by step of 1%	Setting of basic zero sequence current characteristic for enabling impedance calculation in phase-to-earth loops. Default setting is 10 %.
IRes Bias	5%...30% by step of 1%	Setting of biasing zero sequence current characteristic for enabling impedance calculation in phase-to-earth loops. Default setting is 10 %.
Load Angle	0 deg…45 deg by step of 1 deg.	Setting of the load encroachment angle of the MHO characteristic. Default setting is 30 deg.
Line Angle	45 deg…90 deg by step of 1 deg.	Setting of the line angle. Default setting is 75 deg.
PSD R_out/R_in	120%…160% by step of 1%.	Resistive reach setting of the ratio of the characteristics for power swing detection. Default setting is 130 %.
PSD X_out/X_in	120%…160% by step of 1%.	Reactive reach setting of the ratio of the characteristics for power swing detection. Default setting is 130 %.
SOTF Current	10%…1000% by step of 1%.	High speed overcurrent setting for the switch-onto-fault function, where the input signal is set to “HSOC”. Default setting is 200 %.

Table 3-44 Distance protection characteristic reach settings for polygon characteristics

Parameter	Setting value, range and step	Description
Zone1 R PhPH	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone1 Resistive reach setting phase-to-phase loop. Default setting is 10 ohm.
Zone2 R PhPH	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone2 Resistive reach setting phase-to-phase loop. Default setting is 10 ohm.
Zone3 R PhPH	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone3 Resistive reach setting phase-to-phase loop. Default setting is 10 ohm.
Zone4 R PhPH	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone4 Resistive reach setting phase-to-phase loop. Default setting is 10 ohm.
Zone5 R PhPH	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone5 Resistive reach setting phase-to-phase loop. Default setting is 10 ohm.
Zone1 X PhPH	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone1 Reactive reach setting phase-to-phase loop. Default setting is 10 ohm.
Zone2 X PhPH	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone2 Reactive reach setting phase-to-phase loop. Default setting is 10 ohm.
Zone3 X PhPH	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone3 Reactive reach setting phase-to-phase loop. Default setting is 10 ohm.
Zone4 X PhPH	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone4 Reactive reach setting phase-to-phase loop. Default setting is 10 ohm.
Zone5 X PhPH	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone5 Reactive reach setting phase-to-phase loop. Default setting is 10 ohm.
Zone1 R PhN	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone1 Resistive reach setting phase-to-ground loop. Default setting is 10 ohm.
Zone2 R PhN	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone2 Resistive reach setting phase-to-ground loop. Default setting is 10 ohm.
Zone3 R PhN	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone3 Resistive reach setting phase-to-ground loop. Default setting is 10 ohm.
Zone4 R PhN	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone4 Resistive reach setting phase-to-ground loop. Default setting is 10 ohm.
Zone5 R PhN	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone5 Resistive reach setting phase-to-ground loop. Default setting is 10 ohm.
Zone1 X PhN	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone1 Reactive reach setting phase-to-ground loop. Default setting is 10 ohm.
Zone2 X PhN	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone2 Reactive reach setting phase-to-ground loop. Default setting is 10 ohm.
Zone3 X PhN	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone3 Reactive reach setting phase-to-ground loop. Default setting is 10 ohm.
Zone4 X PhN	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone4 Reactive reach setting phase-to-ground loop. Default setting is 10 ohm.
Zone5 X PhN	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone5 Reactive reach setting phase-to-ground loop. Default setting is 10 ohm.

Table 3-45: Distance protection characteristic reach settings for MHO characteristics

Parameter	Setting value, range and step	Description
Zone1 Z	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone1 reach setting. Default setting is 10 ohm.
Zone2 Z	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone2 reach setting. Default setting is 10 ohm.
Zone3 Z	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone3 reach setting. Default setting is 10 ohm.
Zone4 Z	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone4 reach setting. Default setting is 10 ohm.
Zone5 Z	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone5 reach setting. Default setting is 10 ohm.
Zone2 ZRev	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone2 reverse setting. Moves the characteristic along the set line in the reverse direction. Active only if Operation Zone 2 is set to “Offset”. Default setting is 10 ohm.
Zone3 ZRev	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone3 reverse setting. Moves the characteristic along the set line in the reverse direction. Active only if Operation Zone 3 is set to “Offset”. Default setting is 10 ohm.
Zone4 ZRev	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone4 reverse setting. Moves the characteristic along the set line in the reverse direction. Active only if Operation Zone 4 is set to “Offset”. Default setting is 10 ohm.
Zone5 ZRev	0.01 ohm … 200 ohm by step of 0.01 ohm	Zone5 reverse setting. Moves the characteristic along the set line in the reverse direction. Active only if Operation Zone5 is set to “Offset”. Default setting is 10 ohm.

Table 3-46 Load encroachment settings of the distance protection characteristics

Parameter	Setting value, range and step	Description
R Load	0.01 ohm…200ohm by step of 0.01	Load encroachment resistance. Default setting is 10 ohm.

Table 3-47 Zero sequence current compensation factors

Parameter	Setting value, range and step	Description
Zone1 (Xo-X1)/3X1 *)	0.00…5.00 by step of 0.01	Reactive compensation factor for Zone1. Default setting is 1.00.
Zone1 (Ro-R1)/3R1 *)	0.00…5.00 by step of 0.01	Resistive compensation factor for Zone1. Default setting is 1.00.
Zone3 (Xo-X1)/3X1	0.00…5.00 by step of 0.01	Reactive compensation factor for Zone3. Default setting is 1.00.
Zone3 (Ro-R1)/3R1	0.00…5.00 by step of 0.01	Resistive compensation factor for Zone3. Default setting is 1.00.
Zone4 (Xo-X1)/3X1	0.00…5.00 by step of 0.01	Reactive compensation factor for Zone4. Default setting is 1.00.
Zone4 (Ro-R1)/3R1	0.00…5.00 by step of 0.01	Resistive compensation factor for Zone4. Default setting is 1.00.
Zone5 (Xo-X1)/3X1	0.00…5.00 by step of 0.01	Reactive compensation factor for Zone5. Default setting is 1.00.
Zone5 (Ro-R1)/3R1	0.00…5.00 by step of 0.01	Resistive compensation factor for Zone5. Default setting is 1.00.

**) Zone 1 and Zone 2 settings are the same and defined by zone 1 settings only*

Table 3-48 Parallel line coupling factor

Parameter	Setting value, range and step	Description
Par Line Xm/3X1	0.00…5.00 by step of 0.01	Reactive coupling factor for the parallel line compensation. Default setting is 0.00.
Par Line Rm/3R1	0.00…5.00 by step of 0.01	Resistive coupling factor for the parallel line compensation. Default setting is 0.00.

Table 3-49 Fault distance calculation parameters

Parameter	Setting value, range and step	Description
Line Length	0.1 km…1000 km by step of 0.1 km	Length of the protected line in kilometers. Default setting is 100 km.
Line Reactance	0.01ohm…200 ohm by step of 0.01 ohm	Reactance of the protected line in ohms. Default setting is 10 ohm.

Table 3-50 Characteristics setting of the power swing detection

Parameter	**Setting value, range and step**	**Description**
PSD Xinner	0.10 ohm…200.00 ohm by step of 0.01 ohm	Setting of the power swing block detector characteristic band reactive inner limit. Default setting is 10.00 ohm.
PSD Rinner	0.10 ohm…200.00 ohm by step of 0.01 ohm	Setting of the power swing block detector characteristic band resistive inner limit. Default setting is 10.00 ohm.

Table 3-51 Timing setting parameters of the distance protection function

Parameter	**Setting value, range and step**	**Description**
Zone1 Time Delay PhPH	0…60000 ms by step of 1 ms.	Time delay setting of the Zone1 phase-to-phase distance characteristics. Default setting is 0 ms.
Zone2 Time Delay PhPH	0…60000 ms by step of 1 ms.	Time delay setting of the Zone2 phase-to-phase distance characteristics. Default setting is 400 ms.
Zone3 Time Delay PhPH	0…60000 ms by step of 1 ms.	Time delay setting of the Zone3 phase-to-phase distance characteristics. Default setting is 800 ms.
Zone4 Time Delay PhPH	0…60000 ms by step of 1 ms.	Time delay setting of the Zone4 phase-to-phase distance characteristics. Default setting is 2000 ms.
Zone5 Time Delay PhPH	0…60000 ms by step of 1 ms.	Time delay setting of the Zone5 phase-to-phase distance characteristics. Default setting is 2000 ms.
Zone1 Time Delay PhN	0…60000 ms by step of 1 ms.	Time delay setting of the Zone1 phase-to-ground distance characteristics. Default setting is 0 ms.
Zone2 Time Delay PhN	0…60000 ms by step of 1 ms.	Time delay setting of the Zone2 phase-to-ground distance characteristics. Default setting is 400 ms.
Zone3 Time Delay PhN	0…60000 ms by step of 1 ms.	Time delay setting of the Zone3 phase-to-ground distance characteristics. Default setting is 800 ms.
Zone4 Time Delay PhN	0…60000 ms by step of 1 ms.	Time delay setting of the Zone4 phase-to-ground distance characteristics. Default setting is 2000 ms.
Zone5 Time Delay PhN	0…60000 ms by step of 1 ms.	Time delay setting of the Zone5 phase-to-ground distance characteristics. Default setting is 2000 ms.
PSD Time Delay	10…1000 ms by step of 1 ms	Power swing detection setting for normal power swings. For the power swing to be detected the measured impedance has to traverse the band of power swing detector in greater time than this setting. Default setting is 40 ms.
Very Slow Swing	100…10000 ms by step of 1 ms	Power swing detection setting for very slow power swings. For the power swing to be detected the measured impedance has to traverse the band of power swing detector in greater time than this setting. Default setting is 500 ms.
PSD Reset	100…10000 ms by step of 1 ms	Reset time for the power swing detector. Default setting is 500 ms.
OutOfStep Pulse	50…10000 ms by step of 1 ms	Pulse length of the out of step detector. When out of step condition is noticed this parameter defines the activation time of the output signal from the function. Default setting is 150 ms.

3.2.2 TELEPROTECTION FUNCTION (85)

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

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

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

- Direct trip command
- Permissive signal
- Blocking signal

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

NOTE: the type of the communication channel is not considered here. It can be one of the following:

- Pilot wire
- Fiber optic channel

- High frequency signal over transmission line
- Radio or microwave
- Binary communication network
- Etc.

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

Principle of operation

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

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

Permissive Underreach Transfer Trip (PUTT)

The IEC standard name of this mode of operation is Permissive Underreach Protection (PUP).

The protection system uses telecommunication, with underreach setting at each section end. The signal is transmitted when a fault is detected by the underreach protection. Receipt of the signal at the other end initiates tripping if other local permissive conditions are also fulfilled, depending on parameter setting.

For trip command generation using the parameter SCH85_PUTT_EPar_ (PUTT Trip), the following options are available:

- with Pickup
- with Overreach

Permissive Underreach Transfer Trip with Pickup

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

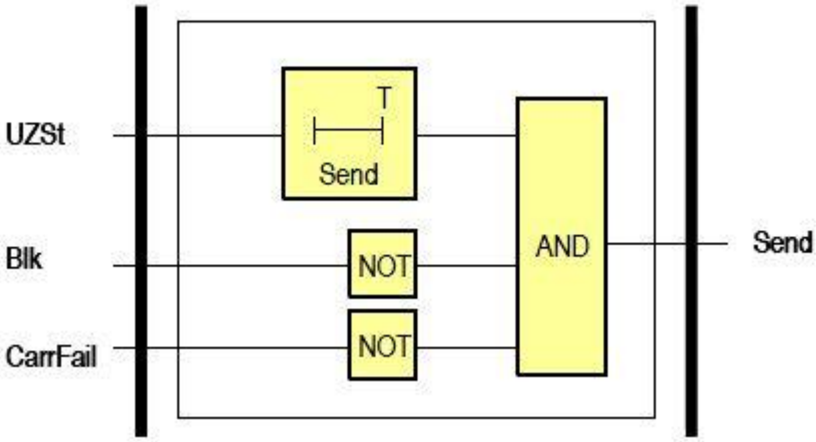


Figure 3-1 Permissive Underreach Transfer Trip with Pickup: Send signal generation.

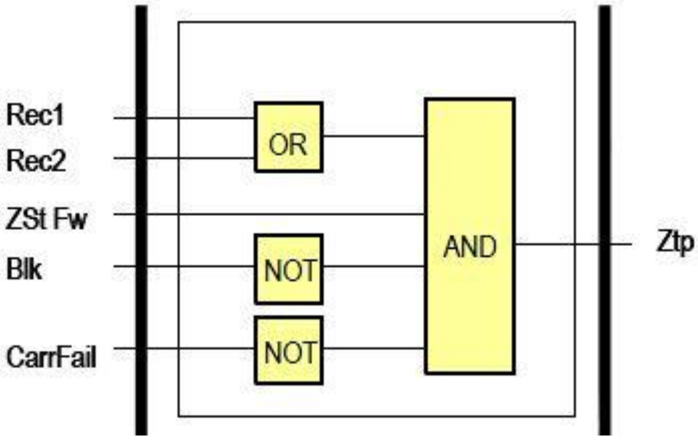


Figure 3-2 Permissive Underreach Transfer Trip with Pickup: Trip command generation.

Permissive Underreach Transfer Trip with Overreach

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

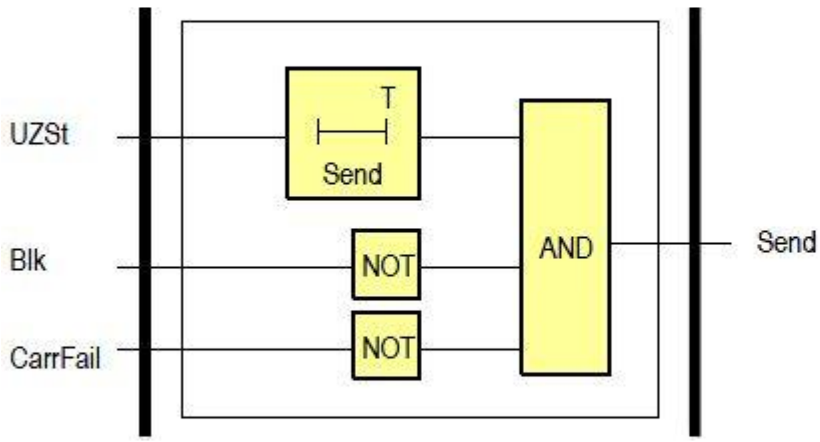


Figure 3-3 Permissive Underreach Transfer Trip with Overreach: Send signal generation.

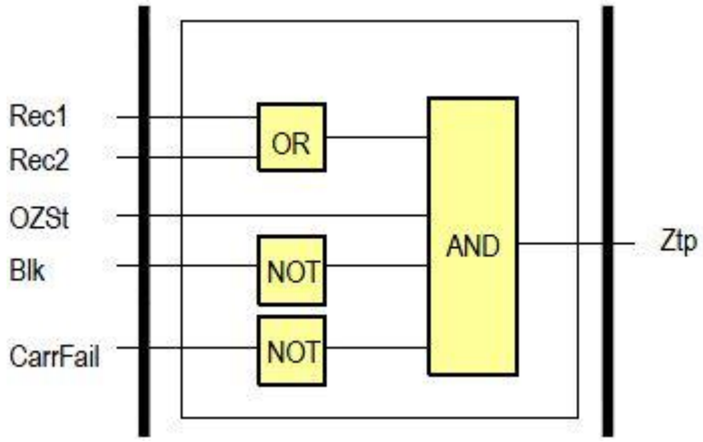


Figure 3-4 Permissive Underreach Transfer Trip with Overreach: Trip command generation.

Permissive Overreach Transfer Trip (POTT)

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

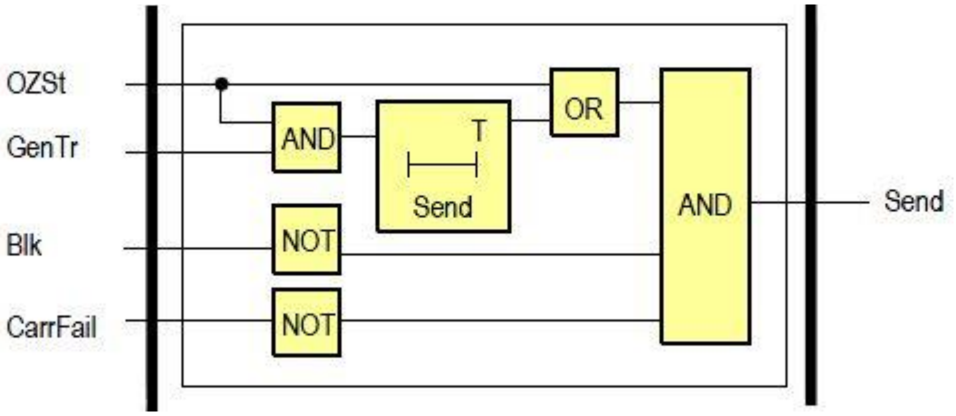


Figure 3-5 Permissive Overreach Transfer Trip: Send signal generation.

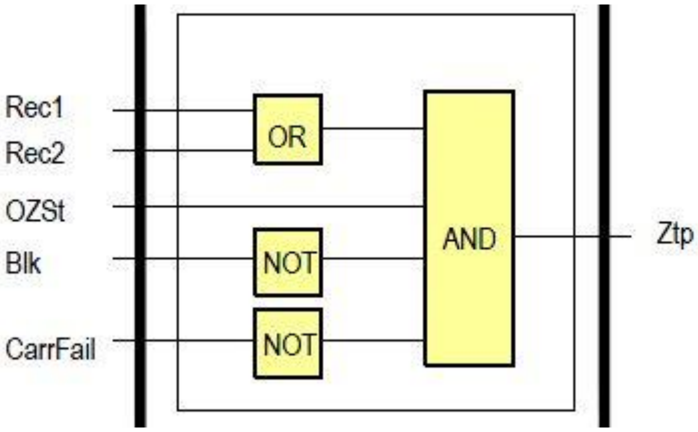


Figure 3-6 Permissive Overreach Transfer Trip: Trip command generation.

Directional comparison (Dir.Comparison)

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

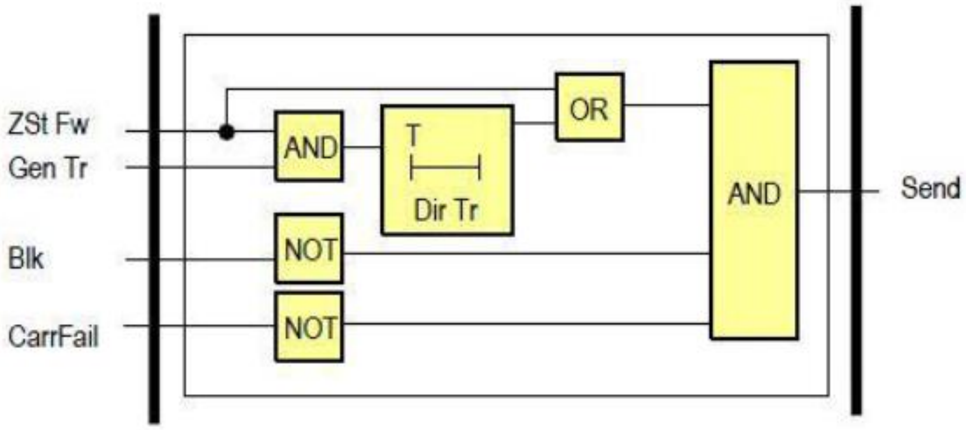


Figure 3-7 Direction comparison: Send signal generation.

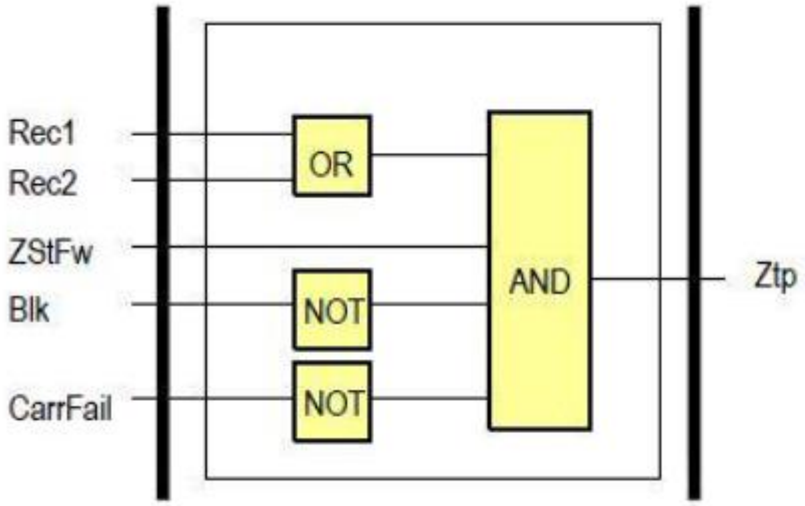


Figure 3-8 Direction comparison: Trip command generation.

Blocking directional comparison (Dir.Blocking)

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

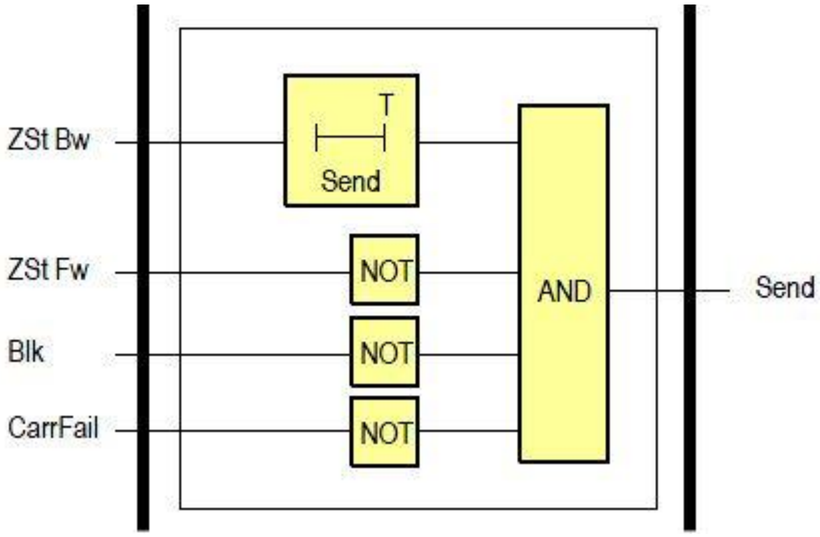


Figure 3-9 Direction blocking: Send signal generation.

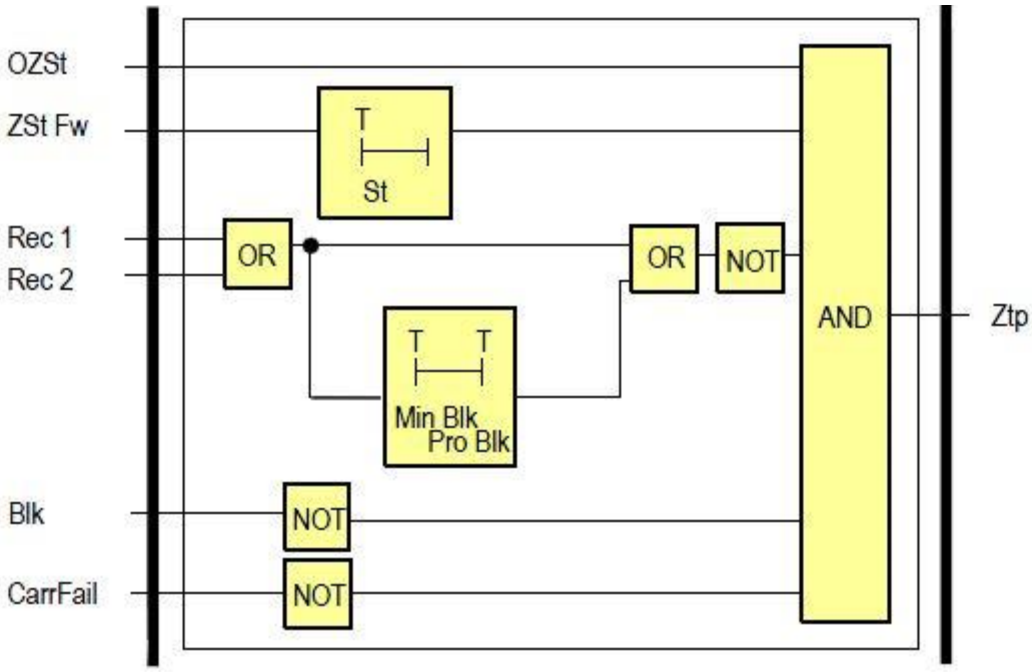


Figure 3-10 Direction blocking: Trip command generation.

Direct underreaching transfer trip (DUTT)

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

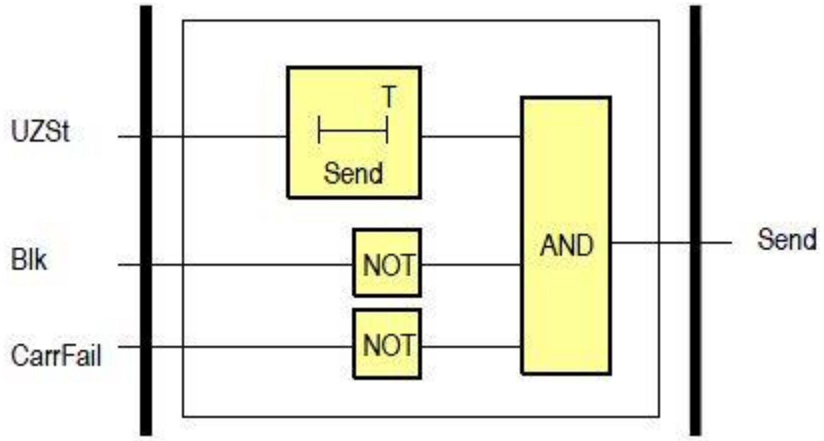


Figure 3-11 Direct underreaching transfer trip: Send signal generation

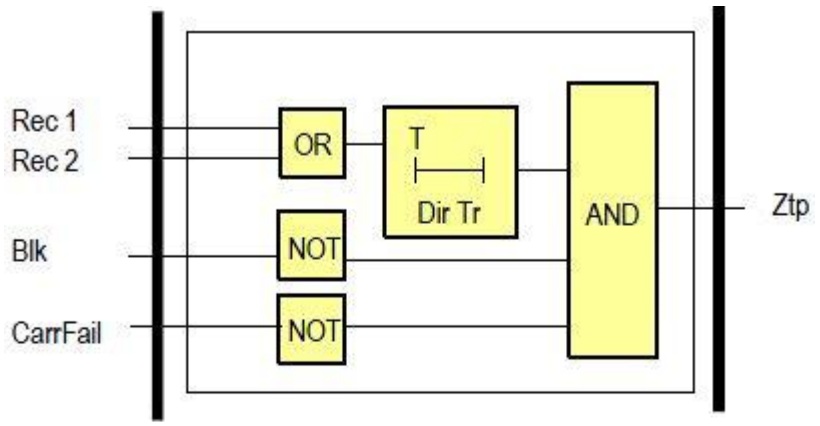


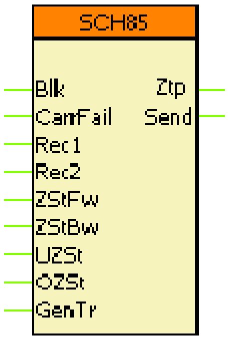
Figure 3-12 Direct underreaching transfer trip: Trip command generation

Table 3-52 Setting parameters of the teleprotection function

Parameter	**Setting value, range and step**	**Description**
Operation	Off PUTT POTT Dir.comparison Dir.blocking DUTT	Operating mode of the function. Default setting is Off.
PUTT trip	with Pickup with Overreach	Tripping command generation setting. Default setting with Overreach.
Send prolong time	1…10000 ms by step of 1 ms	Setting for prolonging the teleprotection signal on the sending end. Default setting 10 ms.
Direct Trip delay PUTT	1…10000 ms by step of 1 ms	Setting for direct trip delay for PUTT function. Default setting 10 ms.
Z start delay (block)	1…10000 ms by step of 1 ms	Setting for under impedance start delay. Default setting 10 ms.
Min.Block time	1…10000 ms by step of 1 ms	Setting for minimum block time for the teleprotection. Default setting 10 ms.

Prolong Block time	1…10000 ms by step of 1 ms	Setting for prolonging the blocked time of teleprotection function. Default setting 10 ms.

Below figure shows the corresponding function block and its input and output signals.



Signal title	Explanation
Block	Blocking signal
Carrier fail	Signal indicating the failure of the communication channel
Receive opp.1	Signal1 received from the opposite end
Receive opp.2	Signal2 received from the opposite end
Z Gen.start Fw	Protection start in forward direction
Z Underreach Start	Start of the underreaching zone (e.g. Z1)
Z Overreach Start	Start of the overreaching zone (e.g. Z2)
General Trip	General protection trip
Z Gen.start Bw	Protection start in back ward direction

Signal title	Explanation
Z Teleprot. Trip	Teleprotection trip command
Send signal	Teleprotection signal to be transmitted to the far end

3.2.3 WEAK END INFEED PROTECTION

3.2.3.1 Application

The communication schemes for the distance protection applicable for the AQ 300 series relays are described in the document teleprotection function block description. The aim of these schemes is to accelerate the trip time in case of faults at the far line ends, which cannot be covered with the fast Zone1.

The permissive communication schemes

- Permissive underreach transfer trip (PUTT). The IEC standard name of this mode of operation is Permissive Underreach Protection (PUP);
- Permissive overreach transfer trip (POTT). The IEC standard name of this mode of operation is Permissive Overreach Protection (POP);
- Directional comparison;
- Direct underreaching transfer trip (DUTT). The IEC standard name of this mode of operation is Intertripping Underreach Protection (IUP)

need permissive signal from the remote end protection device. If this signal is not received then the trip signal can be generated with the selective time delay only.

The protection at the far end of the line cannot detect the fault if

- The circuit breaker is open in all three phases, or
- The fault current, due to the weak source at the far end, is not enough to detect the fault.

In these cases the “weak end infeed logic” function block can generate the required permissive signal of the far end protection.

3.2.3.2 Mode of operation

The “weak end infeed logic” can be blocked

- by parameter setting (Operation=Off) (Op_Epar=0)
- by blocking input signal (Blk), programmed y the user, using the graphic logic.

If the operation of the function is not blocked then the function can generate binary output signals:

- “WEI trip”: this signal is intended to input in the trip logic to generate a trip signal to the own circuit breaker
- “Send signal”: this signal is the permissive signal, intended to be sent to the protection at the far line end.
- “Send echo”: this signal is the echoed signal received from the far line end device, and to be sent back to the far line end device.

The signal selection is performed using the parameter “Operation”:

- If the setting is “Operation=Echo only” then no signal is generated to he own circuit breaker.
- If the setting is “Operation=Echo and Trip” then both Echo and Trip signals can be generated.

3.2.3.3 Structure of the weak infeed logic

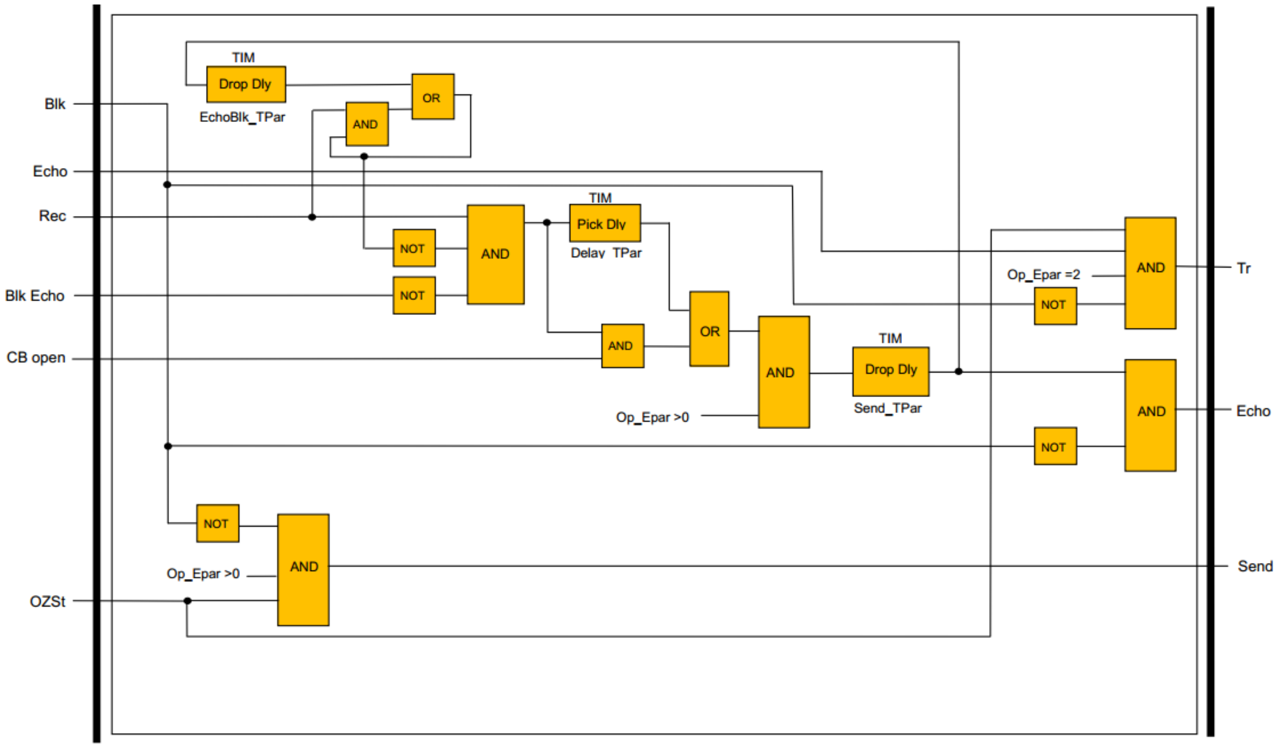


Figure 3-35 Structure of the weak infeed logic

The short explanation of the logic is as follows:

The function generates a “Send” signal, if forward fault is detected (OZst: the overreach zone started) and the function is enabled (Op_Epar >0) and the function is not blocked (Blk). In this case no “weak end” condition is valid.

Weak end means that either the circuit breaker is open or no forward fault detection is possible due to high source impedance.

If the circuit breaker is open (Input “CB open” signal is active) and permissive signal is received (input “Rec”) then this signal is echoed back to the far end (output signal “Echo”). The drop-delay timer with parameter “Send_Tpar” sets the minimal duration of the Echo signal.

If the circuit breaker is not open then the pick delay timer leaves time for the “Blk Echo” signal (e.g. in case of detection reverse fault) to block echoing. If this signal is not received during the running time then the function generates the “Echo” signal.

The drop delay timer with parameter “EchoBlk_Tpar” prevents repeated signal generation.

The function generates also “Trip signal” if forward fault is detected and received “Echo” signal accelerates trip signal generation. The additional condition is that the parameter setting for “Op_Epar” enables Trip command and the function is not blocked.

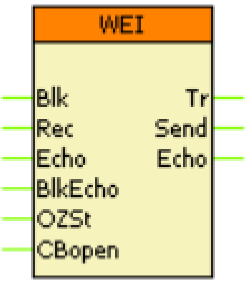


Figure 3-36 The function block of the directional weak end infeed logic

Table 3-53 The binary output status signals of the directional weak end infeed logic.

Binary status signal	Title	Explanation
WEI_Tr_Grl_	WEI Trip	Trip signal of the function
WEI_Send_Grl_	Send Signal	Signal to be sent if start signal of the overreaching zone is available
WEI_Echo_Grl_	Send Echo	Echo signal to be sent

Table 3-54 The binary input signal of the directional weak end infeed logic.

Binary status signal	Title	Explanation
WEI_Blk_GrO	Block	Signal for blocking the function
WEI_Rec_GrO_	Receive Signal	Received carrier signal
WEI_Echo_GrO_	Receive Echo	Received echo signal
WEI_BlkEcho_GrO_	Block Echo	Blocking echo signal sending
WEI_OZSt_GrO_	Z Overreach Start	Start signal of the overreach impedance zone
WEI_CBopen_GrO_	CB Open 3pole	Status of the circuit breaker indicating three-phase open state

Table 3-55: Setting parameters of the overvoltage function

Parameter	Setting value, range and step	Description
Operation	Off On	Operating mode selection for the function. Operation can be either enabled “On” or disabled “Off”. Default setting is “Off”.
Echo pulse duration	1…100 msec by step of 1msec	Duration of the echo pulse. Default value is 10 ms.
Echo delay	1…100 msec by step of 1msec	Delay before activation of the echo pulse. Default value is 10ms.
Echo block time	1…100 msec by step of 1msec	Drop delay of the echo block. Default setting is 10 ms.

3.2.4 Three-phase instantaneous overcurrent I>>> (50)

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.

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

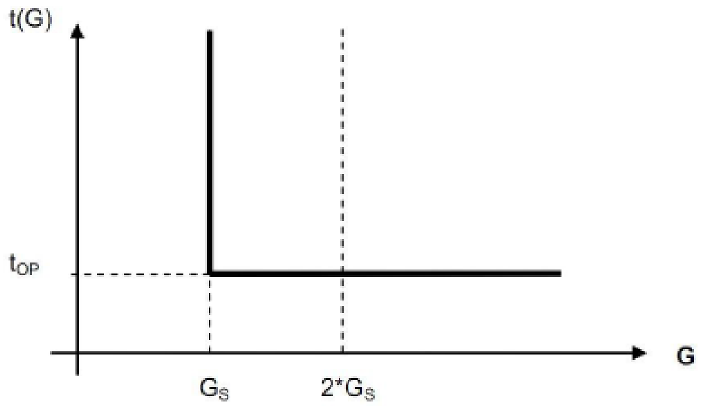


Figure 3-13. Operating characteristics of the instantaneous overcurrent protection function.

, where

t_{OP} (seconds)	Theoretical operating time if G> GS (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 3-14 is presented the structure of the instantaneous overcurrent algorithm.

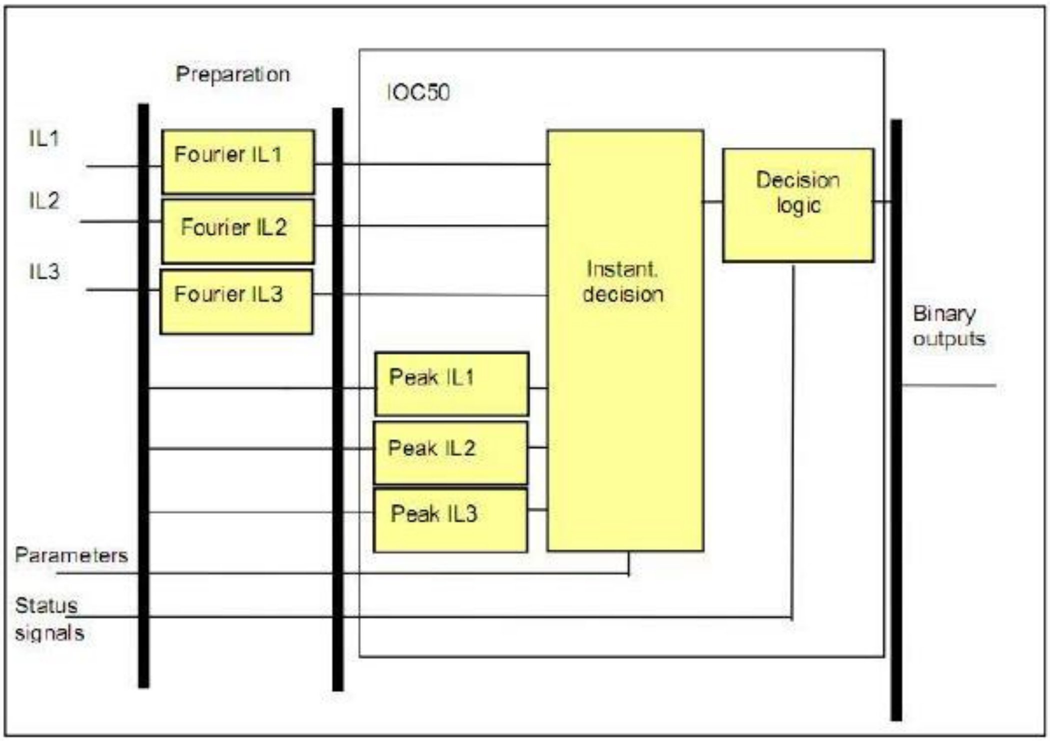


Figure 3-14 Structure of the instantaneous overcurrent algorithm.

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.

Setting parameters of the instantaneous protection function are presented in the Table 3-56.

Table 3-56 Setting parameters of the instantaneous overcurrent function

Parameter	Setting value, range and step	Description
Operation	Off Peak value Fundamental 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. Default setting is “Peak value”
Start current	20…3000 %, by step of 1%	Pick-up setting of the function. Setting range is from 20 % to 3000 % of the configured nominal secondary current. Setting step is 1 %. Default setting is 200 %

3.2.5 Residual instantaneous overcurrent I0>>> (50N)

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.

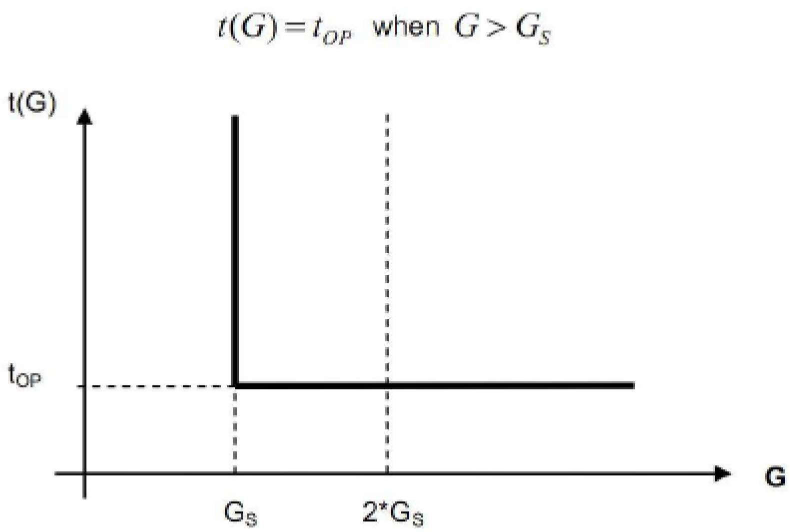


Figure 3-15. Operating characteristics of the residual instantaneous overcurrent protection function.

, where

t_{OP} (seconds)	Theoretical operating time if G> GS (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.

In the Figure 3-16 Structure of the instantaneous residual overcurrent algorithm. is presented the structure of the instantaneous residual overcurrent algorithm.

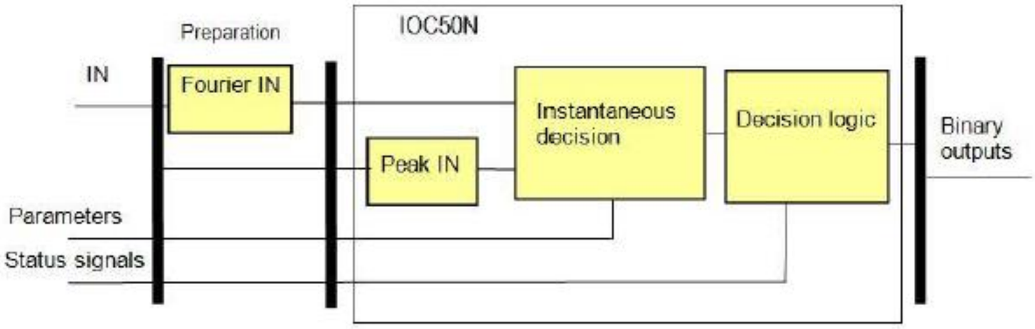


Figure 3-16 Structure of the instantaneous residual overcurrent algorithm.

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.

Setting parameters of the instantaneous residual protection function are presented in the Table 3-57.

Table 3-57 Setting parameters of the instantaneous residual overcurrent function

Parameter	Setting value, range and step	Description

Operation	Off Peak value Fundamental 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. Default setting is “Peak value”.
Start current	10…400 %, by step of 1%	Pick-up setting of the function. Setting range is from 10 % to 400 % of the configured nominal secondary current. Setting step is 1 %. Default setting is 200 %.

3.2.6 THREE-PHASE TIME OVERCURRENT I>, 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 3-17 is presented the structure of the time overcurrent algorithm.

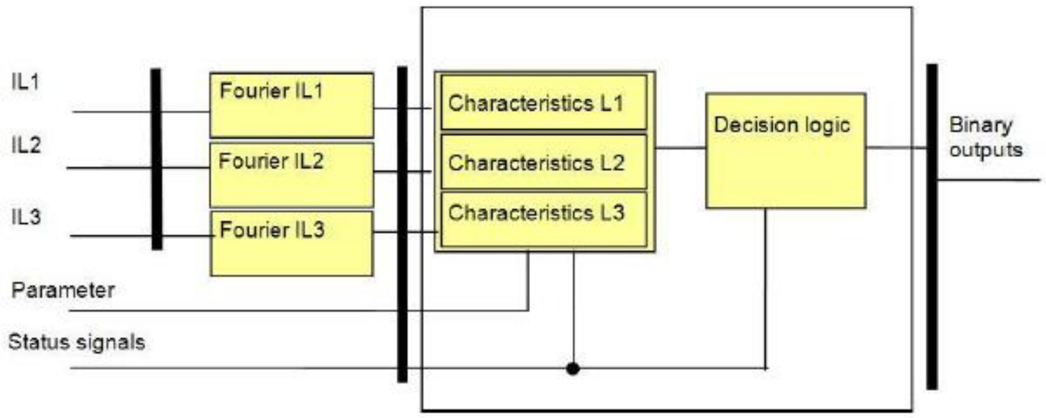


Figure 3-17 Structure of the time overcurrent algorithm.

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 3-18.

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

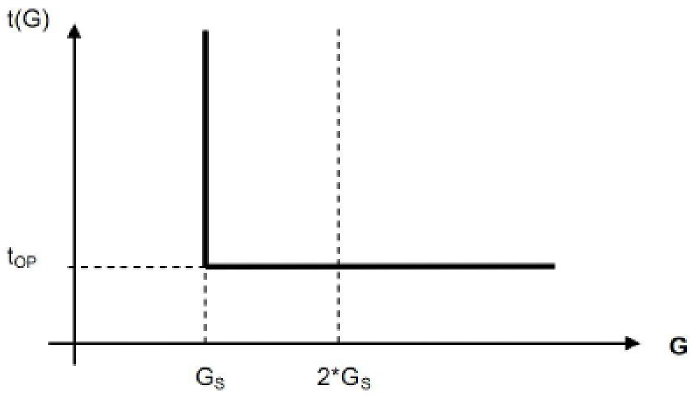


Figure 3-18. Operating characteristics of the definite time overcurrent protection function.

, where

t_{OP} (seconds)	Theoretical operating time if G> GS (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 Equation 3-2.

Equation 3-2. IDMT characteristics equation.

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

, where

t(G)(seconds) Theoretical operate time with constant value of G

k, c	constants 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
TMS	time dial setting / preset time multiplier

The parameters and operating curve types follow corresponding standards presented in the Table 3-58

Table 3-58 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.

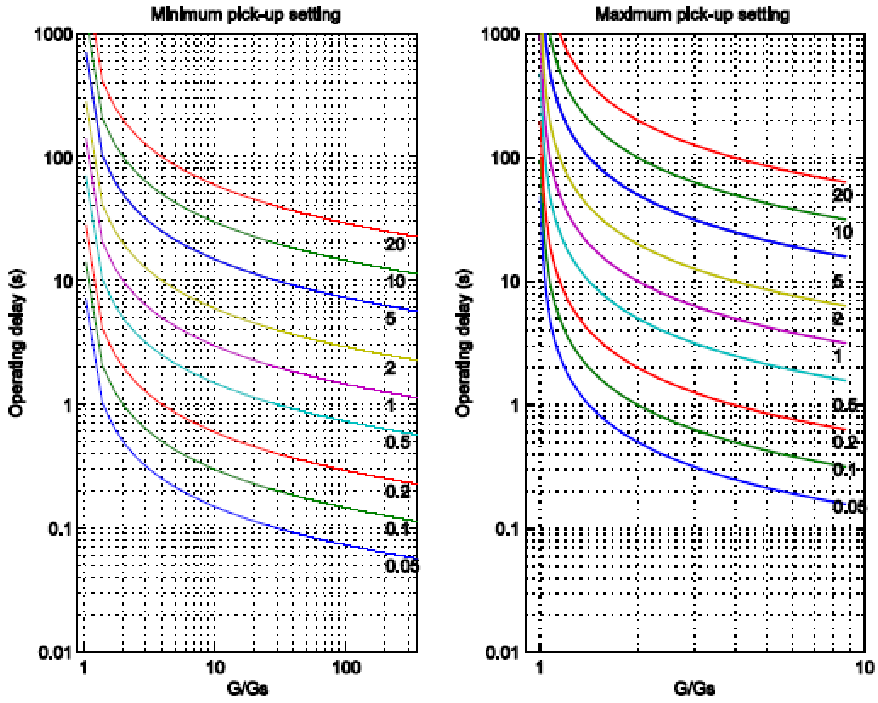


Figure 3-19 IEC Normally Inverse operating curves with minimum and maximum pick up settings and TMS settings from 0.05 to 20.

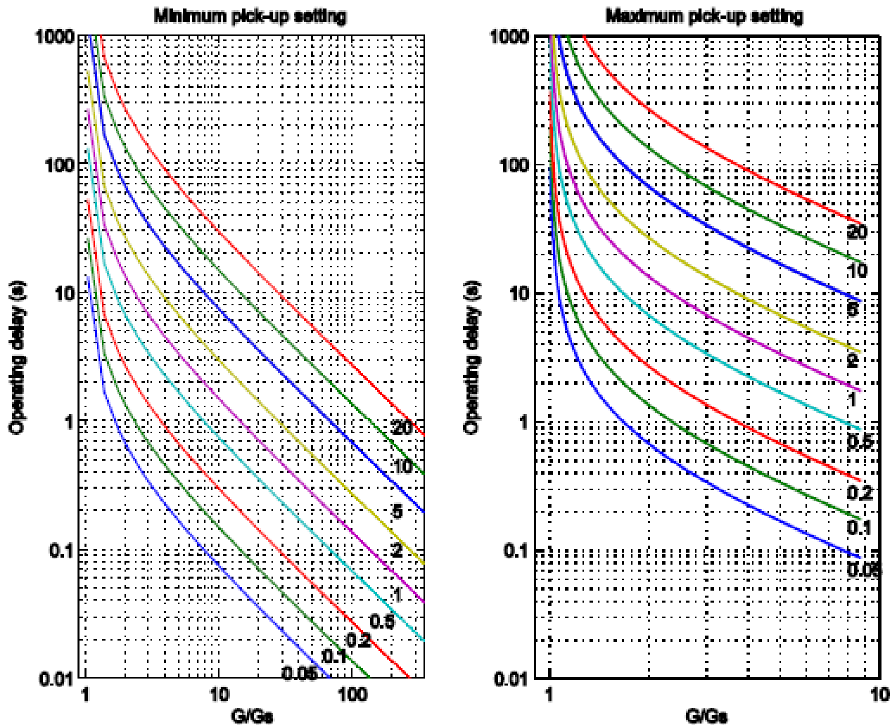


Figure 3-20 IEC Very Inverse operating curves with minimum and maximum pick up settings and TMS settings from 0.05 to 20.

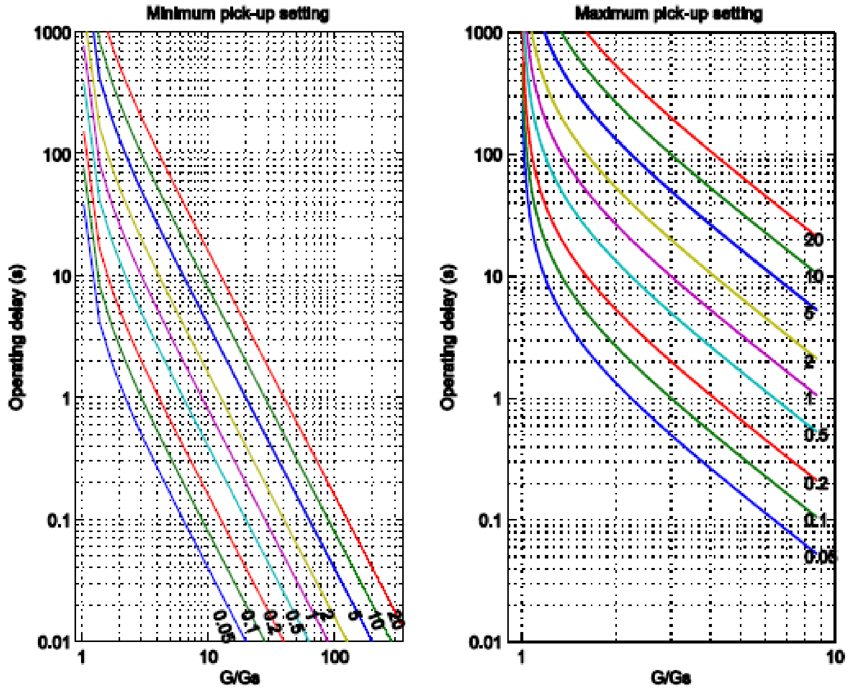


Figure 3-21 IEC Extremely Inverse operating curves with minimum and maximum pick up settings and TMS settings from 0.05 to 20.

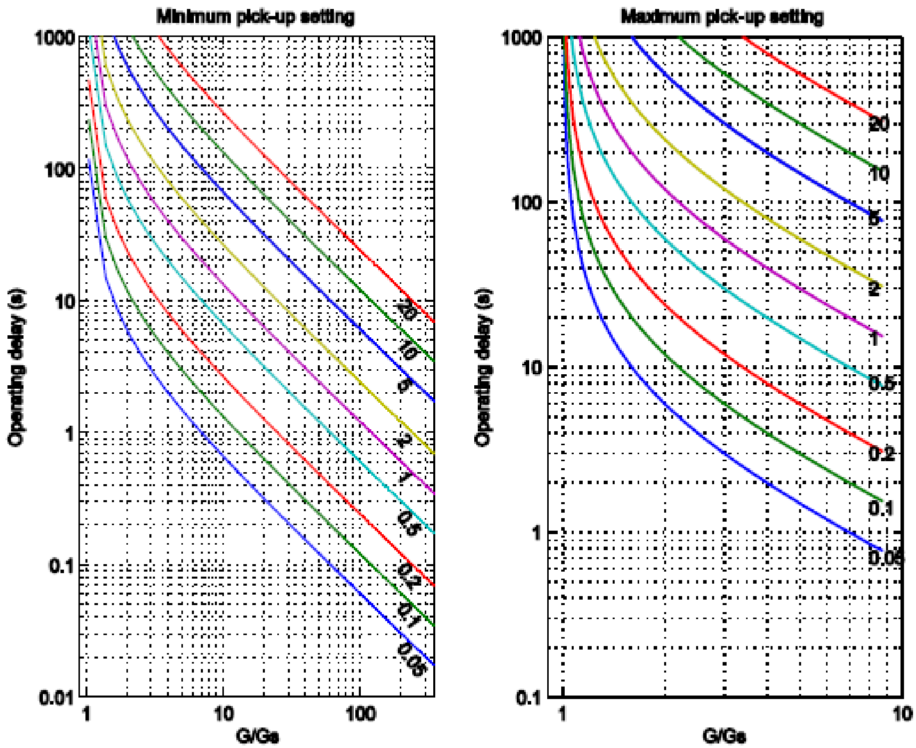


Figure 3-22 IEC Long Time Inverse operating curves with minimum and maximum pick up settings and TMS settings from 0.05 to 20.

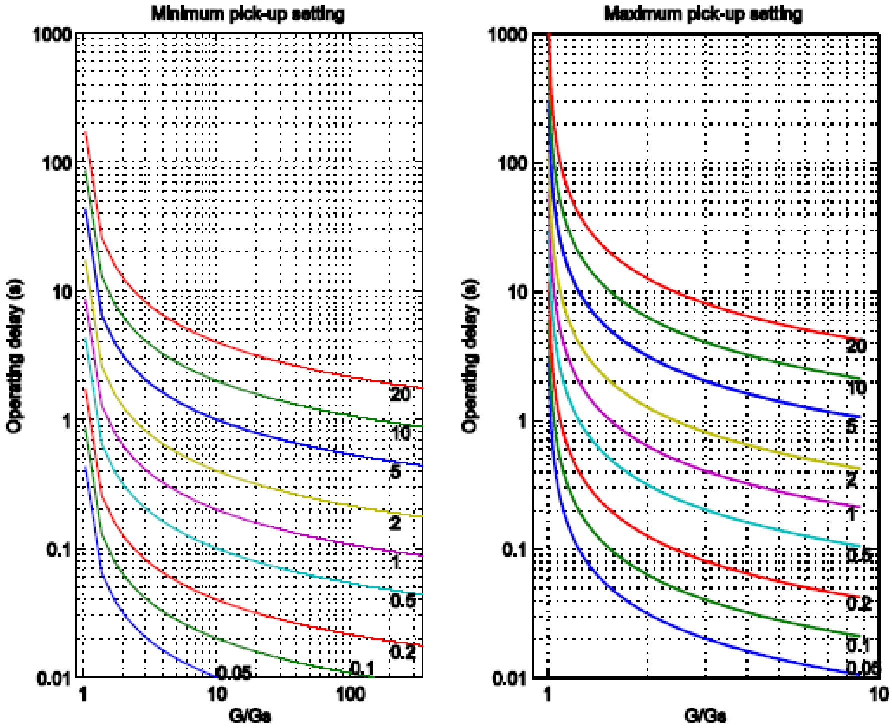


Figure 3-23 ANSI/IEEE Normally Inverse operating curves with minimum and maximum pick up settings and TMS settings from 0.05 to 20.

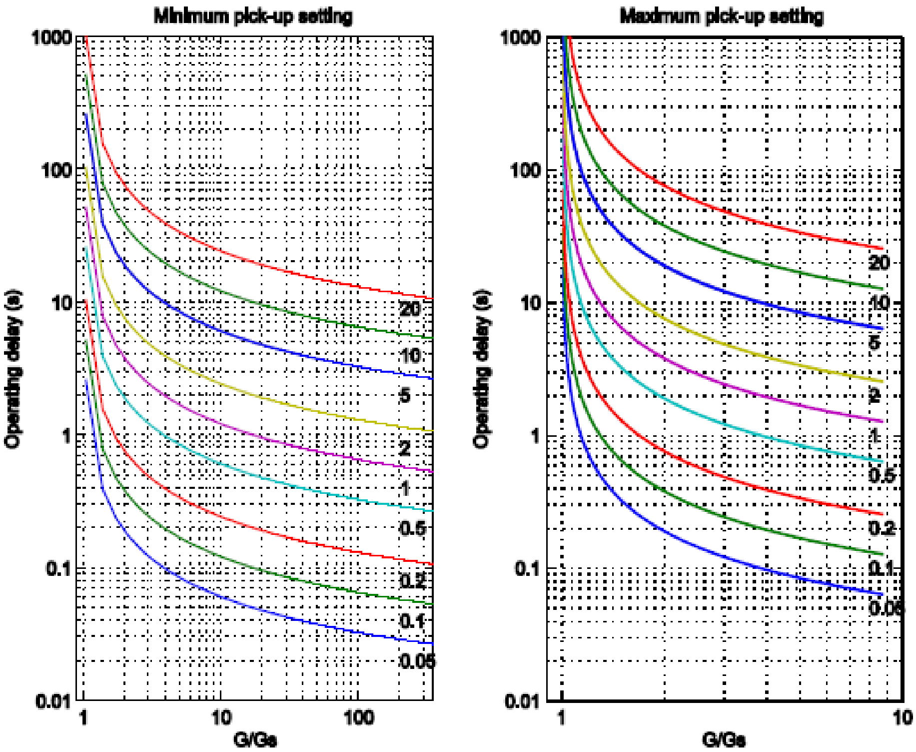


Figure 3-24 ANSI/IEEE Moderately Inverse operating curves with minimum and maximum pick up settings and TMS settings from 0.05 to 20.

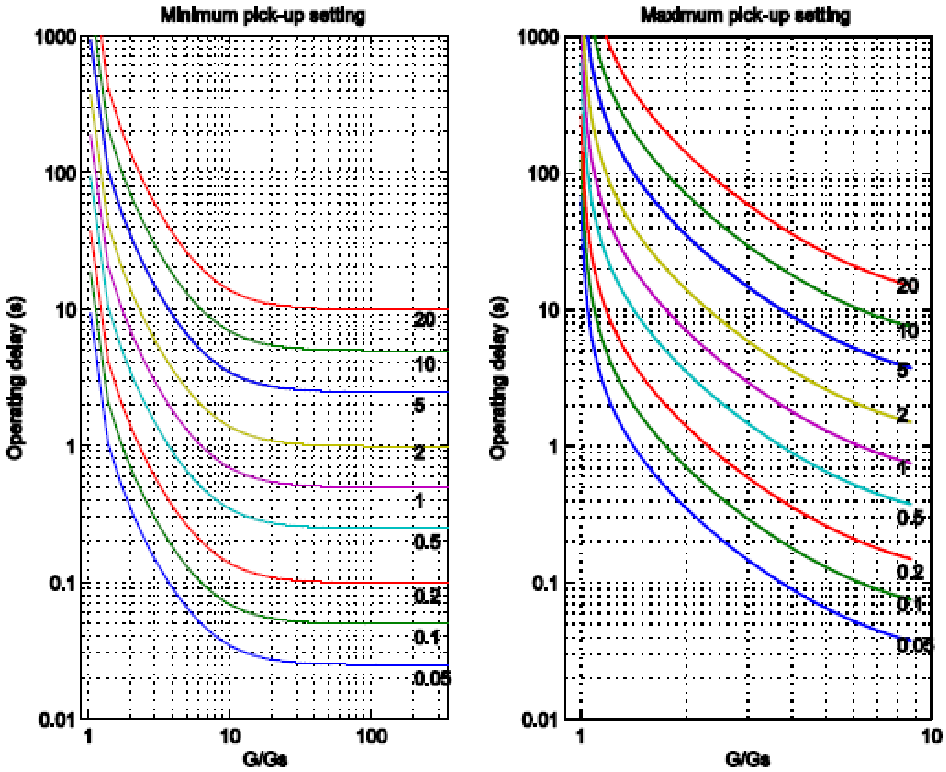


Figure 3-25 ANSI/IEEE Very Inverse operating curves with minimum and maximum pick up settings and TMS settings from 0.05 to 20.

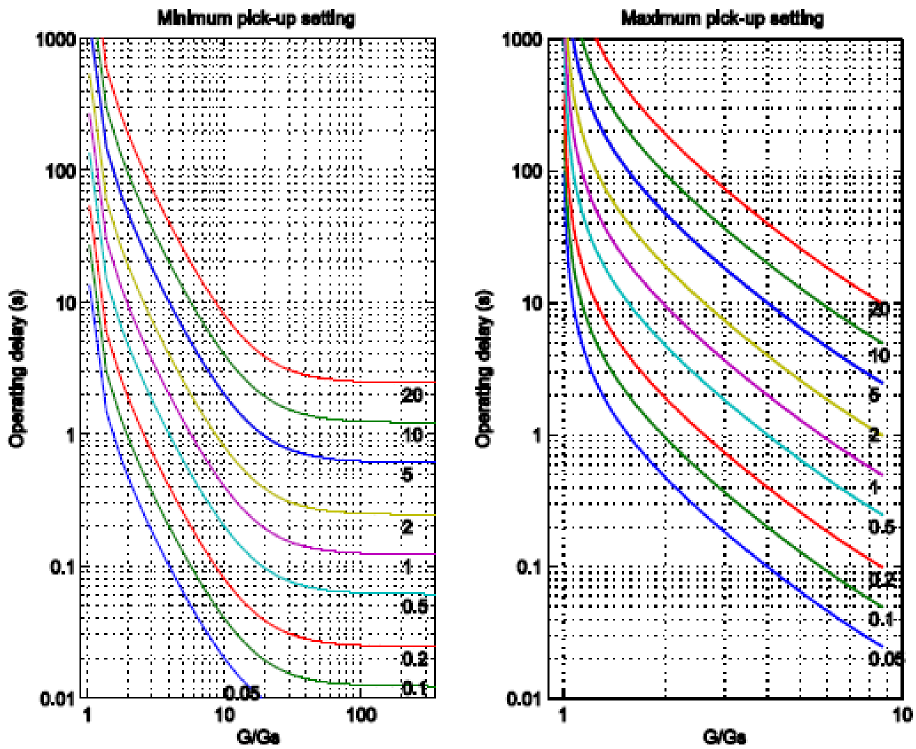


Figure 3-26 ANSI/IEEE Extremely Inverse operating curves with minimum and maximum pick up settings and TMS settings from 0.05 to 20.

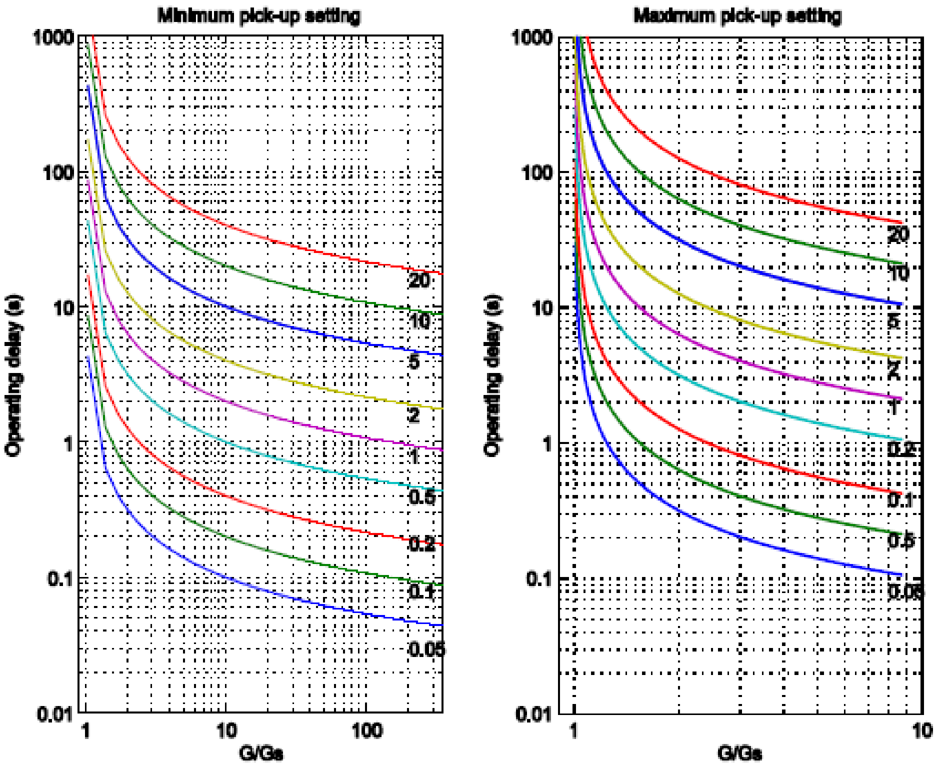


Figure 3-27 ANSI/IEEE Long Time Inverse operating curves with minimum and maximum pick up settings and TMS settings from 0.05 to 20.

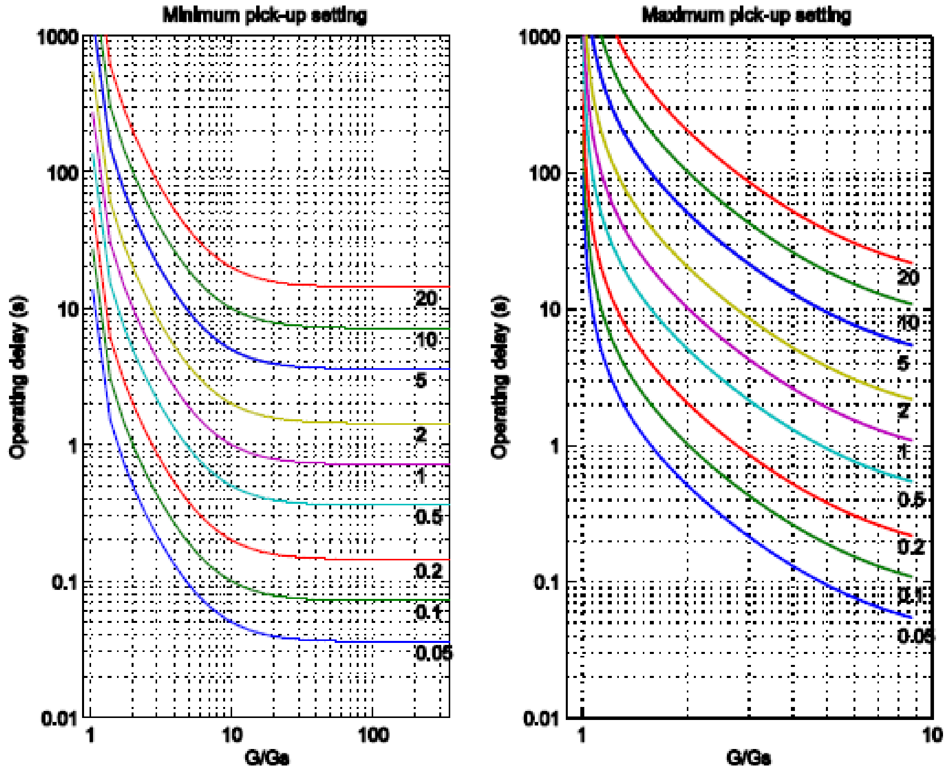


Figure 3-28 ANSI/IEEE Long Time Very Inverse operating curves with minimum and maximum pick up settings and TMS settings from 0.05 to 20.

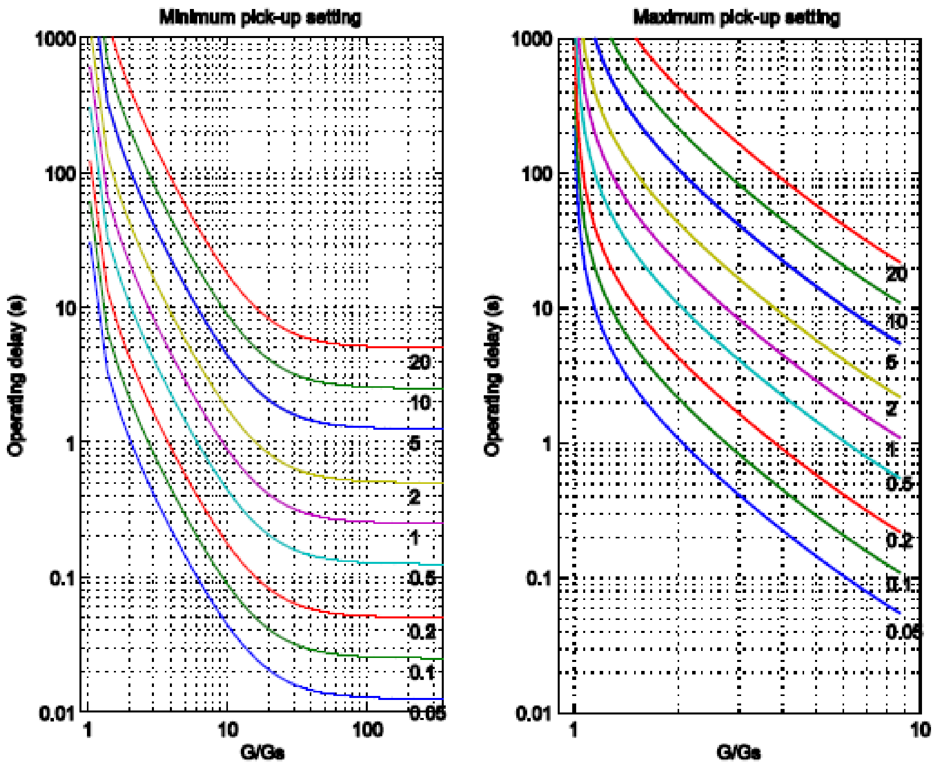


Figure 3-29 ANSI/IEEE Long Time Extremely Inverse operating curves with minimum and maximum pick up settings and TMS settings from 0.05 to 20.

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

Equation 3-3. Resetting characteristics for ANSI/IEEE IDMT

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

, where

$t_r(G)$(seconds)	Theoretical reset time with constant value of G
k_r	constants characterizing the selected curve
α	constants characterizing the selected curve
G	measured value of the Fourier base harmonic of the phase currents
G_S	pick-up setting
TMS	Time dial setting / preset time multiplier

The parameters and operating curve types follow corresponding standards presented in the Table 3-59.

Table 3-59 Parameters and operating curve types for the IDMT characteristics reset times.

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

Setting parameters of the time overcurrent protection function are presented in the Table 3-60.

Table 3-60 Setting parameters of the time overcurrent function

Parameter	Setting value, range and step	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	Operating mode selection of the function. Can be disabled, Definite time or IDMT operation based into IEC or ANSI/IEEE standards. Default setting is “DefinitTime”
Start current	5…400 %, by step of 1%. Default 200 %.	Pick-up current setting of the function. Setting range is from 5% of nominal current to 400% with step of 1 %. Default setting is 200 % of nominal current.
Min Delay	0…60000 ms, by step of 1 ms. Default 100 ms.	Minimum operating delay setting for the IDMT characteristics. Additional delay setting is from 0 ms to 60000 ms with step of 1 ms. Default setting is 100 ms.
Definite delay time	0…60000 ms by step of 1 ms. Default 100 ms.	Definite time operating delay setting. Setting range is from 0 ms to 60000 ms with step of 1 ms. Default setting is 100 ms. This parameter is not in use when IDMT characteristics is selected for the operation.
Reset delay	0…60000 ms by step of 1 ms. Default 100 ms.	Settable reset delay for definite time function and IEC IDMT operating characteristics. Setting range is from 0 ms to 60000 ms with step of 1 ms. Default setting is 100 ms. This parameter is in use with definite time and IEC IDMT chartacteristics-
Time Mult	0.05…999.00 by step of 0.01. Default 1.00.	Time multiplier / time dial setting of the IDMT operating characteristics. Setting range is from 0.05 to 999.00 with step of 0.01. This parameter is not in use with definite time characteristics.

3.2.7 RESIDUAL TIME OVERCURRENT I0>, I0>> (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 3-30 is presented the operating characteristics of the function.

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

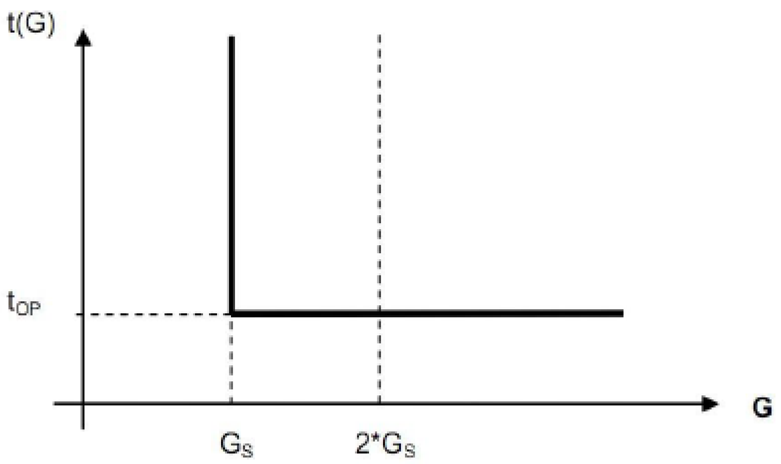


Figure 3-30. Operating characteristics of the residual time overcurrent protection function.

, where

t_{OP} (seconds)	Theoretical operating time if G> GS (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 3-31 is presented the structure of the residual time overcurrent algorithm.

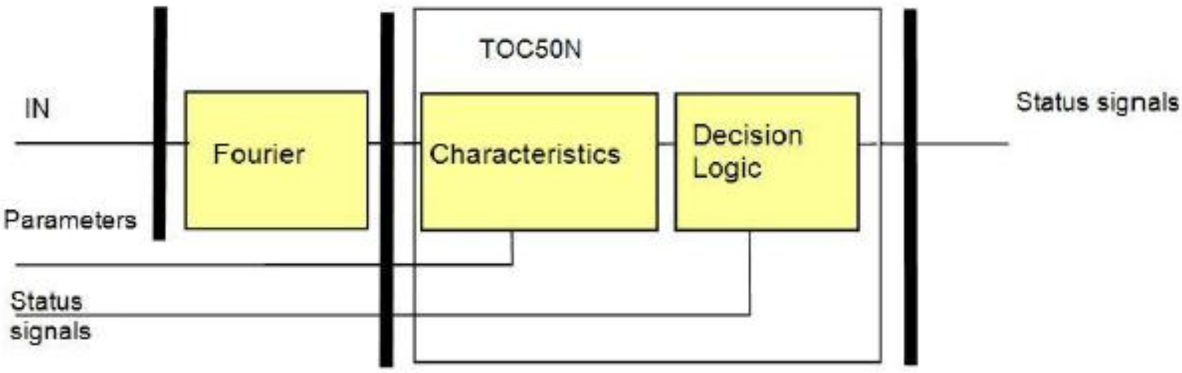


Figure 3-31 Structure of the residual time overcurrent algorithm.

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 3-61 Setting parameters of the residual time overcurrent function

Parameter	Setting value, range and step	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	Operating mode selection of the function. Can be disabled, Definite time or IDMT operation based into IEC or ANSI/IEEE standards. Default setting is “DefinitTime”
Start current	1…200 %, by step of 1%. Default 50 %.	Pick-up current setting of the function. Setting range is from 1% of nominal current to 200% with step of 1 %. Default setting is 50 % of nominal current.
Min Delay	0…60000 ms, by step of 1 ms. Default 100 ms.	Minimum operating delay setting for the IDMT characteristics. Additional delay setting is from 0 ms to 60000 ms with step of 1 ms. Default setting is 100 ms.
Definite delay time	0…60000 ms by step of 1 ms. Default 100 ms.	Definite time operating delay setting. Setting range is from 0 ms to 60000 ms with step of 1 ms. Default setting is 100 ms. This parameter is not in use when IDMT characteristics is selected for the operation.
Reset time	0…60000 ms by step of 1 ms. Default 100 ms.	Settable reset delay for definite time function and IEC IDMT operating characteristics. Setting range is from 0 ms to 60000

		ms with step of 1 ms. Default setting is 100 ms. This parameter is in use with definite time and IEC IDMT chartacteristics-
Time Mult	0.05…999.00 by step of 0.01. Default 1.00.	Time multiplier / time dial setting of the IDMT operating characteristics. Setting range is from 0.05 to 999.00 with step of 0.01. This parameter is not in use with definite time characteristics.

3.2.8 THREE-PHASE DIRECTIONAL OVERCURRENT IDIR>, 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 3-32 is presented the structure of the directional overcurrent protection algorithm.

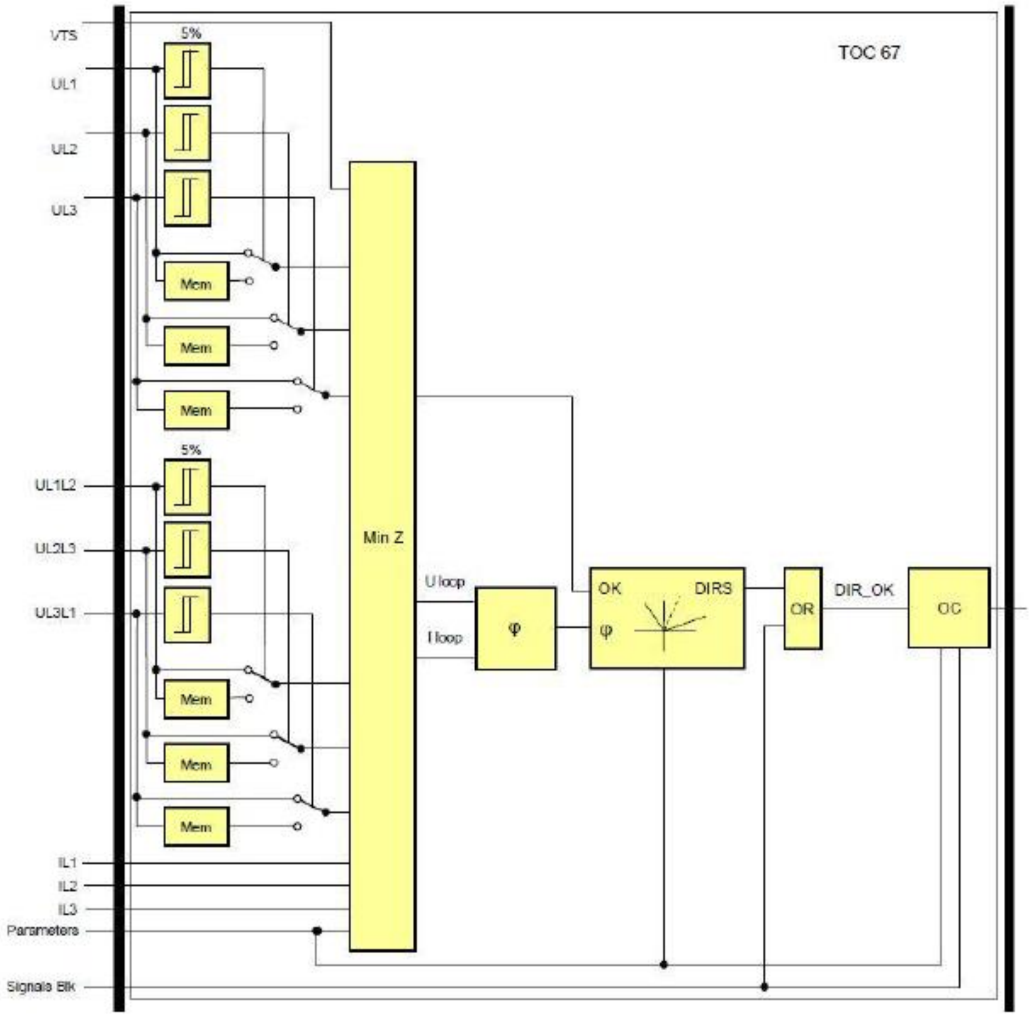


Figure 3-32 Structure of the directional overcurrent protection algorithm.

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”.

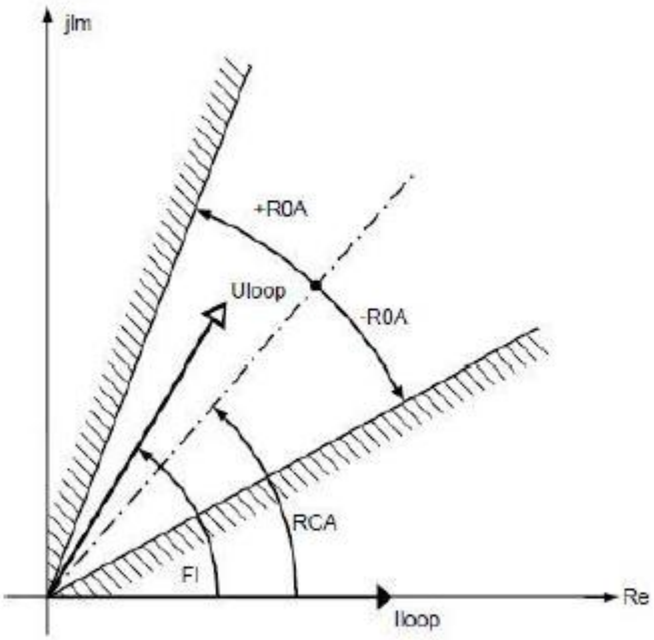


Figure 3-33 Directional decision characteristics.

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 chapter 3.2.6 Three-phase time overcurrent I>, I>> (50/51).

In the Table 3-62 are presented the setting parameters of the directional overcurrent protection function.

Table 3-62 Setting parameters of the directional overcurrent function

Parameter	Setting value, range and step	Description
Direction	NonDir Forward Backward	Direction mode selection. Operation can be non directional, forward direction or backward direction. Default setting is “Forward”.
Operating angle	30…90 deg with step of 1 deg	Operating angle setting. Defines the width of the operating characteristics in both sides of the characteristic angle. Default setting is 60 deg which means that the total width of the operating angle is 120 deg.
Characteristic angle	40…90 deg with step of 1 deg	Characteristic angle setting. Defines the center angle of the characteristics. Default setting is 60 deg.
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	Operating mode selection of the function. Can be disabled, Definite time or IDMT operation based into IEC or ANSI/IEEE standards. Default setting is “DefinitTime”
Start current	5…1000 %, by step of 1%. Default 50 %	Pick-up current setting of the function. Setting range is from 5% of nominal current to 1000% with step of 1 %. Default setting is 50 % of nominal current.
Min Delay	0…60000 ms, by step of 1 ms. Default 100 ms	Minimum operating delay setting for the IDMT characteristics. Additional delay setting is from 0 ms to 60000 ms with step of 1 ms. Default setting is 100 ms.
Definite delay time	0…60000 ms by step of 1 ms. Default 100 ms	Definite time operating delay setting. Setting range is from 0 ms to 60000 ms with step of 1 ms. Default setting is 100 ms. This parameter is not in use when IDMT characteristics is selected for the operation.
Reset delay	0…60000 ms by step of 1 ms. Default 100 ms	Settable reset delay for definite time function and IEC IDMT operating characteristics. Setting range is from 0 ms to 60000 ms with step of 1 ms. Default setting is 100 ms. This parameter is in use with definite time and IDMT characteristics.
Time Mult	0.05…999.00 by step of 0.01. Default 1.00	Time multiplier / time dial setting of the IDMT operating characteristics. Setting range is from 0.05 to 999.00 with step of 0.01. This parameter is not in use with definite time characteristics.

3.2.9 Residual directional overcurrent I0Dir >, 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 3-34 is presented the structure of the residual directional overcurrent algorithm.

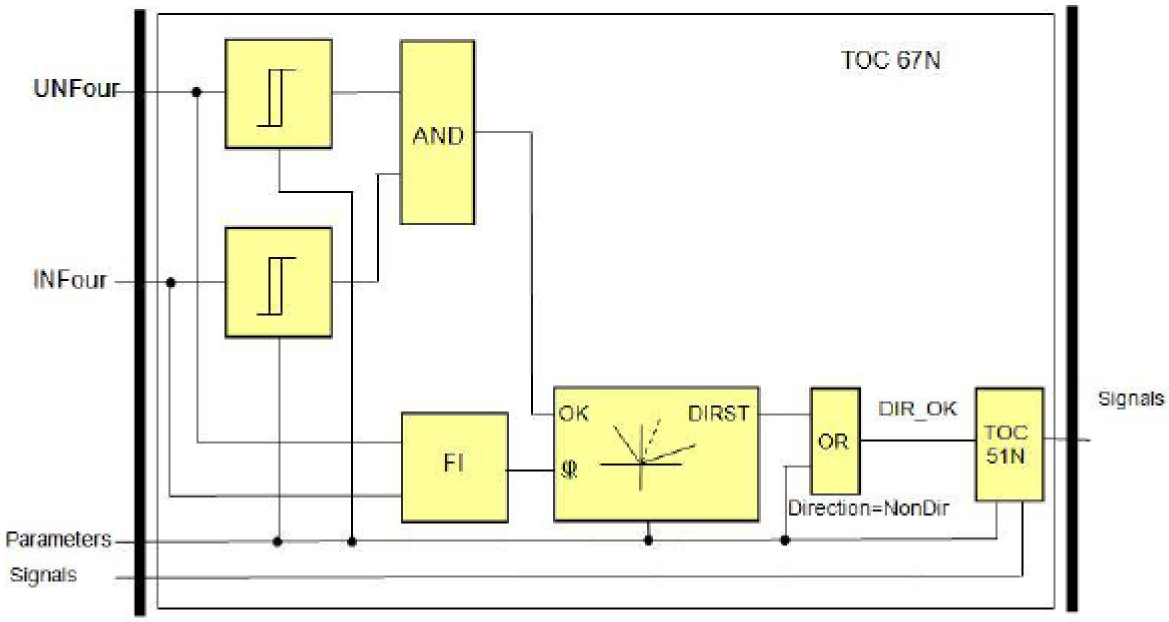


Figure 3-34. Structure of the residual directional overcurrent algorithm.

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.

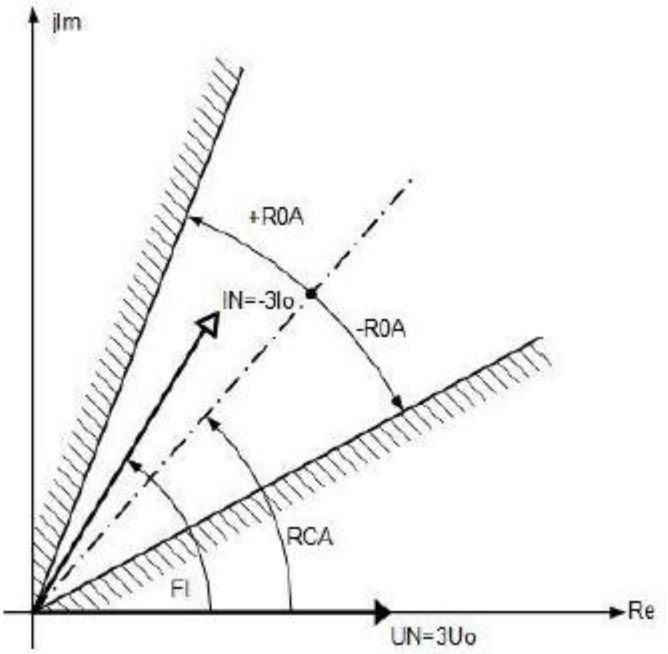


Figure 3-35 Directional decision characteristics of operating angle mode.

In the Figure 3-35 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.

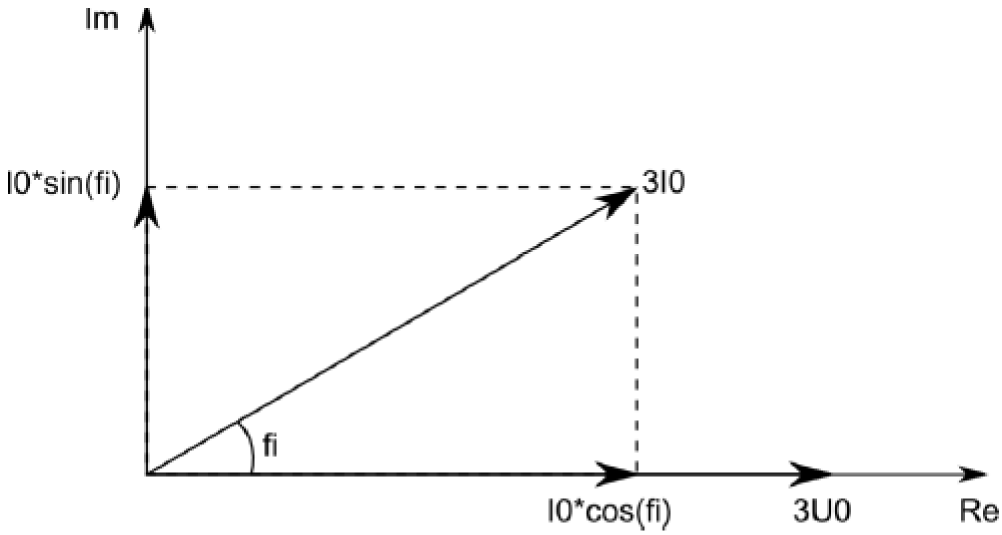


Figure 3-36 Wattmetric and varmetric operating characteristics.

In the Figure 3-36 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 3-63 Setting parameters of the residual directional overcurrent function

Parameter	Setting value, range and step	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.
Uo min	1…10 %, by step of 1%	The threshold value for the 3Uo zero sequence voltage, below this setting no directionality is possible. % of the rated voltage of the voltage transformer input.
Io min	1…50 % by step of 1%	The threshold value for the 3Io 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 by step of 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 by step of 1 deg	The base angle of the operating characteristics.

Operation	Off Definit time IEC Inv IEC VeryInv IEC ExtInv IEC LongInv ANSI Inv ANSI ModInv ANSI VeryInv ANSI ExtInv ANSI LongInv ANSI LongVeryInv ANSI LongExtInv	Selection of the function disabled and the timing characteristics. Operation when enabled can be either Definite time or IDMT characteristic.
Start current	1…200 % by step of 1%	Pick-up residual current
Time Mult	0.05…999 by step of 0.01	Time dial/multiplier setting used with IDMT operating time characteristics.
Min. Time	0…60000 ms by step of 1 ms	Minimum time delay for the inverse characteristics.
Def Time	0…60000 ms by step of 1 ms	Definite operating time
Reset Time	0…60000 ms by step of 1 ms	Settable function reset time

3.2.10 CURRENT UNBALANCE (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 3-37.

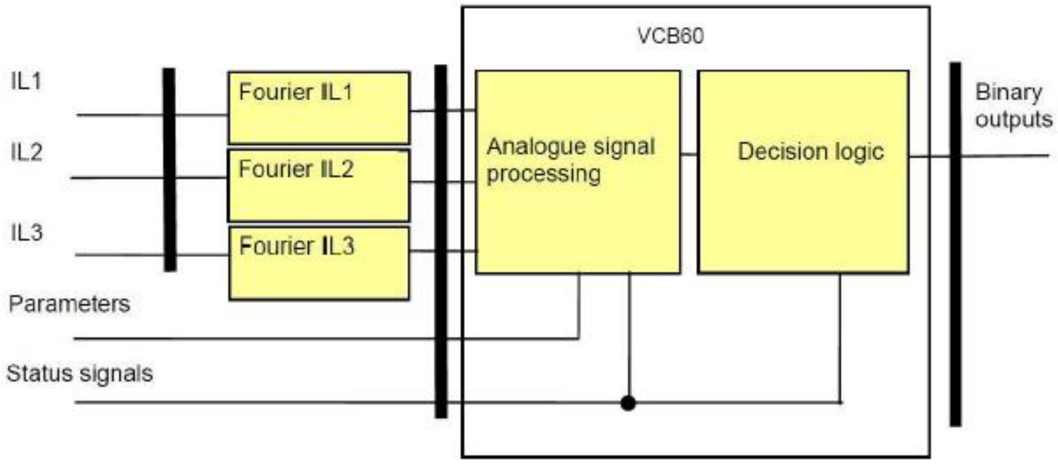


Figure 3-37. Structure of the current unbalance protection algorithm.

The analogue signal processing principal scheme is presented in the Figure 3-38.

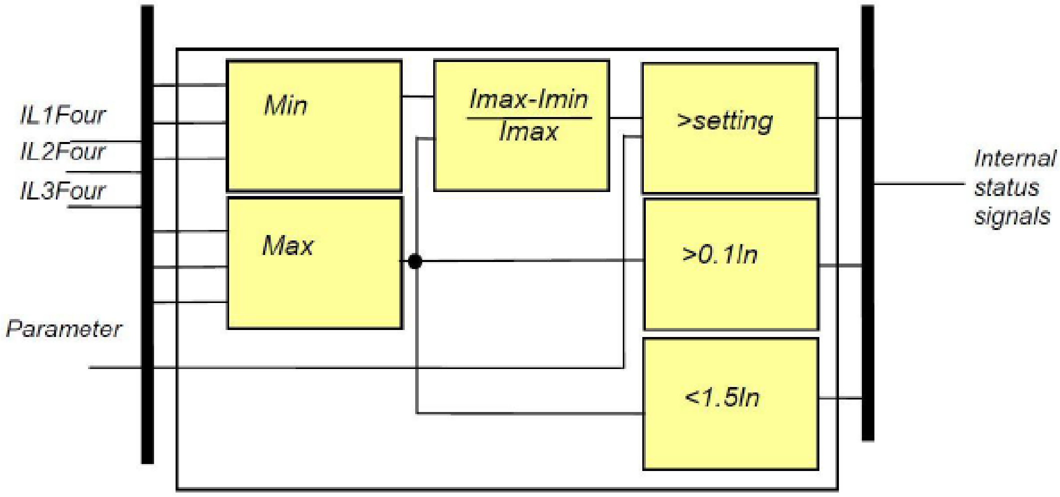


Figure 3-38 Analogue signal processing for the current unbalance function.

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 short circuit 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 3-64 Setting parameters of the current unbalance function

Parameter	Setting value, range and step	Description
Operation	On Off	Selection for the function enabled or disabled. Default setting is “On” which means function is enabled.
Start signal only	Activated Deactivated	Selection if the function issues either “Start” signal alone or both “Start” and after set time delay “Trip” signal. Default is that both signals are generated (=deactivated).
Start current	10…90 % by step of 1 %	Pick up setting of the current unbalance. Setting is the maximum allowed difference in between of the min and max phase currents. Default setting is 50 %.
Time delay	0…60000 ms by step of 100 ms	Operating time delay setting for the “Trip” signal from the “Start” signal. Default setting is 1000 ms.

3.2.11 STUB PROTECTION

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

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

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

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

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

The **inputs** of the stub protection function are

- The Fourier components of three phase currents,
- Binary inputs for enabling and activating the operation,
- Parameters.

The output of the stub protection function is

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

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

The function can be disabled by programming the blocking signal.

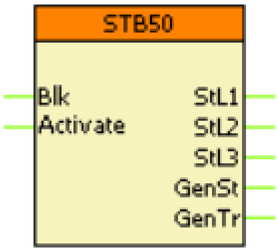


Figure 3-37 The function block of the stub protection function

Table 3-65The binary output status signals of the stub protection function

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

Table 3-66 The binary input status signals of the stub protection function

Binary input signal	**Signal title**	**Explanation**
Disabling the function		
STB50_**Blk**_GrO_	Disable	The programmed True state of this input disables the operation of the function
Activating status signal		
STB50_**Activate**_GrO_	Activate	The programmed True state of this signal indicates the open state of the circuit breaker or maybe the isolator.

Table 3-67 Parameter settings of the STUB protection.

Parameter	Setting value, range and step	Description
Operation	Off On	Operating mode selection for the function. Operation can be either disabled “Off” or enabled “On”. Default setting is disabled.
Start current	10…400% by step of 1.	Maximum current setting. Default setting is 50.
Time delay	0…60000ms by step of 1.	Definite time delay of the trip command. Default setting is 100.

3.2.12 THERMAL OVERLOAD T>, (49L)

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.

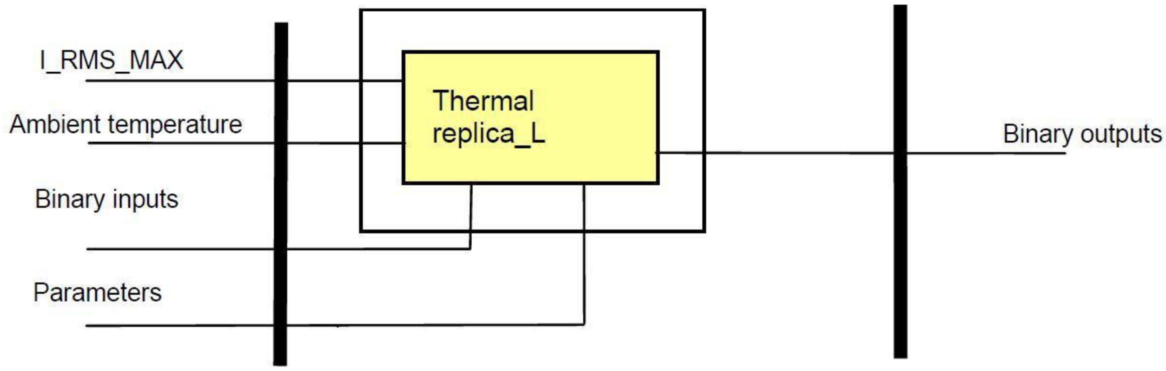


Figure 3-38: The principal structure of the thermal overload function.

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

The thermal replica of the function follows the following equation.

Equation 3-4: Thermal replica equation of the thermal overload protection.

$$H(t) = \frac{\Theta(t)}{\Theta_n} = \frac{I^2}{I_n^2}\left(1 - e^{-\frac{t}{T}}\right) + \frac{\Theta_o}{\Theta_n} e^{-\frac{t}{T}}$$

$H(t)$	Is the thermal level of the heated object. This is the temperature as a percentage of θ_n reference temperature.
Θ_n	Is the reference temperature above the ambient temperature, which can be measured in steady state in case of a continuous I_n reference current.
I_n	Is the reference current (can be considered as the nominal current of the heated object). If the current flows continuously then the reference temperature can be measured in steady state.
I	Measured current.
Θ_o	Starting temperature
T	Heating time constant

Table 3-68: Setting parameters of the thermal overload function

Parameter	Setting value, range and step	Description
Operation	Off Pulsed Locked	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. Default setting is "Pulsed".
Alarm temperature	60…200 deg by step of 1 deg	Temperature setting for the alarming of the overloading. When the calculated temperature exceeds the set alarm limit function issues an alarm signal. Default setting is 80 deg.
Trip temperature	60…200 deg by step of 1 deg	Temperature setting for the tripping of the overloading. When the calculated temperature exceeds the set alarm limit function issues a trip signal. Default setting is 100 deg.
Rated temperature	60…200 deg by step of 1 deg	Rated temperature of the protected object. Default setting is 100 deg.
Base temperature	0…40 deg by step of 1 deg	Rated ambient temperature of the device related to allowed temperature rise. Default setting is 40 deg.
Unlock temperature	20…200 deg by step of 1 deg	Releasing of the function generated trip signal when the calculated thermal load is cooled under this setting. Restart inhibit release limit. Default setting is 60 deg.
Ambient temperature	0…40 deg by step of 1 deg	Setting of the ambient temperature of the protected device. Default setting is 25 deg.
Startup Term	0…60 % by step of 1 %	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. Default setting is 0 %.
Rated LoadCurrent	20…150 % by step of 1%	The rated nominal load of the protected device. Default setting is 100 %

Time constant	1…999 min by step of 1 min	Heating time constant of the protected device. Default setting is 10 min.

3.2.13 OVER VOLTAGE U>, 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.

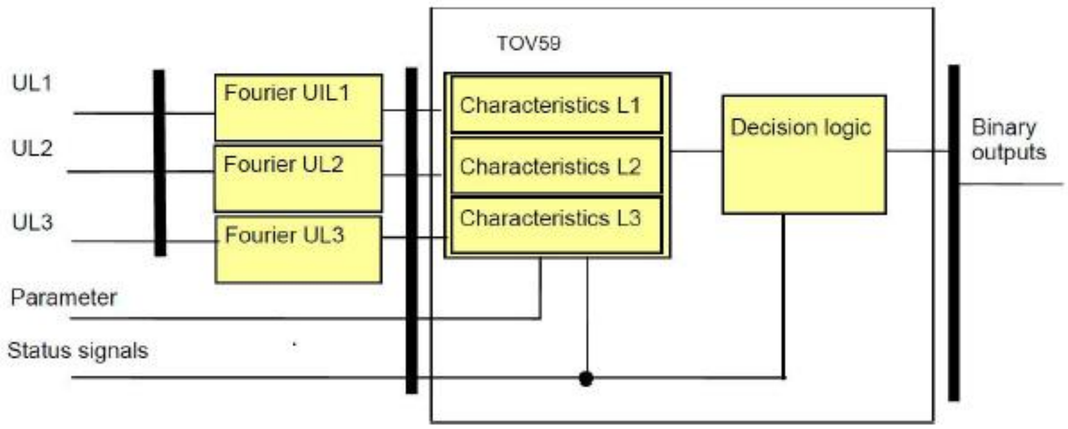


Figure 3-39 The principal structure of the overvoltage function.

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 3-69 Setting parameters of the overvoltage function

Parameter	Setting value, range and step	Description
Operation	Off On	Operating mode selection for the function. Operation can be either enabled “On” or disabled “Off”. Default setting is “On”.
Start voltage	30…130 % by step of 1 %	Voltage pick-up setting. Default setting 63 %.
Start signal only	Activated Deactivated	Selection if the function issues either “Start” signal alone or both “Start” and after set time delay “Trip” signal. Default is that both signals are generated (=deactivated).
Reset ratio	1…10% by step of 1%	Reset ratio of the overvoltage function. Default setting is 5 %.
Time delay	0…60000 ms by step of 1 ms.	Operating time delay setting for the “Trip” signal from the “Start” signal. Default setting is 100 ms.

3.2.14 UNDER VOLTAGE U<, 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.

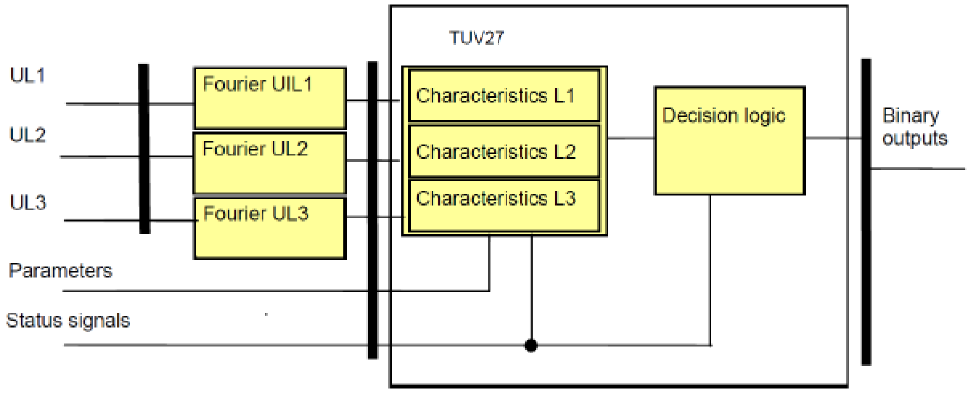


Figure 3-40 The principal structure of the undervoltage function.

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 3-70 Setting parameters of the undervoltage function

Parameter	Setting value, range and step	Description
Operation	Off 1 out of 3 2 out of 3 All	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. Default setting is “1 out of 3” which means that any phase under the setting limit will cause operation.
Start voltage	30…130 % by step of 1 %	Voltage pick-up setting. Default setting is 90 %.
Block voltage	0…20 % by step of 1 %	Undervoltage blocking setting. This setting prevents the function from starting in undervoltage condition which is caused for example from opened breaker. Default setting is 10 %.
Start signal only	Activated Deactivated	Selection if the function issues either “Start” signal alone or both “Start” and after set time delay “Trip” signal. Default is that both signals are generated (=deactivated).
Reset ratio	1…10% by step of 1%	Reset ratio of the undervoltage function. Default setting is 5 %.
Time delay	0…60000 ms by step of 1 ms.	Operating time delay setting for the “Trip” signal from the “Start” signal. Default setting is 100 ms.

3.2.15 RESIDUAL OVER VOLTAGE U0>, 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).

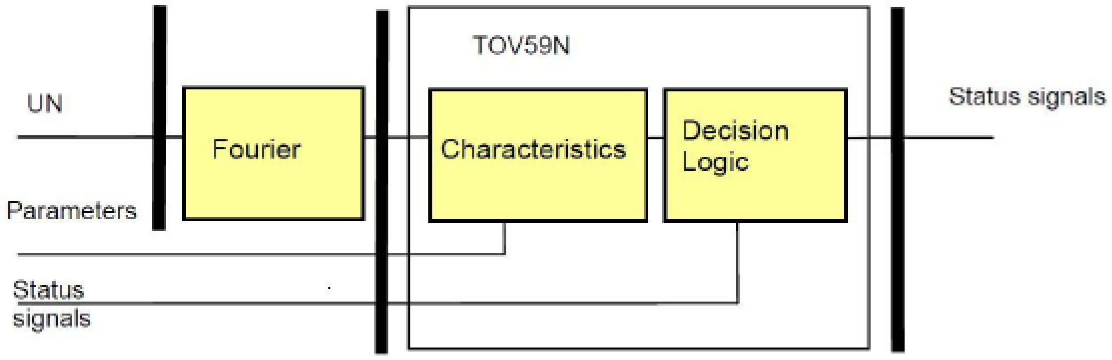


Figure 3-41 The principal structure of the residual overvoltage function.

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 3-71 Setting parameters of the residual overvoltage function

Parameter	Setting value, range and step	Description
Operation	Off On	Operating mode selection for the function. Operation can be either enabled “On” or disabled “Off”. Default setting is “On”.
Start voltage	2…60 % by step of 1 %	Voltage pick-up setting. Default setting 30 %.
Start signal only	Activated Deactivated	Selection if the function issues either “Start” signal alone or both “Start” and after set time delay “Trip” signal. Default is that both signals are generated (=deactivated).
Reset ratio	1…10% by step of 1%	Reset ratio of the residual voltage function. Default setting is 5 %.
Time delay	0…60000 ms by step of 1 ms.	Operating time delay setting for the “Trip” signal from the “Start” signal. Default setting is 100 ms.

3.2.16 OVER FREQUENCY F>, F>>, F>>>, F>>>> (81O)

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 large compared to the consumption by the load connected to the power system, then the system frequency 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.

In the Table 3-72 are presented the function setting parameters.

Table 3-72 Setting parameters of the over-frequency function

Parameter	Setting value, range and step	Description
Operation	Off On	Operating mode selection for the function. Operation can be either disabled “Off” or enabled “On”. Default setting is enabled.
Start signal only	Activated Deactivated	Selection if the function issues either “Start” signal alone or both “Start” and after set time delay “Trip” signal. Default is that both signals are generated (=deactivated).
Start frequency	40.00…70.00 Hz by step of 0.01 Hz	Pick up setting of the function. When the measured frequency value exceeds the setting value function initiates “Start” signal. Default setting is 51 Hz

Time delay	100…60000 ms by step of 1 ms.	Operating time delay setting for the “Trip” signal from the “Start” signal. Default setting is 200 ms.

3.2.17 UNDER FREQUENCY F<, F<<, F<<<, F<<<< (81L)

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 3-73 Setting parameters of the under-frequency function

Parameter	Setting value, range and step	Description
Operation	Off On	Operating mode selection for the function. Operation can be either disabled “Off” or enabled “On”. Default setting is enabled.
Start signal only	Activated Deactivated	Selection if the function issues either “Start” signal alone or both “Start” and after set time delay “Trip” signal. Default is that both signals are generated (=deactivated).
Start frequency	40.00…70.00 Hz by step of 0.01 Hz	Pick up setting of the function. When the measured frequency value exceeds the setting value function initiates “Start” signal. Default setting is 49 Hz

Time delay	100…60000 ms by step of 1 ms.	Operating time delay setting for the “Trip” signal from the “Start” signal. Default setting is 200 ms.

3.2.18 Rate of change of frequency df/dt>, df/dt>>, df/dt>>>, df/dt>>>> (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 large compared to the consumption by the load connected to the power system, then the system frequency is above 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 3-74 Setting parameters of the df/dt-frequency function

Parameter	Setting value, range and step	Description

Operation	Off On	Operating mode selection for the function. Operation can be either disabled “Off” or enabled “On”. Default setting is enabled.
Start signal only	Activated Deactivated	Selection if the function issues either “Start” signal alone or both “Start” and after set time delay “Trip” signal. Default is that both signals are generated (=deactivated).
Start df/dt	-5…5 Hz/s by step of 0.01 Hz	Pick up setting of the function. When the measured frequency value exceeds the setting value function initiates “Start” signal. Default setting is 0.5 Hz
Time delay	100…60000 ms by step of 1 ms.	Operating time delay setting for the “Trip” signal from the “Start” signal. Default setting is 200 ms.

3.2.19 BREAKER FAILURE PROTECTION FUNCTION CBFP, (50BF)

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.

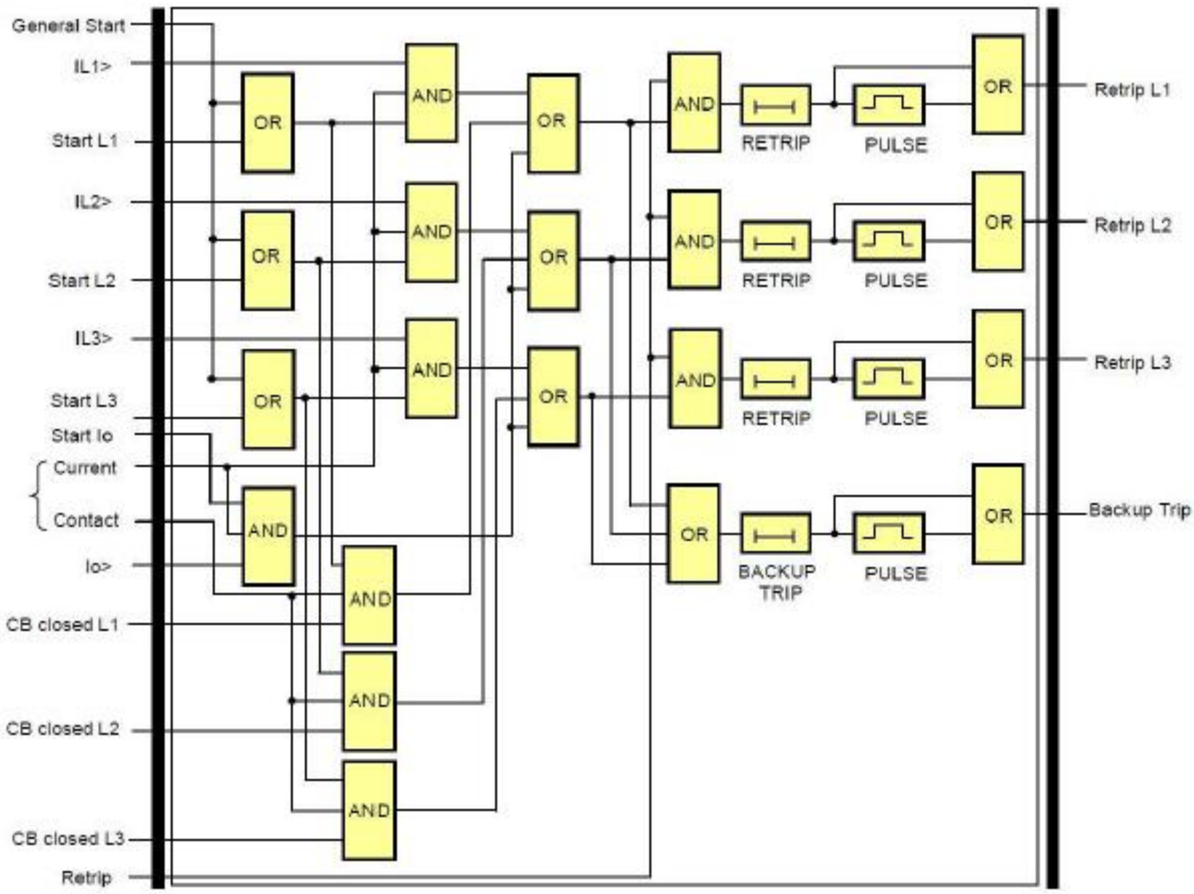


Figure 3-42 Operation logic of the CBFP function

In the Figure 3-42 is presented the operating logic of the CBFP function and in the Table 3-75 are presented the setting parameters of the CBFP function.

Table 3-75 Setting parameters of the CBFP function

Parameter	Setting value, range and step	Description
Operation	Off Current Contact Current/Contact	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. Default setting is “Current”.
Start current Ph	20…200 % by step of 1 %	Pick-up current for the phase current monitoring. Default setting is 30 %.

Start current N	10…200 % by step of 1 %	Pick-up current for the residual current monitoring. Default setting is 30 %
Backup Time Delay	60…1000 ms by step of 1 ms	Time delay for CBFP tripping command for the back-up breakers from the pick-up of the CBFP function monitoring. Default setting is 200 ms.
Pulse length	0…60000 ms by step of 1 ms	CBFP pulse length setting. Default setting is 100 ms.

3.2.20 INRUSH CURRENT DETECTION (INR2), (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 3-76 Setting parameters of the inrush function

Parameter	Setting value, range and step	Description
Operation	On Off	Operating mode selection for the function. Operation can be either disabled "Off" or enabled "On". Default setting is enabled.
2.Harm Ratio	5…50 % by step of 1 %	Pick up setting of the function. The ratio presents the 2.nd harmonic magnitude in relation to the fundamental frequency component. Default setting is 15 %.
Iph base sens (phase)	5…100 % by step of 1 %	Minimum fundamental frequency current setting for the inrush blocking activation. Default setting is 100%
IN Base sens (residual)	2…100 % by step of 1 %	Minimum fundamental frequency residual current setting for the inrush blocking activation. Default setting is 100%

3.2.21 POLE SLIP (78) (OPTION)

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.

3.2.21.1 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”.)

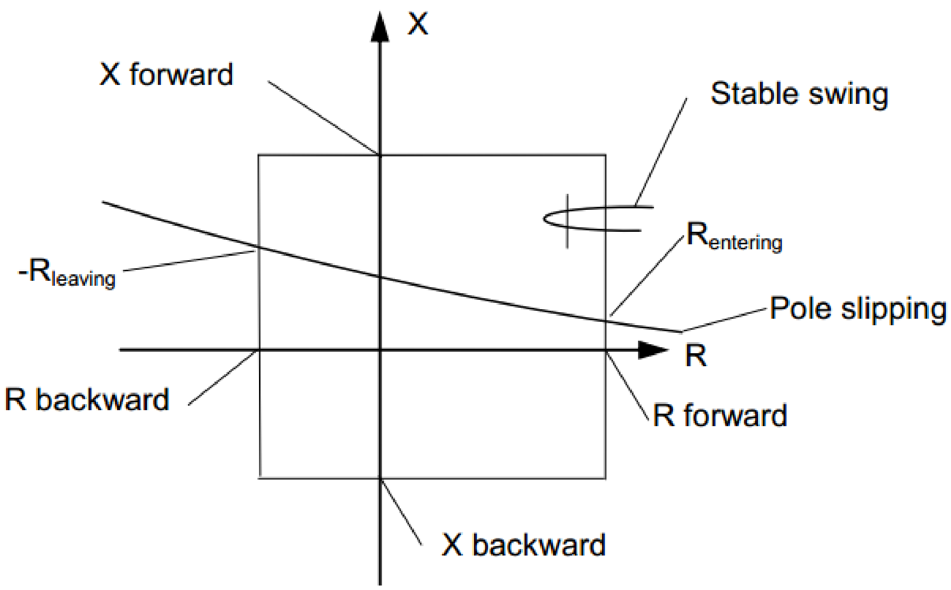


Figure 3-39 Pole slipping

The characteristic feature of pole slipping is that the impedance locus leaves the characteristic at a location, where the sign of the calculated resistance (e.g –Rleaving) is opposite to that of the entering location (e.g. $+R_{entering}$).

If basically other protections on the network are expected to stop the pole slipping, then more than one vector revolution is permitted. In this case the number of the revolution can be set higher then 1, and the subsequent revolution is expected within a defined "Dead time", also set by parameter.

The duration of the generated trip pulse is a parameter value.

3.2.21.2 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.

3.2.21.3 Structure of the pole slipping protection

Fig.1-1 shows the structure of the pole slipping protection function with quadrilateral characteristic.

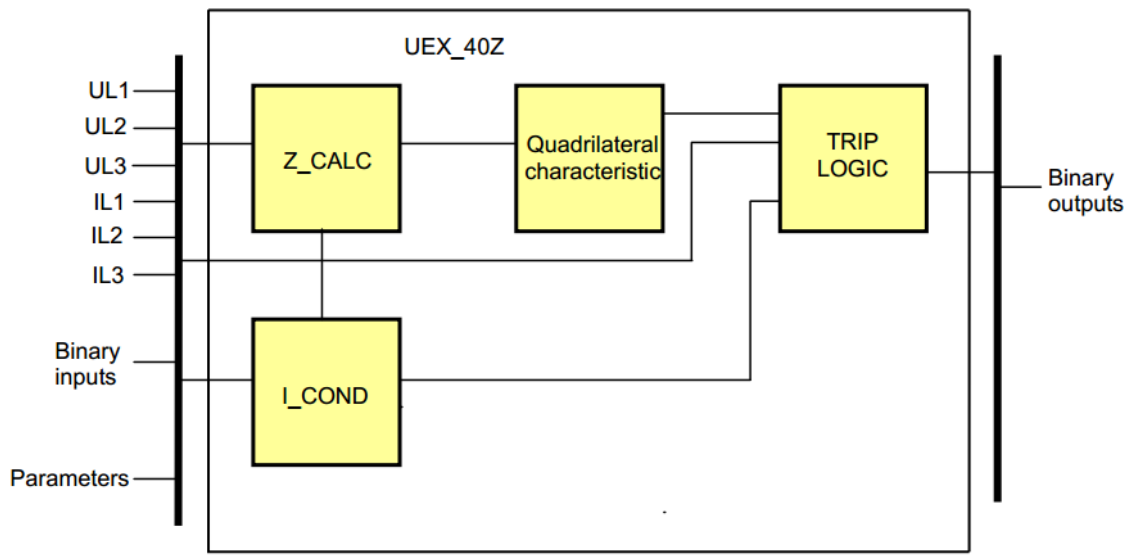


Figure 3-40 Structure of the pole slipping algorithm

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.

3.2.21.4 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 Table 1-1. The result of this calculation is the positive sequence impedance of the current loops.

Table 3-77 Formulas for the calculation of the impedance to fault

Loop	Calculation of Z
L1L2	$Z_{L1L2} = \frac{U_{L1} - U_{L2}}{I_{L1} - I_{L2}}$
L2L3	$Z_{L2L3} = \frac{U_{L2} - U_{L3}}{I_{L2} - I_{L3}}$
L3L1	$Z_{L3L1} = \frac{U_{L3} - U_{L1}}{I_{L3} - I_{L1}}$

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

R1 is the positive sequence resistance of the line or cable section between the fault location and the relay location,

L1 is the positive sequence inductance of the line or cable section between the fault location and the relay location,

L1, L2, L3 indicate 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.

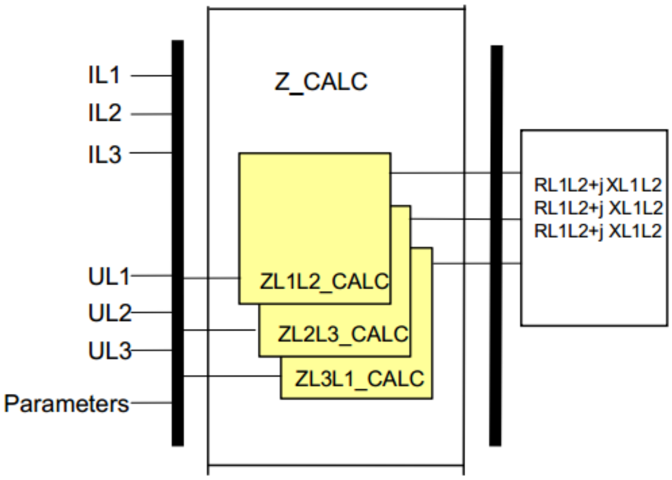


Figure 3-41 Principal scheme of the impedance calculation Z_CALC

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 3-78 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.

3.2.21.5 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 Figure 3-42. Parameter settings decide the size and the position of the rectangle. The parameters are: R forward, X forward, R backward, X backward.

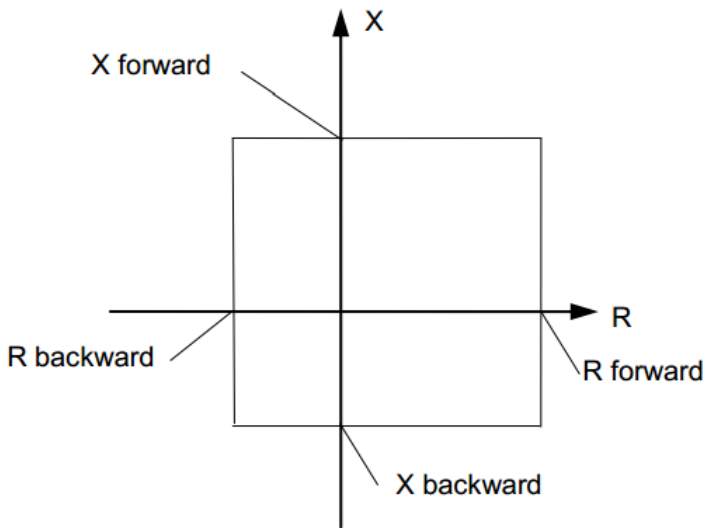


Figure 3-42 The quadrilateral characteristic

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.

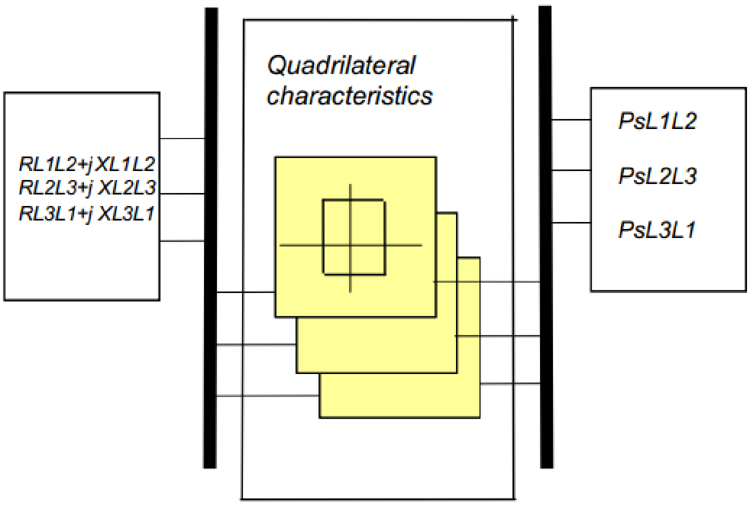


Figure 3-43 Principal scheme of the Quadrilateral characteristic decision

Input values

The input values are calculated by the module Z_CALC.

Table 3-79The 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 3-80 The output status signals of the Quadrilateral characteristic module

Output values	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.

Parameter	Setting value, range and step	Description
Max. cycle number	1…10 cylces, by step of 1	Definition of the number of the vector revolution up to the trip command

Parameter	Setting value, range and step	Description
R forward	0.10…150.00 ohm, by step of 0.01 ohm	R setting of the impedance characteristics in forward direction
X forward	0.10…150.00 ohm, by step of 0.01 ohm	X setting of the impedance characteristics in forward direction
R backward	0.10…150.00 ohm, by step of 0.01 ohm	R setting of the impedance characteristics in backward direction
X backward	0.10…150.00 ohm, by step of 0.01 ohm	X setting of the impedance characteristics in backward direction

3.2.21.6 The trip logic (TRIP LOGIC) and timing

Parameter	Setting value, range and step	Description
Dead time	1000…60000msec, by step of 1msec	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

Parameter	Setting value, range and step	Description
Operation	Off On	Parameter for disabling the function

Input values:

Input values	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

Binary status signal	Explanation
Block	Blocking of the pole slipping function

3.2.21.7 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.

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

Parameter	Setting value, range and step	Description
IPh Base Sens	10…30, by step of 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.

3.2.21.8 The symbol of the function in the AQtivate 300 software

Figure 3-44 The function block of the pole slip function

Binary status signal	Explanation
Start	Start signal of the function
Trip	Trip command of the function

Binary status signal	Explanation
Block	Blocking of the pole slipping function

3.3 CONTROL AND MONITORING FUNCTIONS

3.3.1 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 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 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.**

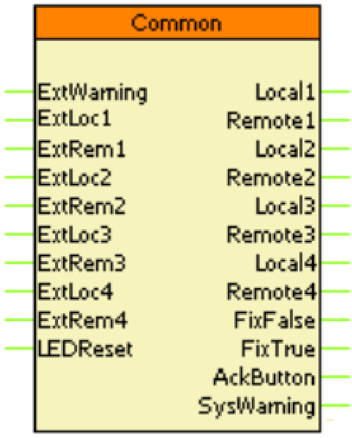


Figure 3-45: The function block of the Common function block

Table 3-81: The binary input status of the common function block

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

Table 3-82: The binary input status of the common function block

Binary status signal	Title	Explanation
Common_Local1_GrI_	Local 1	Output1 to indicate the state of group 1 as Local
Common_Remote1_GrI_	Remote 1	Output1 to indicate the state of group 1 as Remote
Common_Local2_GrI_	Local 2	Output2 to indicate the state of group 2 as Local
Common_Remote2_GrI_	Remote 2	Output2 to indicate the state of group 2 as Remote
Common_Local3_GrI_	Local 3	Output3 to indicate the state of group 3 as Local
Common_Remote3_GrI_	Remote 3	Output3 to indicate the state of group 3 as Remote
Common_Local4_GrI_	Local 4	Output4 to indicate the state of group 4 as Local
Common_Remote4_GrI_	Remote 4	Output4 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 LED-s, 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 3-83: Setting parameters of the Common function

Parameter	Setting value, range and step	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.

3.3.2 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.

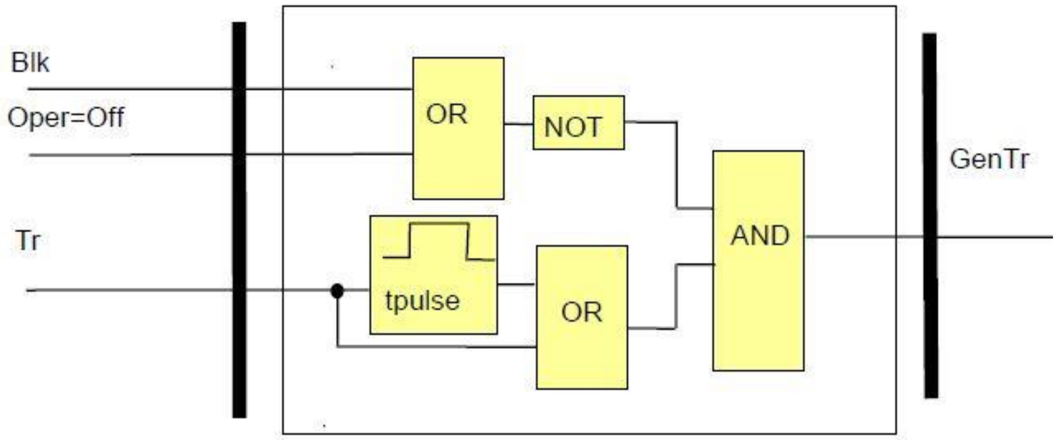


Figure 3-43 Operation logic of the trip logic function.

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

3.3.2.1 Application example

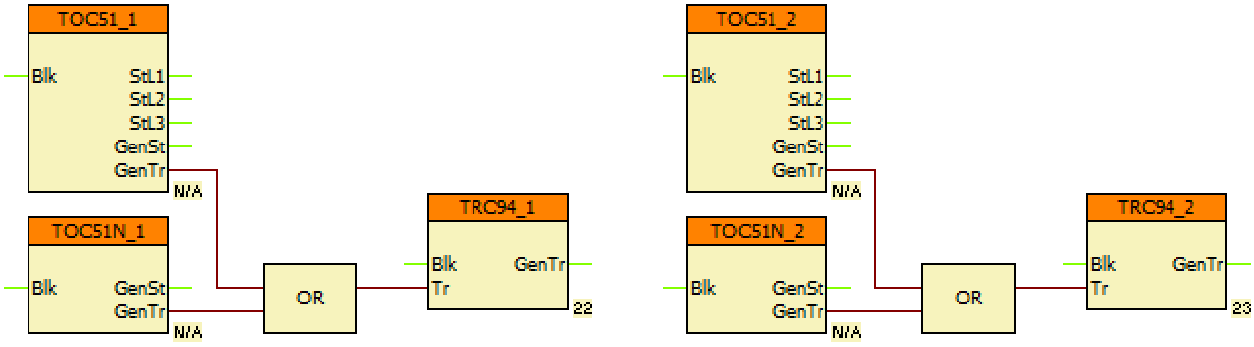


Figure 3-44 Example picture where two I> TOC51 and I0> TOC51N trip signals are connected to two trip logic function blocks.

In this example we have a transformer protection supervising phase and residual currents on 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.

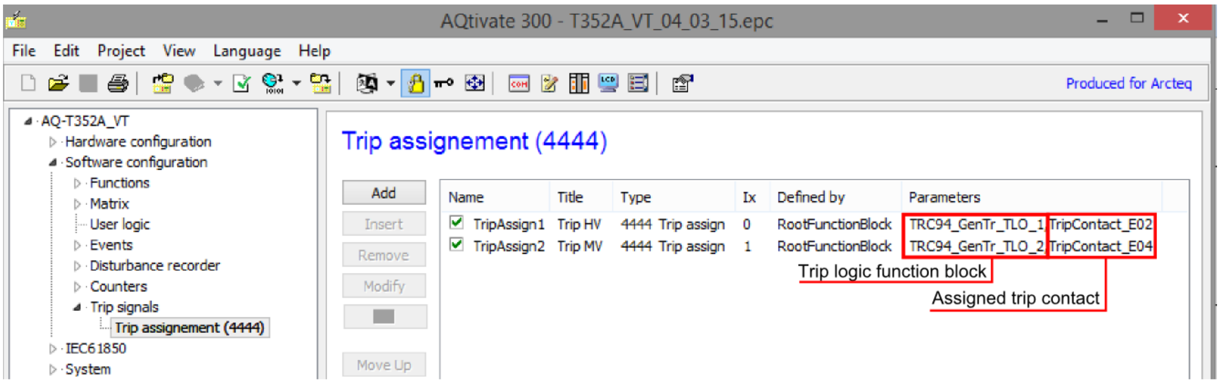


Figure 3-45 Trip logic block #1 has been assigned as HV side trip to activate trip contact E02. Trip logic block #2 has been assigned as MV side trip to activate trip contact E04.

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

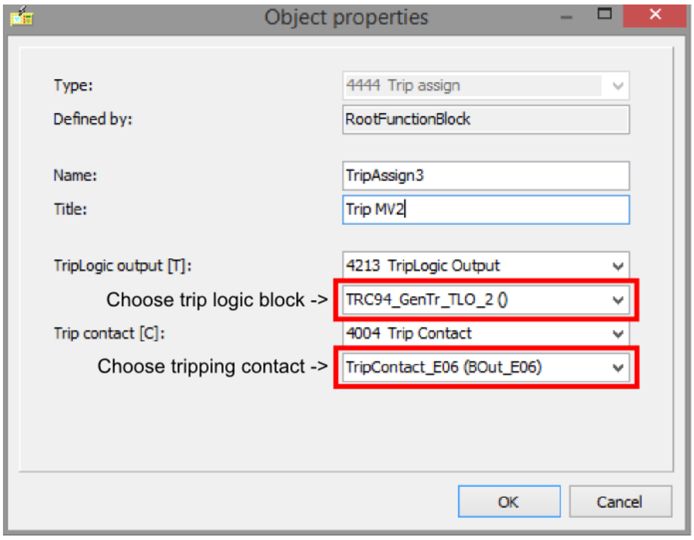


Figure 3-46 Instructions on adding/modifying trip assignment.

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.

Table 3-84 Setting parameters of the trip logic function

Parameter	Setting value, range and step	Description
Operation	On Off	Operating mode selection for the function. Operation can be either disabled “Off” or enabled “On”. Default setting is enabled.
Min pulse length	50…60000 ms by step of 1 ms	Minimum tripping pulse length setting. Default setting is 150 ms.

3.3.3 Dead line detection

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.

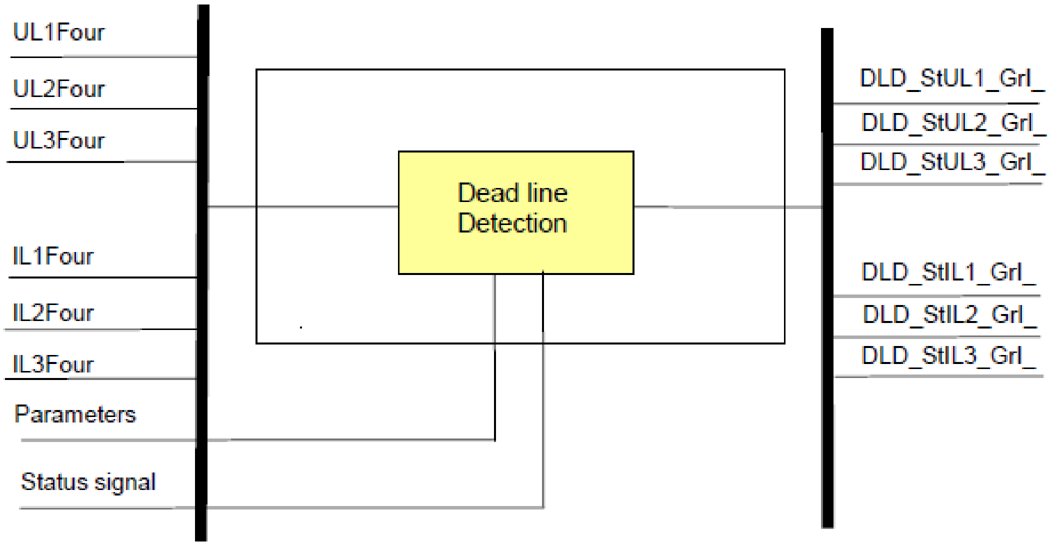


Figure 3-46: Principal scheme of the dead line detection function

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.

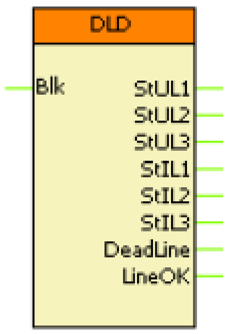


Figure 3-47: The function of the dead line detection function

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

Table 3-85: The binary input signal of the dead line detection function

Binary status signal	Explanation
DLD_Blk_GrO_	Output status defined by the user to disable the dead line detection function.

Table 3-86: The binary output status signals of the dead line detection function

Binary output signals	Signal title	Explanation
DLD function		
DLD_StUL1_GrI_	Start UL1	The voltage of phase L1 is above the setting limit
DLD_StUL2_GrI_	Start UL2	The voltage of phase L2 is above the setting limit
DLD_StUL3_GrI_	Start UL3	The voltage of phase L3 is above the setting limit
DLD_StIL1_GrI_	Start IL1	The current of phase L1 is above the setting limit
DLD_StIL2_GrI_	Start IL2	The current of phase L2 is above the setting limit
DLD_StIL3_GrI_	Start IL3	The current of phase L3 is above the setting limit
DLD_DeadLine_GrI_	DeadLine condition	The requirements of "DeadLine condition" are fulfilled
DLD_LineOK_GrI_	LineOK condition	The requirements of "Live line condition" (LineOK) are fulfilled

3.3.4 Voltage transformer supervision function (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.

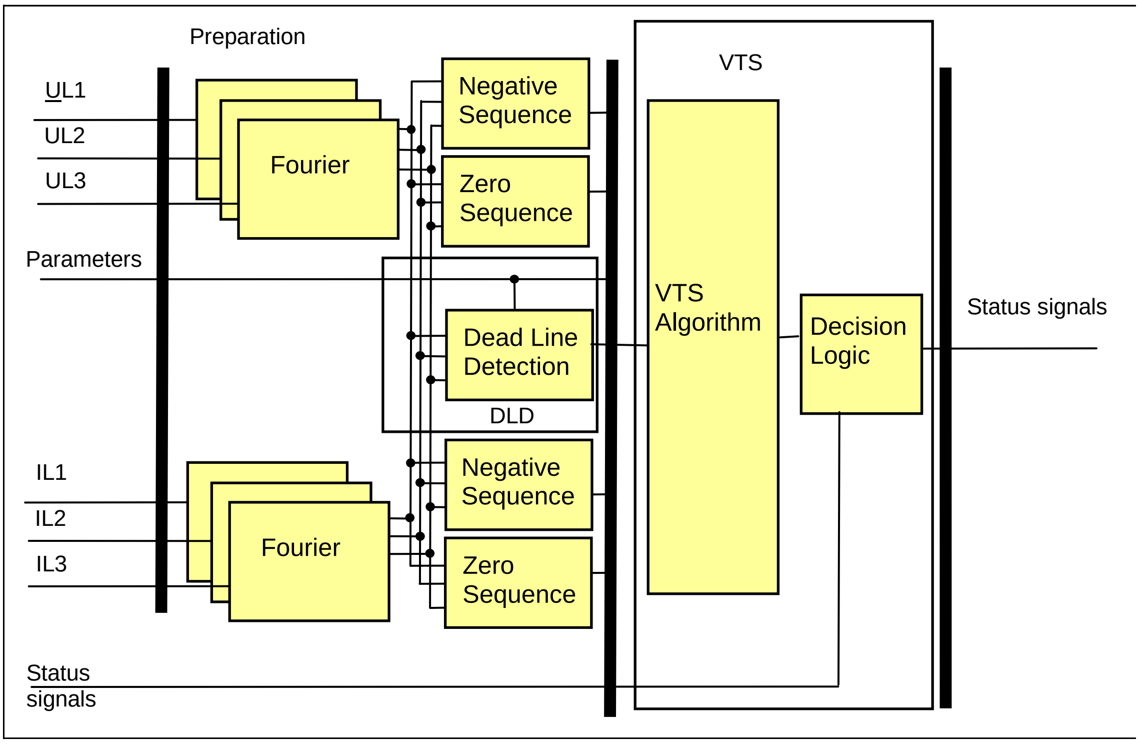


Figure 3-48: Operation logic of the voltage transformer supervision and dead line detection.

The voltage transformer supervision logic operates through decision logic presented in the following figure.

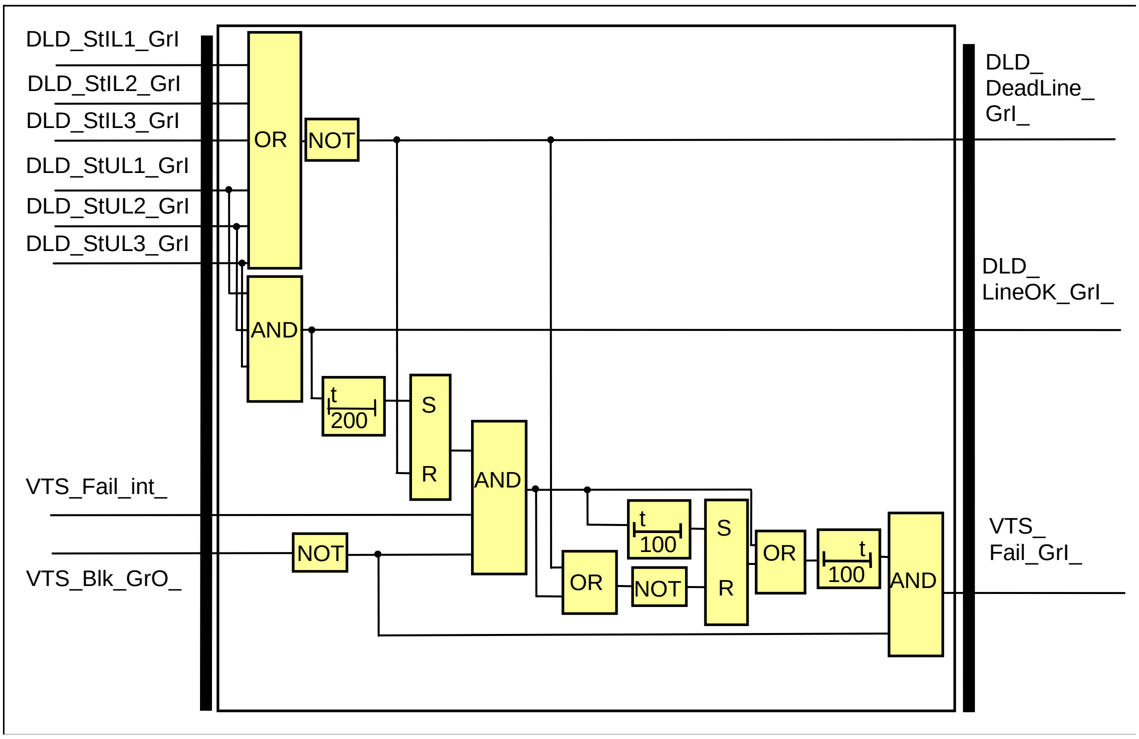


Figure 3-49: Decision logic of the voltage transformer supervision function.

NOTE: 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

3.3.4.1 The symbol of the function block in the AQtivate 300 software

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.

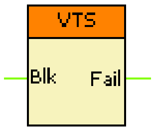


Figure 3-50: The function block of the voltage transformer supervision function

The binary input and output status signals of voltage transformer supervision function are listed in tables below.

Binary status signal	Explanation
VTS_Blk_GrO_	Output status defined by the user to disable the voltage transformer supervision function.

Table 3-87: The binary input signal of the voltage transformer supervision function

Binary output signals	Signal title	Explanation
VTS_Fail_GrI	VT Failure	Failure status signal of the VTS function

Table 3-88: The binary output signal of the voltage transformer supervision function

3.3.4.2 Setting parameters

Parameter	Setting value, range and step	Description
Operation	Off Neg. Sequence Zero sequence Special	Operating mode selection for the function. Operation can be either disabled “Off” or enabled with criterions “Neg.Sequence”, “Zero sequence” or “Special”. Default setting is enabled with negative sequence criterion.
Start URes	5…50 % by step of 1 %	Residual voltage setting limit. Default setting is 30 %.
Start IRes	10…50 % by step of 1 %	Residual current setting limit. Default setting is 10 %.

Start UNeg	5…50 % by step of 1 %	Negative sequence voltage setting limit. Default setting is 10 %.
Start INeg	10…50 % by step of 1 %	Negative sequence current setting limit. Default setting is 10 %.

Table 3-89: Setting parameters of the voltage transformer supervision function

3.3.5 CT SUPERVISION

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.

3.3.5.1 The symbol of the function block in the AQtivate 300 software

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 AQtivate 300 software.

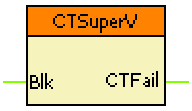


Figure 3-51: The function block of the current transformer supervision function

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

Binary status signal	**Title**	**Explanation**
CTSuperV_**Blk**_GrO_	Block	Blocking of the function

Table 3-90: The binary input signal of the current transformer supervision function

Binary status signal	**Title**	**Explanation**
CTSuperV_**CtFail**_GrI_	CtFail	CT failure signal

Table 3-91: The binary output status signals of the current transformer supervision function

3.3.5.2 Setting parameters

Parameter	Setting value, range and step	Description
Operation	On Off	Operating mode selection for the function. Operation can be either disabled “Off” or enabled “ON”. Default setting is enabled.
IPhase Diff	50…90 % by step of 1 %	Phase current difference setting. Default setting is 80 %.
Time delay	100…60000ms	CT supervision time delay. Default setting is 1000ms.

Table 3-92: Setting parameters of the current transformer supervision function

3.3.6 Synchrocheck function DU/DF (25)

Several problems can occur in the power system if the circuit breaker closes and connects two systems operating asynchronously. The high current surge can cause damage in the interconnecting elements, the accelerating forces can overstress the shafts of rotating machines or the actions taken by the protective system can result in the eventual isolation of parts of the power system.

To prevent such problems, this function checks if the systems to be interconnected are operating synchronously. If yes, then the close command is transmitted to the circuit breaker. In case of asynchronous operation, the close command is delayed to wait for the appropriate vector position of the voltage vectors on both sides of the circuit breaker. If the conditions for safe closing cannot be fulfilled within an expected time, then closing is declined.

NOTE: For capacitive reference voltage measurement, the voltage measurement card can be ordered with <50 mVA burden special input.

The conditions for safe closing are as follows:

- The difference of the voltage magnitudes is below the set limit
- The difference of the frequencies is below the set limit
- The angle difference between the voltages on both sides of the circuit breaker is within the set limit.

The function processes both automatic reclosing and manual close commands.

The limits for automatic reclosing and manual close commands can be set independently of each other.

The function compares the voltage of the line and the voltage of one of the busbar sections (Bus1 or Bus2). The bus selection is made automatically based on a binary input signal defined by the user.

For the reference of the synchrocheck any phase-to-ground or phase-to-phase voltage can be selected.

The function processes the signals of the voltage transformer supervision function and enables the close command only in case of plausible voltages.

The synchrocheck function monitors three modes of conditions:

- Energizing check:
    - Dead bus, live line,
    - Live bus, dead line,
    - Any Energizing case (including Dead bus, dead line).
- Synchro check (Live line, live bus)
- Synchro switch (Live line, live bus)

If the conditions for “Energizing check” and “Synchro check” are fulfilled, then the function generates the release command, and in case of a manual or automatic close request, the close command is generated.

If the conditions for energizing and synchronous operation are not met when the close request is received, then synchronous switching is attempted within the set time-out. In this case, the rotating vectors must fulfill the conditions for safe switching within the set waiting time: at the moment the contacts of the circuit breaker are closed, the voltage vectors must match each other with appropriate accuracy. For this mode of operation, the expected operating time of the circuit breaker must be set as a parameter value, to generate the close command in advance taking the relative vector rotation into consideration.

Started closing procedure can be interrupted by a cancel command defined by the user.

In “bypass” operation mode, the function generates the release signals and simply transmits the close command.

In the following figure is presented the operating logic of the synchrocheck function.

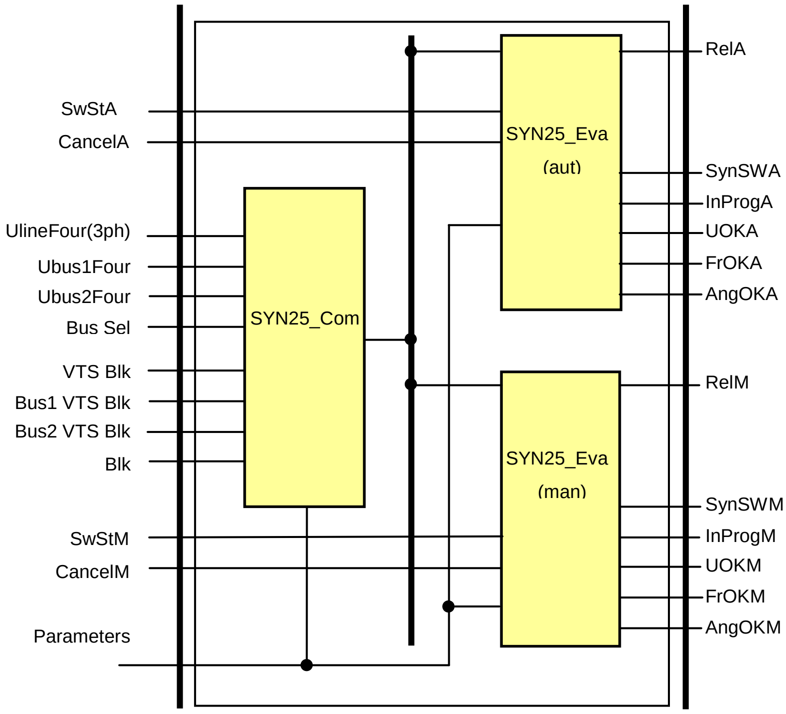


Figure 3-52: Operation logic of the synchrocheck function.

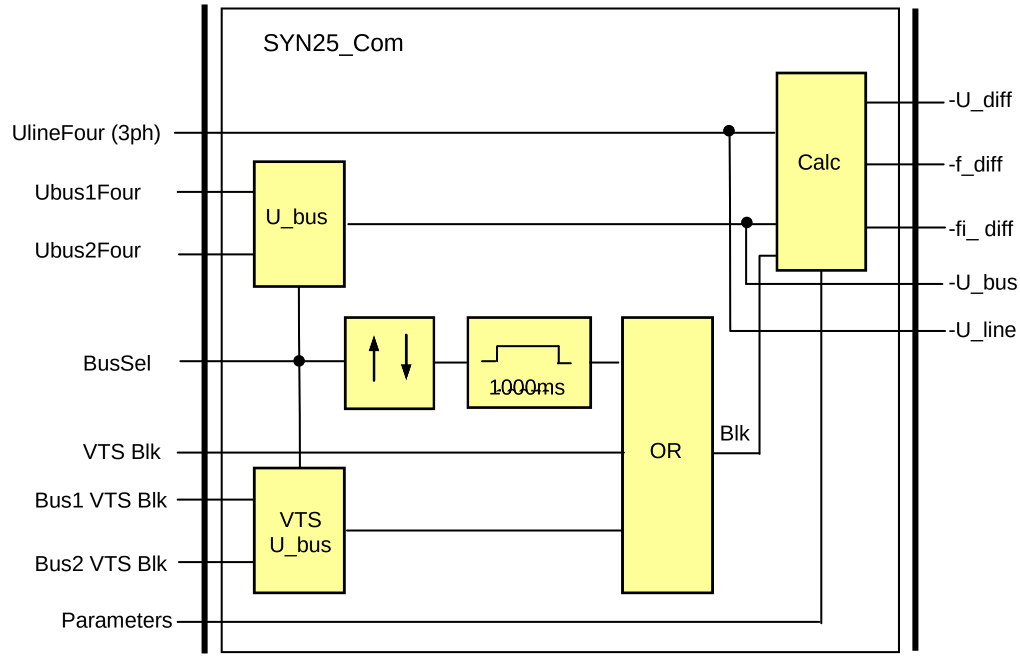
The synchro check/synchro switch function contains two kinds of software blocks:

SYN25_Com *is a common block for manual switching and automatic switching*

SYN25_EVA *is an evaluation block, duplicated for manual switching and for automatic switching*

The SYN25_Com block selects the appropriate voltages for processing and calculates the voltage difference, the frequency difference and the phase angle difference between the selected voltages. The magnitude of the selected voltages is passed for further evaluation. The structure of this software block is shown in Figure 3-53).

- These values are further processed by the evaluation software blocks (see Figure 3-54). The function is disabled if the binary input (Block) signal is TRUE. The activation of voltage transformer supervision function of the line voltage blocks the operation (VTS Block). The activation of voltage transformer supervision function of the selected bus section blocks the operation (VTS Bus1 Block or VTS Bus2 Block).



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- Figure 3-53: Synchrocheck common difference calculation function structure.

If the active bus section changes the function is dynamically blocked for 1000ms and no release signal or switching command is generated. The processed line voltage is selected based on the preset parameter (Voltage select). The choice is: L1-N, L2-N, L3-N, L1-L2, L2-L3 or L3-L1. The parameter value must match the input voltages received from the bus sections. The active bus section is selected by the input signal (Bus select). If this signal is logic TRUE, then the voltage of Bus2 is selected for evaluation.

The software block SYN25_Eva is applied separately for automatic and manual commands. This separation allows the application to use different parameter values for the two modes of operation.

The structure of the evaluation software block is shown in the following figure.

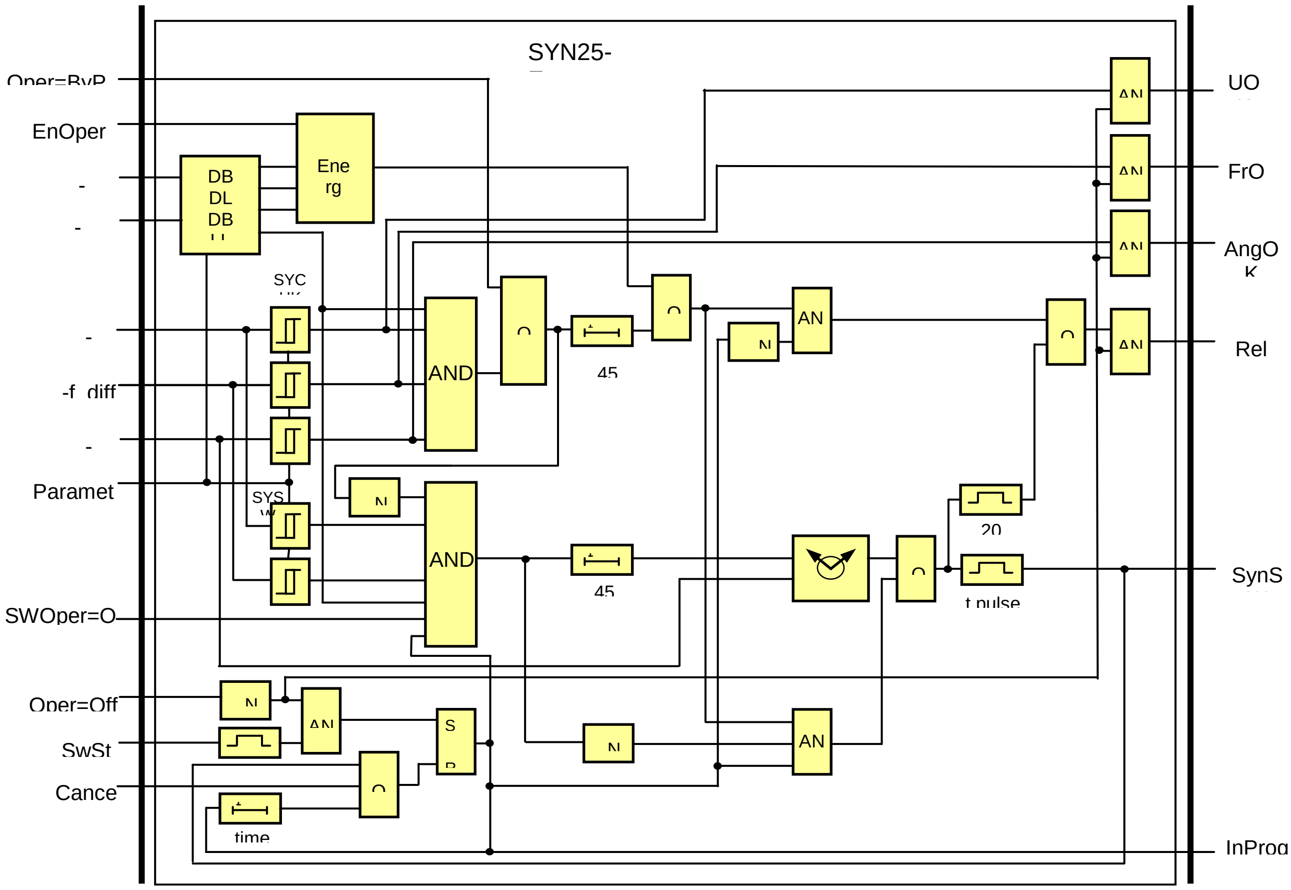


Figure 3-54: Synchrocheck evaluation function structure.

This evaluation software block is used for two purposes: for the automatic reclosing command (the signal names have the suffix “A”) and for the manual close request (the signal names have the suffix “M”). As the first step, based on the selected line voltage and bus voltage, the state of the required switching is decided (Dead bus-Dead line, Dead bus-Live line, Live bus-Dead line or Live bus- Live line). The parameters for decision are (U Live) and (U Dead). The parameters (Energizing Auto/Manual) enable the operation individually. The choice is: (Off, DeadBus LiveLine, LiveBus DeadLine, Any energ case). In simple energizing modes, no further checking is needed. This mode selection is bypassed if the parameter (Operation Auto/Manual) is set to “ByPass”. In this case the command is transmitted without any further checking.

First, the function tries switching with synchro check. This is possible if: the voltage difference is within the defined limits (Udiff SynChk Auto/Manual)) the frequency difference is within the defined limits (FrDiff SynChk Auto) and the phase angle difference is within the defined limits (MaxPhaseDiff Auto/Manual)).

If the conditions are fulfilled for at least 45 ms, then the function generates a release output signal (Release Auto/Manual).

If the conditions for synchro check operation are not fulfilled and a close request is received as the input signal (SySwitch Auto/Manual), then synchro switching is attempted. This is possible if: the voltage difference is within the defined limits (Udiff SynSW Auto /Manual)) the frequency difference is within the defined limits (FrDiff SynSW Auto).

These parameters are independent of those for the synchro check function. If the conditions for synchro check are not fulfilled and the conditions for synchro switch are OK, then the relative rotation of the voltage vectors is monitored. The command is generated before the synchronous position, taking the breaker closing time into consideration (Breaker Time). The pulse duration is defined by the parameter (Close Pulse). In case of slow rotation and if the vectors are for long time near-opposite vector positions, no switching is possible, therefore the waiting time is limited by the preset parameter (Max.Switch Time).

The progress is indicated by the output status signal (SynInProgr Auto/Manual). The started command can be canceled using the input signal (Cancel Auto/Manual).

The symbol of the function block in the AQtivate 300 software

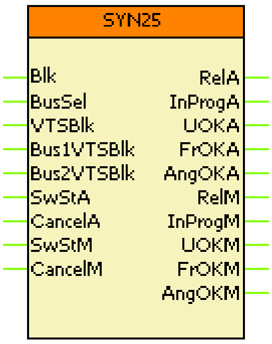


Figure 3-55 The function block of the synchro check / synchro switch function

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

Binary status signal	Title	Explanation
SYN25_BusSel_GrO_	Bus select	If this signal is logic TRUE, then the voltage of Bus2 is selected for evaluation
SYN25_VTSBlk_GrO_	VTS Block	Blocking signal of the voltage transformer supervision function evaluating the line voltage
SYN25_Bus1VTSBlk_GrO_	VTS Bus1 Block	Blocking signal of the voltage transformer supervision function evaluating the Bus1 voltage
SYN25_Bus2VTSBlk_GrO_	VTS Bus2 Block	Blocking signal of the voltage transformer supervision function evaluating the Bus2 voltage
SYN25_SwStA_GrO_	SySwitch Auto	Switching request signal initiated by the automatic reclosing function
SYN25_CancelA_GrO_	Cancel Auto	Signal to interrupt (cancel) the automatic switching procedure
SYN25_Blk_GrO_	Block	Blocking signal of the function
SYN25_SwStM_GrO_	SySwitch Manual	Switching request signal initiated by manual closing
SYN25_CancelM_GrO_	Cancel Manual	Signal to interrupt (cancel) the manual switching procedure

Table 3-93: The binary input signal of the synchro check / synchro switch function

Binary status signal	Title	Explanation
SYN25_RelA_GrI_	Release Auto	Releasing the close command initiated by the automatic reclosing function
SYN25_InProgA_GrI_	SynInProgr Auto	Switching procedure is in progress, initiated by the automatic reclosing function
SYN25_UOKA_GrI_	Udiff OK Auto	The voltage difference is appropriate for automatic closing command
SYN25_FrOKA_GrI_	FreqDiff OK Auto	The frequency difference is appropriate for automatic closing command, evaluated for synchro-check **
SYN25_AngOKA_GrI_	Angle OK Auto	The angle difference is appropriate for automatic closing command
SYN25_RelM_GrI_	Release Man	Releasing the close command, initiated by manual closing request
SYN25_InProgM_GrI_	SynInProgr Man	Switching procedure is in progress, initiated by the manual closing command
SYN25_UOKM_GrI_	Udiff OK Man	The voltage difference is appropriate for manual closing command
SYN25_FrOKM_GrI_	FreqDiff OK Man	The frequency difference is appropriate for manual closing command, evaluated for synchro-check **
SYN25_AngOKM_GrI_	Angle OK Man	The angle difference is appropriate for manual closing command

Table 3-94 The binary output status signals of the synchro check / synchro switch function

3.3.6.1 Setting parameters

Parameter	Setting value, range and step	Description
Voltage select	L1-N L2-N L3-N L1-L2 L2-L3 L3-L1	Reference voltage selection. The function will monitor the selected voltage for magnitude, frequency and angle differences. Default setting is L1-N
U Live	60…110 % by step of 1 %	Voltage setting limit for “Live Line” detection. When measured voltage is above the setting value the line is considered “Live”. Default setting is 70 %.
U Dead	10…60 % by step of 1%	Voltage setting limit for “Dead Line” detection. When measured voltage is below the setting value the line is considered “dead”. Default setting is 30 %.
Breaker Time	0…500 ms by step of 1 ms	Breaker operating time at closing. This parameter is used for the synchro switch closing command compensation and it describes the breaker travel time from open position to closed position from the close command. Default setting is 80 ms.

Close Pulse	10…60000 ms by step of 1 ms	Close command pulse length. This setting defines the duration of close command from the IED to the circuit breaker. Default setting is 1000 ms.
Max Switch Time	100…60000 ms by step of 1 ms	Maximum allowed switching time. In case synchro check conditions are not fulfilled and the rotation of the networks is slow this parameter defines the maximum waiting time after which the close command is failed. Default setting is 2000ms.
Operation Auto	On Off ByPass	Operation mode for automatic switching. Selection can be automatic switching off, on or bypassed. If the Operation Auto is set to “Off” automatic switch checking is disabled. If selection is “ByPass” Automatic switching is enabled with bypassing the bus and line energization status checking. When the selection is “On” also the energization status of bus and line are checked before processing the command. Default setting is “On”
SynSW Auto	On Off	Automatic synchroswitching selection. Selection may be enabled “On” or disabled “Off”. Default setting is Enabled “On”.
Energizing Auto	Off DeadBus LiveLine LiveBus DeadLine Any energ case	Energizing mode of automatic synchroswitching. Selections consist of the monitoring of the energization status of the bus and line. If the operation is wanted to be LiveBus LiveLine or DeadBus DeadLine the selection is “Any energ case”. Default setting is DeadBus LiveLine.
Udiff SynChk Auto	5…30 % by step of 1 %	Voltage difference checking of the automatic synchrocheck mode. If the measured voltage difference is below this setting the condition applies. Default setting is 10 %.
Udiff SynSW Auto	5…30 % by step of 1 %	Voltage difference checking of the automatic synchroswitch mode. If the measured voltage difference is below this setting the condition applies. Default setting is 10 %.
MaxPhasediff Auto	5…80 deg by step of 1 deg	Phase difference checking of the automatic synchroswitch mode. If the measured phase difference is below this setting the condition applies. Default setting is 20 deg.
FrDiff SynChk Auto	0.02…0.50 Hz by step of 0.01 Hz	Frequency difference checking of the automatic synchrocheck mode. If the measured phase difference is below this setting the condition applies. Default setting is 0.02 Hz.
FrDiff SynSW Auto	0.10…1.00 Hz by step of 0.01 Hz	Frequency difference checking of the automatic synchroswitch mode. If the measured phase difference is below this setting the condition applies. Default setting is 0.2 Hz.
Operation Man	On Off ByPass	Operation mode for manual switching. Selection can be manual switching off, on or bypassed. If the Operation Man is set to “ Off” manual switch checking is disabled. If selection is “ByPass ” manual switching is enabled with bypassing the bus and line energization status checking. When the selection is “On” also the energization status of bus and line are checked before processing the command. Default setting is “On”
SynSW Man	On Off	Manual synchroswitching selection. Selection may be enabled “On” or disabled “Off”. Default setting is Enabled “On”.
Energizing Man	Off DeadBus LiveLine LiveBus DeadLine Any energ case	Energizing mode of manual synchroswitching. Selections consist of the monitoring of the energization status of the bus and line. If the operation is wanted to be LiveBus LiveLine or DeadBus DeadLine the selection is “Any energ case”. Default setting is DeadBus LiveLine.
Udiff SynChk Man	5…30 % by step of 1 %	Voltage difference checking of the manual synchrocheck mode. If the measured voltage difference is below this setting the condition applies. Default setting is 10 %.

Udiff SynSW Man	5…30 % by step of 1 %	Voltage difference checking of the manual synchroswitch mode. If the measured voltage difference is below this setting the condition applies. Default setting is 10 %.
MaxPhaseDiff Man	5…80 deg by step of 1 deg	Phase difference checking of the manual synchroswitch mode. If the measured phase difference is below this setting the condition applies. Default setting is 20 deg.
FrDiff SynChk Man	0.02…0.50 Hz by step of 0.01 Hz	Frequency difference checking of the manual synchrocheck mode. If the measured phase difference is below this setting the condition applies. Default setting is 0.02 Hz.
FrDiff SynSW Man	0.10…1.00 Hz by step of 0.01 Hz	Frequency difference checking of the manual synchroswitch mode. If the measured phase difference is below this setting the condition applies. Default setting is 0.2 Hz.

Table 3-95: Setting parameters of the synchro check / synchro switch function

3.3.7 Autoreclosing (Medium Voltage) (79)

The automatic reclosing function for medium-voltage networks can perform up to four shots of reclosing. The dead time can be set individually for each reclosing and separately for earth faults and for multi-phase faults.

The starting signal of the cycles can be generated by any combination of the protection functions or external signals of the binary inputs defined by user.

The automatic reclosing function is triggered if as a consequence of a fault a protection function generates a trip command to the circuit breaker and the protection function resets because the fault current drops to zero and/or the circuit breakers auxiliary contact signals open state. According to the preset parameter values, either of these two conditions starts counting the dead time, at the end of which the automatic reclosing function generates a close command. If the fault still exist or reappears, then within the "Reclaim time" (according to parameter setting, started at the close command) the auto-reclose function picks up again and the subsequent cycle is started. If no pickup is detected within this time, then the automatic reclosing function resets and a new fault will start the procedure with the first cycle again.

Following additional requirements apply to performing automatic reclosing:

- The automatic reclosing function can be blocked with any available signal or combination of signals defined by user.

- After a pickup of the protection function, a timer starts to measure the "**Action time**" (the duration depends on parameter setting (Action time)). The trip command must be generated within this time to start reclosing cycles, or else the automatic function enters blocked state.
- At the moment of generating the close command, the circuit breaker must be ready for operation, which is signaled via binary input (CB Ready). The preset parameter value (CB Supervision time) decides how long the automatic reclosing function is allowed to wait at the end of the dead time for this signal. If the signal is not received during this dead time extension, then the automatic reclosing function terminates and after a "**dynamic blocking time**" (depending on the preset parameter value (Dynamic Blocking time)) the function resets.

In case of a manual close command (which is assigned to the logic variable (Manual Close) using equation programming), a preset parameter value decides how long the MV autorecloser function should be disabled **after the manual close** command.

The **duration of the close command** depends on preset parameter value (Close command time), but the close command terminates if any of the protection functions issues a trip command.

The automatic reclosing function can control up to four reclosing cycles, separately for earth faults and for multi-phase faults. Depending on the preset parameter values (EarthFaults Rec,Cycle) and (PhaseFaults Rec,Cycle), there are different modes of operation, both for earth faults and for multi-phase faults:

Disabled	No automatic reclosing is selected,
1. Enabled	Only one automatic reclosing cycle is selected,
1.2. Enabled	Two automatic reclosing cycles are activated,
1.2.3. Enabled	Three automatic reclosing cycles are activated,
1.2.3.4. Enabled	All automatic reclosing cycles are activated.

The MV automatic reclosing function enters into the dynamic blocking state:

- If the parameter selection for (Reclosing started by) is "Trip reset" and the trip impulse is too long

- If the parameter selected for (Reclosing started by) is "CB open", then during the runtime of the timer CB open signal is received)

The start of dead time counter of any reclosing cycle can be delayed. The delay is activated if the value of the (Dead Time St.Delay) status signal is TRUE. This delay is defined by the timer parameter (DeadTime Max.Delay).

For all four reclosing cycles, separate dead times can be defined for line-to-line faults and for earth faults.

The timer parameters for line-to-line faults are:

1. Dead Time Ph
2. Dead Time Ph
3. Dead Time Ph
4. Dead Time Ph

The timer parameters for earth faults are:

1. Dead Time EF
2. Dead Time EF
3. Dead Time EF
4. Dead Time EF

In case of evolving faults, the dead times depend on the first fault detection.

The automatic reclosing function is prepared to generate three-phase trip commands only. The applied dead time setting depends on the first detected fault type indicated by the input signal (EarthFaultTrip NoPhF). (This signal is TRUE in case of an earth fault.) The subsequent cycles do not change this decision.

If the circuit breaker is not ready, the controller function waits for a pre-programmed time for this state. The waiting time is defined by the user as parameter value (CB Supervision time). If circuit breaker ready signal does not activate during the waiting time, then the automatic reclosing function enters into "Dynamic blocked" state.

Reclosing is possible only if the conditions required by the "synchro-check" function are fulfilled. This state is signaled by the binary variable (SYNC Release). The automatic reclosing function waits for a pre-programmed time for this signal. This time is defined by the user as parameter value (Sync-check Max.Tim). If the "SYNC Release" signal is not received during the running time of this timer, then the “synchronous switch” operation is started and the signal (CloseRequ.SynSwitch) is generated.

If the conditions of the synchronous state are not fulfilled, another timer starts. The waiting time is defined by the user as parameter value (Sync-switch Max.Tim). This separate function controls the generation of the close command in case of relatively rotating voltage vectors for the circuit breaker to make contact at the synchronous state of the rotating vectors. For this calculation, the closing time of the circuit breaker must be defined. This mode of operation is indicated by the output variable (CloseRequ. SynSwitch)If no switching is possible during the running time of this timer, then the automatic reclosing function enters “Dynamic blocked” state and resets.When the close command is generated, a timer is started to measure the “Reclaim time”. The duration is defined by the parameter value (Reclaim time), but it is prolonged up to the reset of the close command (if the close command duration is longer than the reclaim time set). If the fault is detected again during this time, then the sequence of the automatic reclosing cycles continues. If no fault is detected, then at the expiry of the reclaim time the reclosing is considered successful and the function resets. If fault is detected after the expiry of this timer, then the cycles restart with the first reclosing cycle.

If the user programmed the status variable (Protection Start) and it gets TRUE during the Reclaim time, then the automatic reclosing function continues even if the trip command is received after the expiry of the Reclaim time.

After a manual close command, the automatic reclosing function enters “Not Ready” state for the time period defined by parameter (Block after Man.Close). If the manual close command is received during the running time of any of the cycles, then the automatic reclosing function enters into “Dynamic blocked” state and resets.

If the fault still exists at the end of the last cycle, the automatic reclosing function trips and generates the signal for final trip: (Final Trip). The same final trip signal is generated in case of an evolving fault if “Block Reclosing” is selected. After final trip, the automatic reclosing function enters “Dynamic blocked” state. A final trip command is also generated if, after a multi-phase fault, a fault is detected again during the dead time.

There are several conditions to cause dynamic blocked state of the automatic reclosing function. This state becomes valid if any of the conditions of the dynamic blocking changes to active during the running time of any of the reclosing cycles. At the time of the change a timer is started. Timer duration is defined by the time parameter (Dynamic Blocking time). During this time, no reclosing command is generated.

The conditions to start the dynamic blocked state are:

- There is no trip command during the “Action time”
- The duration of the starting impulse for the MV automatic reclosing function is too long
- If no “CB ready” signal is received at the intended time of reclosing command
- The dead time is prolonged further then the preset parameter value (DeadTime Max.Delay)
- The waiting time for the “SYNC Release” signal is too long
- After the final trip command
- In case of a manual close command or a manual open command (if the status variable (CB OPEN single-pole) gets TRUE without (AutoReclosing Start)).
- In case of a general block (the device is blocked)

In a dynamic blocked state, the (Blocked) status signal is TRUE (similar to “Not ready” conditions).

There are several conditions that must be satisfied before the automatic reclosing function enters “Not Ready” state. This state becomes valid if any of the conditions of the blocking get TRUE outside the running time of the reclosing cycles.

- Reclosing is disabled by the parameter if it is selected to “Off”
- The circuit breaker is not ready for operation
- After a manual close command
- If the parameter (CB State Monitoring) is set to TRUE and the circuit breaker is in Open state, i.e., the value of the (CB OPEN position) status variable gets TRUE.
- The starting signal for automatic reclosing is selected by parameter (Reclosing started by) to be “CB open” and the circuit breaker is in Open state.
- In case of a general block (the device is blocked)

In the Table 3-96 are presented the setting parameters of the autorecloser function.

Table 3-96 Setting parameters of the autorecloser function

Parameter	Setting value, range and step	Description
Operation	On Off	Enabling / Disabling of the autorecloser function. Default setting is Enabled.
EarthFault RecCycle	Disabled 1. Enabled 1.2. Enabled	Selection of the number of reclosing sequences for earth faults. default setting is 1. reclosing sequence enabled.

	1.2.3. Enabled 1.2.3.4. Enabled	
PhaseFault RecCycle	Disabled 1. Enabled 1.2. Enabled 1.2.3. Enabled 1.2.3.4. Enabled	Selection of the number of reclosing sequences for line-to-line faults. default setting is 1. reclosing sequence enabled.
Reclosing started by	Trip reset CB Open	Selection of triggering the dead time counter (trip signal reset or circuit breaker open position). Default setting is Trip reset.
CB State monitoring	Enabled Disabled	Enable CB state monitoring for “Not Ready” state. Default setting is Disabled.
Reclaim time	100…100000 ms by step of 10 ms	Reclaim time setting. Default setting is 2000 ms.
Close Command time	10…10000 ms by step of 10 ms	Pulse duration setting for the CLOSE command from the IED to circuit breaker. Default setting is 100 ms.
Dynamic Blocking time	0...100000 ms by step of 10 ms	Setting of the dynamic blocking time. Default setting is 1500 ms.
Block after Man.Close	0...100000 ms by step of 10 ms	Setting of the blocking time after manual close command. Default setting is 1000 ms.
Action time	0...20000 ms by step of 10 ms	Setting of the action time. Default setting is 1000 ms.
Start-signal Max.Tim	0...10000 ms by step of 10 ms	Time limitation of the starting signal. Default setting is 1000 ms.
DeadTime Max.Delay	0...1000000 ms by step of 10 ms	Delaying the start of the dead-time counter. Default setting is 3000 ms.
CB Supervision Time	10...100000 ms by step of 10 ms	Waiting time for circuit breaker ready signal. Default setting is 1000 ms.
Sync-check Max.Tim	500...100000 ms by step of 10 ms	Waiting time for synchronous state signal. Default setting is 10000 ms.
Sync-switch Max.Tim	500...100000 ms by step of 10 ms	Waiting time for synchronous switching. Default setting is 10000 ms.
1.Dead Time Ph	0...100000 ms by step of 10 ms	Dead time setting for the first reclosing cycle for line-to-line fault. Default setting is 500 ms.
2.Dead Time Ph	10...100000 ms by step of 10 ms	Dead time setting for the second reclosing cycle for line-to-line fault. Default setting is 600 ms.
3.Dead Time Ph	10...100000 ms by step of 10 ms	Dead time setting for the third reclosing cycle for line-to-line fault. Default setting is 700 ms.
4.Dead Time Ph	10...100000 ms by step of 10 ms	Dead time setting for the fourth reclosing cycle for line-to-line fault. Default setting is 800 ms.
1.Dead Time Ef	0...100000 ms by step of 10 ms	Dead time setting for the first reclosing cycle for earth fault. Default setting is 1000 ms.
2.Dead Time Ef	10...100000 ms by step of 10 ms	Dead time setting for the second reclosing cycle for earth fault. Default setting is 2000 ms.
3.Dead Time Ef	10...100000 ms by step of 10 ms	Dead time setting for the third reclosing cycle for earth fault. Default setting is 3000 ms.
4.Dead Time Ef	10...100000 ms by step of 10 ms	Dead time setting for the fourth reclosing cycle for earth fault. Default setting is 4000 ms.
Accelerate 1. Trip	Enabled Disabled	Acceleration of the 1st reclosing cycle trip command. Default setting is Disabled.

Accelerate 2. Trip	Enabled Disabled	Acceleration of the 2nd reclosing cycle trip command. Default setting is Disabled.
Accelerate 3. Trip	Enabled Disabled	Acceleration of the 3rd reclosing cycle trip command. Default setting is Disabled.
Accelerate 4. Trip	Enabled Disabled	Acceleration of the 4th reclosing cycle trip command. Default setting is Disabled.
Accelerate final Trip	Enabled Disabled	Acceleration of the final trip command. Default setting is Disabled.

3.3.8 AUTORECLOSER (HIGH-VOLTAGE) (79)

The HV automatic reclosing function for high voltage networks can realize up to four shots of reclosing. The dead time can be set individually for each reclosing and separately for singlephase faults and for multi-phase faults.

The starting signal of the cycles can be generated by any combination of the protection functions or external signals of the binary inputs. The selection is made by graphic equation programming.

The automatic reclosing function is triggered if as a consequence of a fault a protection function generates a trip command to the circuit breaker and the protection function resets because the fault current drops to zero or the circuit breaker's auxiliary contact signals open state. According to the preset parameter values, either of these two conditions starts counting the dead time, at the end of which the HV automatic reclosing function generates a close command automatically. If the fault still exists or reappears, then within the "Reclaim time" (according to parameter setting REC79_Rec_TPar_), started at the close command, the protection functions picks up again and the subsequent cycle is started. If no pickup is detected within this time, then the HV automatic reclosing cycle resets and a new fault will start the procedure with the first cycle again.

There are some additional requirements to perform automatic reclosing:

- The HV automatic reclosing function can be blocked by the variable REC79_Blk_GrO_, for which the user has to compose a graphic logical equation.
- After a pickup of the protection function, a timer starts to measure the "Action time" (the duration of which depends on parameter setting REC79_Act_TPar_ (Action time)). The trip command must be generated within this time to start reclosing cycles, or else the HV automatic function enters dynamic blocked state.

- At the moment of generating the close command, the circuit breaker must be ready for operation, which is signaled via binary input REC79_CBRdy_GrO_ (CB Ready). The preset parameter value REC79_CBTO_TPar_ (CB Supervision time) decides how long the HV automatic reclosing function is allowed to wait when the function is in "In Progress" state. If the signal is not received during this time, then the HV automatic reclosing function terminates and after a "dynamic blocking time" (depending on the preset parameter value REC79_DynBlk_TPar_ (Dynamic Blocking time)) the function resets.

Depending on the preset parameter value, the HV automatic reclosing function can influence the operation of the protection functions as well. The binary outputs of the HV automatic reclosing function, including the "In progress" (Run) state, can be applied for this purpose in the graphic equation editor.

In case of a manual close command which is assigned to the logic variable REC79_ManCl_GrO_ (Manual Close) using graphic equation programming, a preset parameter value decides how long the HV automatic reclosing function should be disabled after the manual close command.

The HV automatic reclosing function can control up to four reclosing cycles. Depending on the preset parameter value REC79_CycEn_EPar_ (Reclosing cycles), there are different modes of operation:

Disabled No automatic reclosing is selected,

1. Enabled Only one automatic reclosing cycle is selected,

1.2. Enabled Two automatic reclosing cycles are activated,

1.2.3. Enabled Three automatic reclosing cycles are activated,

1.2.3.4. Enabled All automatic reclosing cycles are activated.

The function can be switched Off /On using the parameter REC79_Op_EPar_ (Operation).

The user can also block the HV automatic reclosing function applying the graphic equation editor. The binary status variable to be programmed is REC79_Blk_GrO_ (Block).

If the device is generally blocked, then the HV automatic reclosing function is also blocked.

Depending on the present parameter value REC79_St_EPar_ (Reclosing started by), the HV automatic reclosing function can be started either by resetting of the TRIP command (setting: Trip reset) or by the binary signal indicating the open state of the circuit breaker (setting: CB open).

If the reset state of the TRIP command is selected to start the HV automatic reclosing function, then the conditions are defined by the user applying the graphic equation editor. The binary status variable to be programmed is: REC79_Tr_GrO_ (AutoReclosing Start).

If the open state of the circuit breaker is selected to start the HV automatic reclosing function, then additionally to programming the REC79_Tr_GrO_ (AutoReclosing Start) signal, the conditions for detecting the open state of the CB are defined by the user applying the graphic equation editor. The binary status variable to be programmed is: REC79_CBOpen_GrO_ (CB OPEN single-pole). This signal is TRUE if at least one of the poles is open.

The HV automatic reclosing function gets the trip commands of the protection functions intended to trigger the reclosing function. The conditions for detecting the triggered state of the protection functions are defined by the user applying the graphic equation editor. The binary status variable to be programmed is: REC79_Tr_GrO_ (AutoReclosing Start). This signal starts a dedicated timer, the elapsed time of which is compared to the preset parameter value REC79_MaxSt_TPar_ (Start-signal Max.Tim).

The HV automatic reclosing function enters the dynamic blocking state:

- If the parameter selected for REC79_St_EPar_ (Reclosing started by) is “Trip reset”, and the trip impulse is too long

- If the parameter selected for REC79_St_EPar_ (Reclosing started by) is “CB open”, then during the runtime of the timer CB open signal is not received.

In the base case, the dead time counter of any reclosing cycle is started by the starting signal but starting can be delayed. The delay is activated if the value of the REC79_DtDel_GrO_ (Dead Time St.Delay) status signal is TRUE. The conditions are defined by the user applying the graphic equation editor. This delay is limited by the timer parameter REC79_DtDel_TPar_ (DeadTime Max.Delay).

For all four reclosing cycles, separate dead times can be defined for single-phase trip commands (as a consequence of single-phase faults) and for three-phase trip commands (as a consequence of multi-phase faults).

The timer parameters for single-phase trip commands are:

- REC79_1PhDT1_TPar_ 1. Dead Time 1Ph
- REC79_1PhDT2_TPar_ 2. Dead Time 1Ph
- REC79_1PhDT3_TPar_ 3. Dead Time 1Ph
- REC79_1PhDT4_TPar_ 4. Dead Time 1Ph

The timer parameters for three-phase trip commands are:

- REC79_3PhDT1_TPar_ 1. Dead Time 3Ph
- REC79_3PhDT2_TPar_ 2. Dead Time 3Ph
- REC79_3PhDT3_TPar_ 3. Dead Time 3Ph
- REC79_3PhDT4_TPar_ 4. Dead Time 3Ph

The different dead time settings can be justified as follows: in case of a single-phase fault, only the circuit breakers of the faulty phase open. In this case, due to the capacitive coupling of the healthy phases, the extinction of the secondary electric arc at the fault location can be delayed. Consequently, a longer dead time is needed for the fault current to die out than in the case of a three-phase open state, when no coupled voltage can sustain the fault current.

From other point of view, in case of a transmission line connecting two power systems, only a shorter dead time is allowed for the three-phase open state because, due to the possible power unbalance between the interconnected systems, a large angle difference can be reached if the dead time is too long. If only a single phase is open, then the two connected healthy phases and the ground can sustain the synchronous operation of both power systems.

3.3.8.1 SPECIAL DEAD TIME FOR THE FIRST CYCLE

This special dead time can be necessary for the following reason:

Assume a line between substations A and B, and a protection system without tele-protection. In the event of a three-phase fault near substation B, the protection at A generates a trip command according to the second zone's time setting only, and starts measuring the dead time with considerable delay as compared to the protection at B, which generates a trip command immediately due to the close-in fault.

If the three-phase dead time is too short, the HV automatic reclosing at B may attempt to close the circuit breaker during the running time of the second zone trip at A, which means that the fault is not cleared yet. Consequently, a prolonged dead time is needed if the fault was detected in the first zone.

The preset timer parameter value is REC79_3PhDT1_TPar_2 (1. special DT 3Ph). The special dead time is valid if the REC79_1cyc3PhFlt_GrO_ (3PhFault for Spec.DT1) status signal is TRUE. The conditions are defined by the user applying the graphic equation editor.

3.3.8.2 Reduced dead time

Dead time reduction may be applicable under the following circumstances:

If healthy voltage is measured in all three phases during the dead time, this means that no fault exists on the line. In this case, the expiry of the normal dead time need not be waited for, a reclosing attempt can be initiated immediately.

The dead time is terminated immediately if the REC79_RDT_GrO_ (Reduced DeadTime) status signal is TRUE. The conditions are defined by the user applying the graphic equation editor.

3.3.8.3 Three-phase trip

The HV automatic reclosing function is prepared to get the general trip command as programmed to the binary input status variable REC79_Tr_GrO_ (AutoReclosing Start) and the three-phase trip signal REC79_3PhTr_GrO_ (3Ph Trip). If no three-phase trip signal is received, then it performs automatic reclosing cycles with the dead times according to the setting for single phase cycles. The three-phase cycles are controlled by the status variable REC79_3PhTr_GrO_ (3Ph Trip). If this is TRUE, three-phase cycles are performed. The conditions are defined by the user applying the graphic equation editor.

If, during the cycles, the three-phase dead time is applied once, then all subsequent cycles will consider the three-phase dead time settings, too.

Three-phase reclosing can be disabled by the preset parameter value REC79_3PhRecBlk_BPar_ (Disable 3Ph Rec.). If the value of this parameter is TRUE, then if a three-phase trip command is received, the HV automatic reclosing function enters “Dynamic blocked” state.

3.3.8.4 Checking the ready state of the circuit breaker

At the end of the dead time, reclosing is possible only if the circuit breaker can perform the command. The binary variable REC79_CBRdy_GrO_ (CB Ready) indicates this state. The conditions are defined by the user applying the graphic equation editor. If the circuit breaker is not ready, the controller functions wait for a pre-programmed time for this state. The waiting time is defined by the user as parameter value REC79_CBTO_TPar_ (CB Supervision time). If this condition is not fulfilled during the waiting time, then the HV automatic reclosing function enters “Dynamic blocked” state.

3.3.8.5 Reclosing with synchronous state supervision

Reclosing is possible only if the conditions required by the “synchro-check” function are fulfilled. This state is signaled by the binary variable REC79_SynRel_GrO_ (SYNC Release). The conditions are defined by the user applying the graphic equation editor. The HV automatic reclosing function waits for a pre-programmed time for this signal. This time is defined by the user as parameter value REC79_SYN1_TPar_ (SynCheck Max Time). If the “SYNC Release” signal is not received during the running time of this timer, then the “synchronous switch” operation is started and the signal REC79_ClReq_GrI_ (CloseRequ.SynSwitch) is generated.

3.3.8.6 Reclosing with synchronous switching

If the conditions of the synchronous state are not fulfilled, another timer starts. This waiting time is defined by the user as parameter value REC79_SYN2_TPar_ (SynSW Max Time).

This separate function controls the generation of the close command in case of relatively rotating voltage vectors on both sides of the circuit breaker to make contact at the synchronous state of the rotating vectors. For this calculation, the closing time of the circuit breaker must be defined.

This mode of operation is indicated by the output variable REC79_ClReq_GrI_ (CloseRequ. SynSwitch).

If no switching is possible during the running time of this timer, then the HV automatic reclosing function enters “Dynamic blocked” state and resets.

3.3.8.7 Impulse duration of the CLOSE command

The "Close" impulse is generated as one of the output status signals of the HV automatic reclosing function REC79_Close_GrI_ (Close command). This signal is common to all three phases. The impulse duration is defined by the user setting the timer parameter REC79_Close_TPar_ (Close command time).

3.3.8.8 Behavior after reclosing

When the close command is generated, a timer is started to measure the "Reclaim time". The duration is defined by the parameter value REC79_Rec_TPar_ (Reclaim time), but it is prolonged up to the reset of the close command (if the close command duration is longer then the reclaim time set). If the fault is detected again during this time, then the sequence of the HV automatic reclosing cycles continues. If no fault is detected, then at the expiry of the reclaim time the reclosing is evaluated as successful and the function resets. If fault is detected after the expiry of this timer, then the cycles restart with the first reclosing cycle.

If the user programmed the status variable REC79_St_GrO_ (Protection Start) and it gets TRUE during the Reclaim time, then the HV automatic reclosing function continues even if the trip command is received after the expiry of the Reclaim time.

3.3.8.9 Behavior after manual close command

This state of manual close command is signaled by the binary variable REC79_ManCl_GrO_ (Manual Close). The conditions are defined by the user applying the graphic equation editor.

After a manual close command, the HV automatic reclosing function enters "Not Ready" state for the time period defined by parameter REC79_MC_TPar_ (Block after Man.Close).

If the manual close command is received during the running time of any of the cycles, then the HV automatic reclosing function enters "Dynamic blocked" state and resets.

3.3.8.10 Behavior in case of evolving fault

In case of evolving faults (when a single-phase fault detected changes to multi-phase fault), the behavior of the automatic reclosing function is controlled by the preset parameter value REC79_EvoFlt_EPar_ (Evolving fault).

The options are:

- “Block Reclosing”
- “Start 3Ph Rec.”

If “Block Reclosing” is selected, the HV automatic reclosing function enters dynamic blocked state and the subsequent reclosing command is not generated.

If “Start 3Ph Rec.” is selected, the HV automatic reclosing function goes on performing the subsequent cycle according to the three-phase parameters.

3.3.8.11 The final trip

If the fault still exists at the end of the last cycle, the HV automatic reclosing function trips and generates the signal for final trip: REC79_FinTr_GrI_ (Final Trip). The same final trip signal is generated in case of an evolving fault if “Block Reclosing” is selected. After final trip, the HV automatic reclosing function enters “Dynamic blocked” state.

A final trip command is also generated if, after a multi-phase fault, a fault is detected again during the dead time.

3.3.8.12 Action time

The user can compose a binary status variable to indicate the start of the protection functions, the operation of which is related to the HV automatic reclosing function. This status variable is REC79_St_GrO_ (Protection Start). This signal starts the “Action time”, the duration of which is defined by the preset parameter value REC79_Act_TPar_ (Action time). During the running time, the HV automatic reclosing function waits for the trip command. If no trip command is received, then the HV automatic reclosing function enters “Dynamic blocked” state.

3.3.8.13 Accelerating trip commands

Depending on binary parameter settings, the automatic reclosing function block can accelerate trip commands of the individual reclosing cycles. This means that the output “TrAcc” of the function block gets active for the first starting state of the protection function or at the end of the dead time of the running cycle, if the dedicated parameter enables acceleration. This signal needs user-programmed graphic equations to generate the accelerated trip command.

3.3.8.14 Dynamic blocking conditions

There are several conditions to result dynamic blocked state of the HV automatic reclosing function. This state becomes valid if any of the conditions of the dynamic blocking get TRUE during the running time of any of the reclosing cycles.

At the time of the change to start the dynamic blocked state a timer is started, the running duration of which is defined by the time parameter REC79_DynBlk_TPar_ (Dynamic Blocking time). During its running time the function is blocked, no reclosing command is generated.

The conditions to start the dynamic blocked state are:

- There is no trip command during the “Action time”
- The duration of the starting impulse for the HV automatic reclosing function is too long.
- If no “CB ready” signal is received at the intended time of reclosing command.
- The dead time is prolonged further then the preset parameter value REC79_DtDel_TPar_ (DeadTime Max.Delay)
- The waiting time for the “SYNC Release” signal is too long
- After the final trip command
- AR is started during the blocking time after a manual close command
- While CB State Monitoring is on, a manual open command (the status variable REC79_CBOpen_GrO_ (CB OPEN single-pole) gets TRUE without REC79_Tr_GrO_ (AutoReclosing Start)).
- In case of a three-phase trip command if the preset parameter REC79_3PhRecBlk_BPar_ (Disable 3Ph Rec.) is set to TRUE.
- In case of evolving faults, if the parameter setting for REC79_EvoFlt_EPar_ (Evolving fault) is “Block Reclosing”
- AR is started during a general block

In a dynamic blocked state, the REC79_Blocked_GrI_ (Blocked) status signal is TRUE (similar to “Not ready” conditions).

3.3.8.15 “Not Ready” conditions

There are several conditions to result “Not Ready” state of the HV automatic reclosing function. This state becomes valid if any of the conditions of the blocking get TRUE outside the running time of the reclosing cycles.

- Reclosing is disabled by the parameter REC79_Op_EPar_ (Operation) if it is selected to “Off”.
- No reclosing cycles are selected by the parameter REC79_CycEn_EPar_ (Reclosing cycles) if it is set to “Disabled”
- The circuit breaker is not ready for operation: the result of the graphic programming of the binary variable REC79_CBRdy_GrO_ (CB Ready) is FALSE.
- After a manual close command
- If the parameter REC79_CBState_BPar_ (CB State Monitoring) is set to TRUE and the circuit breaker is in Open state, i.e., the value of the REC79_CBOpen_GrO_ (CB OPEN single-pole) status variable gets TRUE.
- The starting signal for automatic reclosing is selected by parameter REC79_St_EPar_ (Reclosing started by) to be “CB open” and the circuit breaker is in Open state.
- In case of a general block

In a “Not ready” state, the REC79_Blocked_GrI_ (Blocked) status signal is TRUE (similar to “Dynamic blocking” conditions).

Table 3-97 Setting parameters of the autorecloser function

Parameter	Setting value, range and step	Description
Operation	On Off	Enabling / Disabling of the autorecloser function. Default setting is Enabled.
EarthFault RecCycle	Disabled 1. Enabled 1.2. Enabled 1.2.3. Enabled 1.2.3.4. Enabled	Selection of the number of reclosing sequences for earth faults. default setting is 1. reclosing sequence enabled.
PhaseFault RecCycle	Disabled 1. Enabled 1.2. Enabled 1.2.3. Enabled 1.2.3.4. Enabled	Selection of the number of reclosing sequences for line-to-line faults. default setting is 1. reclosing sequence enabled.
Reclosing started by	Trip reset CB Open	Selection of triggering the dead time counter (trip signal reset or circuit breaker open position). Default setting is Trip reset.
Evolving fault	Block Reclosing, Start 3Ph Rec.	Selection of behavior in case of evolving fault (block reclosing or perform three-phase automatic reclosing cycle. Default setting is Block reclosing.
CB State monitoring	Enabled Disabled	Enable CB state monitoring for “Not Ready” state. Default setting is Disabled.
Reclaim time	100…100000 ms by step of 10 ms	Reclaim time setting. Default setting is 2000 ms.
Close Command time	10…10000 ms by step of 10 ms	Pulse duration setting for the CLOSE command from the IED to circuit breaker. Default setting is 100 ms.
Dynamic Blocking time	0...100000 ms by step of 10 ms	Setting of the dynamic blocking time. Default setting is 1500 ms.
Block after Man.Close	0...100000 ms by step of 10 ms	Setting of the blocking time after manual close command. Default setting is 1000 ms.
Action time	0...20000 ms by step of 10 ms	Setting of the action time. Default setting is 1000 ms.
Start-signal Max.Tim	0...10000 ms by step of 10 ms	Time limitation of the starting signal. Default setting is 1000 ms.
DeadTime Max.Delay	0...1000000 ms by step of 10 ms	Delaying the start of the dead-time counter. Default setting is 3000 ms.
CB Supervision Time	10...100000 ms by step of 10 ms	Waiting time for circuit breaker ready signal. Default setting is 1000 ms.
Sync-check Max.Tim	500...100000 ms by step of 10 ms	Waiting time for synchronous state signal. Default setting is 10000 ms.
Sync-switch Max.Tim	500...100000 ms by step of 10 ms	Waiting time for synchronous switching. Default setting is 10000 ms.
1.Dead Time 3Ph	0...100000 ms by step of 10 ms	Dead time setting for the first reclosing cycle for multi-phase fault. Default setting is 500 ms.
2.Dead Time 3Ph	10...100000 ms by step of 10 ms	Dead time setting for the second reclosing cycle for multi-phase fault. Default setting is 600 ms.
3.Dead Time 3Ph	10...100000 ms by step of 10 ms	Dead time setting for the third reclosing cycle for multi-phase fault. Default setting is 700 ms.

4.Dead Time 3Ph	10...100000 ms by step of 10 ms	Dead time setting for the fourth reclosing cycle for multi-phase fault. Default setting is 800 ms.
1.Dead Time 1PH	0...100000 ms by step of 10 ms	Dead time setting for the first reclosing cycle for single-phase fault. Default setting is 1000 ms.
2.Dead Time 1PH	10...100000 ms by step of 10 ms	Dead time setting for the second reclosing cycle for single-phase fault. Default setting is 2000 ms.
3.Dead Time 1PH	10...100000 ms by step of 10 ms	Dead time setting for the third reclosing cycle for single-phase fault. Default setting is 3000 ms.
4.Dead Time 1PH	10...100000 ms by step of 10 ms	Dead time setting for the fourth reclosing cycle for single-phase fault. Default setting is 4000 ms.
Accelerate 1. Trip	Enabled Disabled	Acceleration of the 1st reclosing cycle trip command. Default setting is Disabled.
Accelerate 2. Trip	Enabled Disabled	Acceleration of the 2nd reclosing cycle trip command. Default setting is Disabled.
Accelerate 3. Trip	Enabled Disabled	Acceleration of the 3rd reclosing cycle trip command. Default setting is Disabled.
Accelerate 4. Trip	Enabled Disabled	Acceleration of the 4th reclosing cycle trip command. Default setting is Disabled.
Accelerate final Trip	Enabled Disabled	Acceleration of the final trip command. Default setting is Disabled.

3.3.9 Switch on to fault logic

For the switch onto fault functionality the IED can be configured to make accelerated trip from the closing of the breaker if any configured protection stages pick up in a given reclaim time.

3.3.10 Voltage sag and swell (Voltage variation)

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.

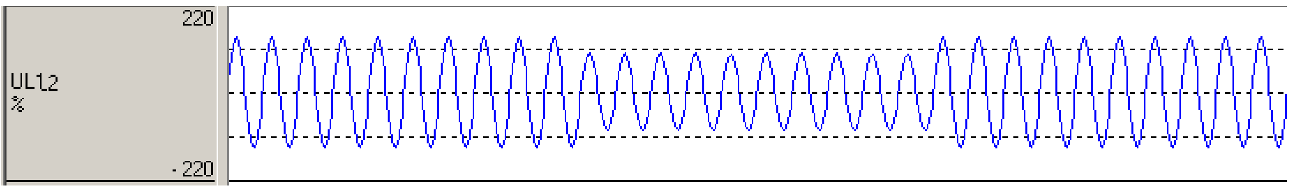


Figure 3-47 Voltage sag

- **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.

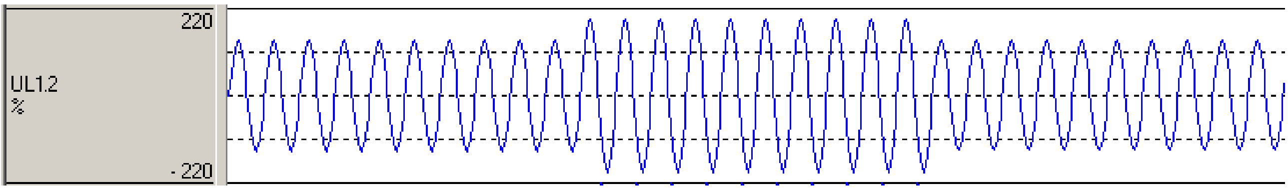


Figure 3-48 Voltage swell

- **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.

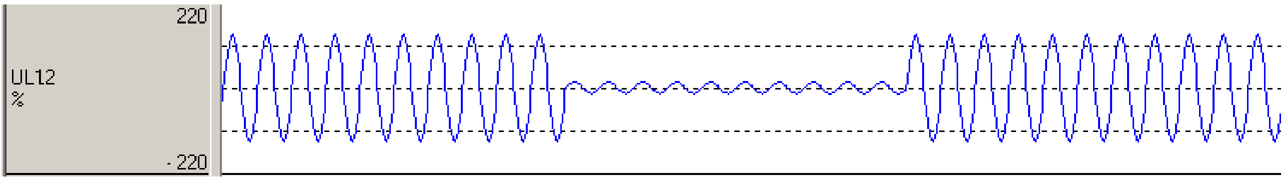


Figure 3-49 Voltage interruption

Sag and swell detection

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

NOTE: 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 3-50 Sag and swell monitoring window in the AQtivate 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 3-51 Example sag and swell events.

Table 3-98 Sag and swell function setting parameters

Parameter	Setting value, range and step	Description
Operation	Off On	Disabling or enabling the operation of the function, Default setting is Off
Swell limit	50…150% by step of 1 %	Voltage swell limit, above which swell is detected, Default setting is 110%
Sag limit	30…100% by step of 1 %	Voltage sag limit, below which sag is detected, Default setting is 90%
Interruption Limit	10…50% by step of 1 %	Voltage interruption limit, below which interruption is detected, Default setting is 20%
Minimum duration	30…60000 ms by step of 1 ms	Lower time limit, Default setting is 50 ms.
Maximum duration	100…60000 ms by step of 1 ms	Upper time limit, Default setting is 10000 ms.

3.3.11 DISTURBANCE RECORDER

The disturbance recorder function can record analog signals and binary status signals. These signals are user configurable. The disturbance recorder function has a binary input signal, which serves the purpose of starting the function. The conditions of starting are defined by the user. The disturbance recorder function keeps on recording during the active state of this signal but the total recording time is limited by the timer parameter setting. The pre-fault time, max-fault time and post-fault time can be defined by parameters.

If the conditions defined by the user - using the graphic equation editor – are satisfied, then the disturbance recorder starts recording the sampled values of configured analog signals and binary signals. The analog signals can be sampled values (voltages and currents) received via input modules or they can be calculated analog values (such as negative sequence components, etc.) The number of the configured binary signals for recording is limited to 64. During the operation of the function, the pre-fault signals are preserved for the time duration as defined by the parameter “PreFault”. The fault duration is limited by the parameter “MaxFault” but if the triggering signal resets earlier, this section is shorter. The post-fault signals are preserved for the time duration as defined by the parameter “PostFault ”. During or after the running of the recording, the triggering condition must be reset for a new recording procedure to start.

The records are stored in standard COMTRADE format.

- The configuration is defined by the file .cfg,
- The data are stored in the file .dat,
- Plain text comments can be written in the file .inf.

The procedure for downloading the records includes a downloading of a single compressed .zip-file. Downloading can be initiated from a web browser tool or from the software tools. This procedure assures that the three component files (.cfg, .dat and .inf) are stored in the same location. The evaluation can be performed using any COMTRADE evaluator software, e.g. Arcteq’s AQview software. Consult your nearest Arcteq representative for availability.

The symbol of the function block in the AQtivate 300 software

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.

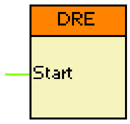


Figure 3-56: The function block of the disturbance recorder function

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

Table 3-99 The binary input signal of the disturbance recorder 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 3-100Setting parameters of the disturbance recorder function

Parameter	**Setting value, range and step**	**Description**
Operation	On, Off	Function enabling / disabling. Default setting is On
PreFault	50...500 ms by step of 1 ms	Pre triggering time included in the recording. Default setting is 200 ms.
PostFault	50...1000 ms by step of 1 ms	Post fault time included in the recording. Default setting is 200 ms.
MaxFault	200...10000 ms by step of 1 ms	Overall maximum time limit in the recording. Default setting is 1000 ms.

3.3.12 EVENT RECORDER

The events of the device and those of the protection functions are recorded with a time stamp of 1 ms time resolution. This information with indication of the generating function can be checked on the touch-screen of the device in the “Events” page, or using an Internet browser of a connected computer.

Table 3-101 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
Synchro check 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 loop L1-L2
Voltage L23	Voltage violation in loop L2-L3
Voltage L31	Voltage violation in loop L3-L1
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	

3.3.13 MEASURED VALUES

The measured values can be checked on the touch-screen of the device in the “On-line functions” page, or using an Internet browser of a connected computer. The displayed values are secondary voltages and currents, except the block “Line measurement”. This specific block displays the measured values in primary units, using the VT and CT primary value settings.

Table 3-102 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

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
Synchro check	
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 between phases L1 L2
Voltage L23	True RMS value of the voltage between phases L2 L3
Voltage L31	True RMS value of the voltage between phases L3 L1
Frequency	Frequency

3.3.14 STATUS MONITORING THE 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.

3.3.15 TRIP CIRCUIT SUPERVISION

All four fast acting trip contacts contain build-in trip circuit supervision function. The output voltage of the circuit is 5V(+-1V). The pickup resistance is 2.5kohm(+-1kohm).

Note: Pay attention to the polarity of the auxiliary voltage supply as outputs are polarity dependent.

3.3.16 LED ASSIGNMENT

On the front panel of the device there is “User LED”-s with the “Changeable LED description label”. Some LED-s are factory assigned, some are free to be defined by the user. Table below shows the LED assignment of the AQ-L3x7 factory configuration.

Table 3-103 The LED assignment

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

4 SYSTEM INTEGRATION

The AQ L3x7 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 L3x7 line protection IED communicates using IEC 61850, IEC 101, IEC 103, IEC 104, Modbus RTU, DNP3.0 and SPA protocols. For details of each protocol refer to respective interoperability lists.

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

5 CONNECTIONS

5.1 BLOCK DIAGRAM AQ-L357 MINIMUM OPTIONS

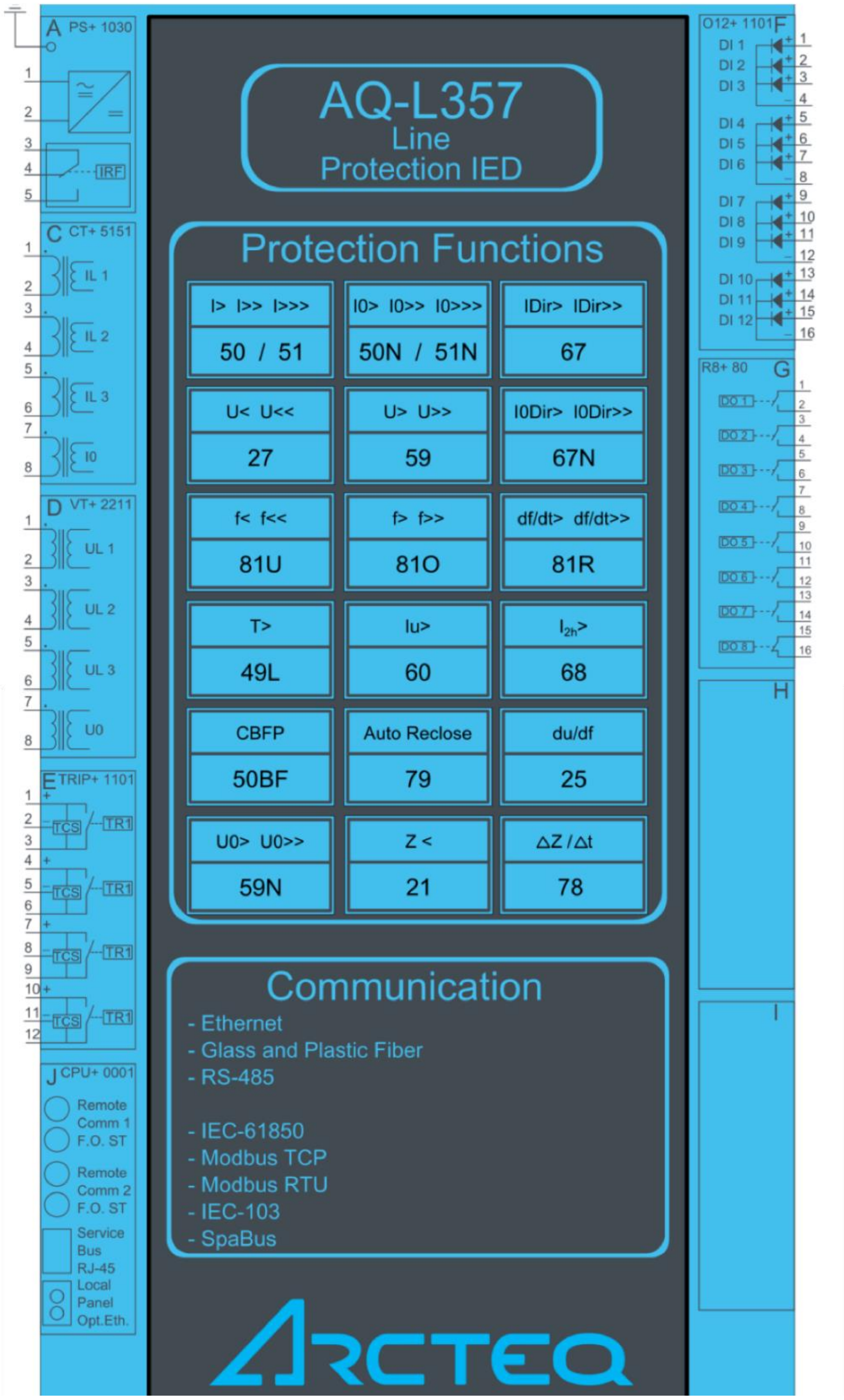


Figure 5-1 Block diagram of AQ-L357 with minimum options installed. In AQ-L397 (full rack version) the structure is the same except there are more option card slots available.

5.2 Block diagram AQ-L357 all options

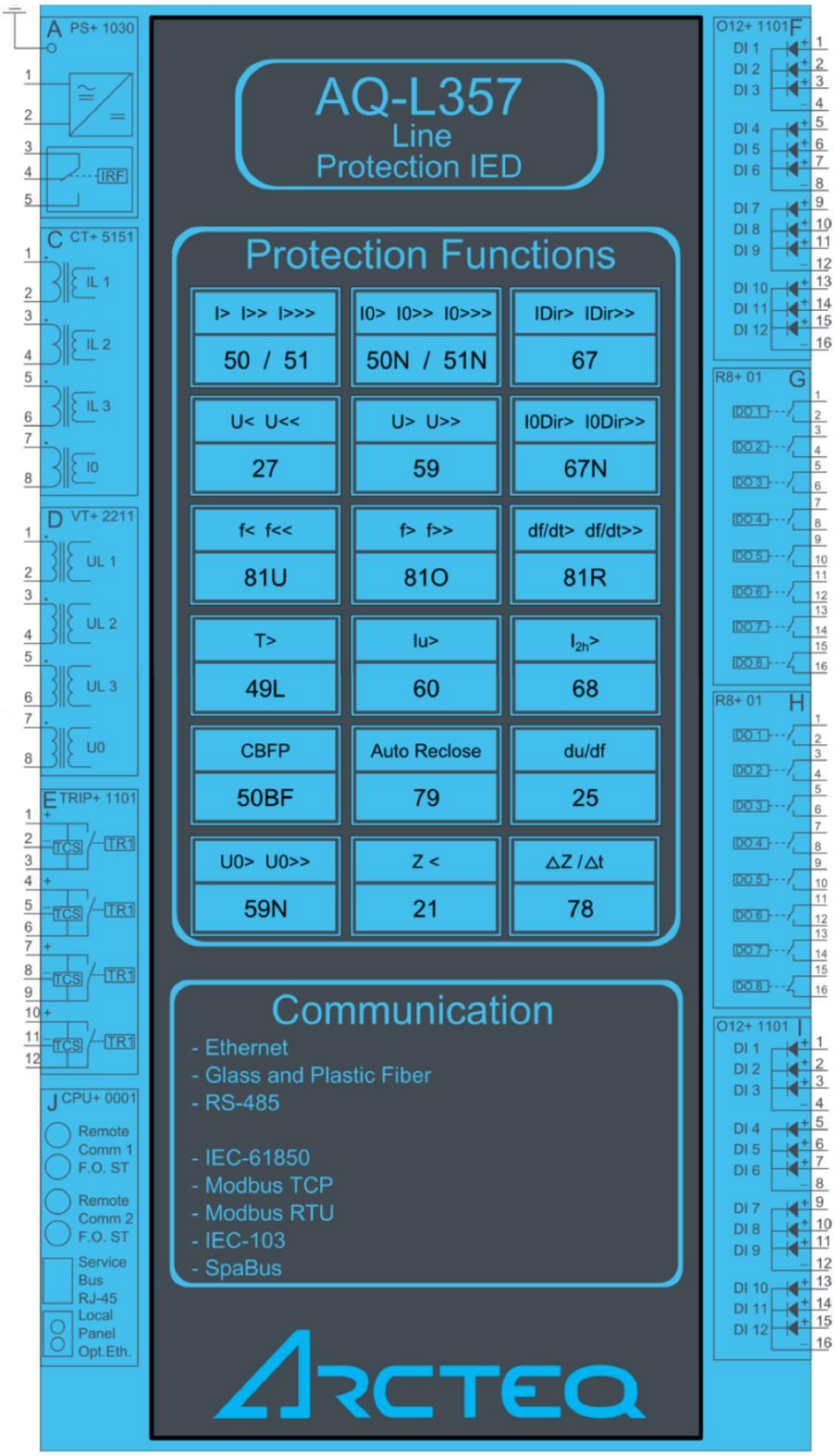


Figure 5-2 Block diagram of AQ-L357 with all options installed. In AQ-L397 (full rack version) the structure is the same except there are more option card slots available.

5.3 CONNECTION EXAMPLE

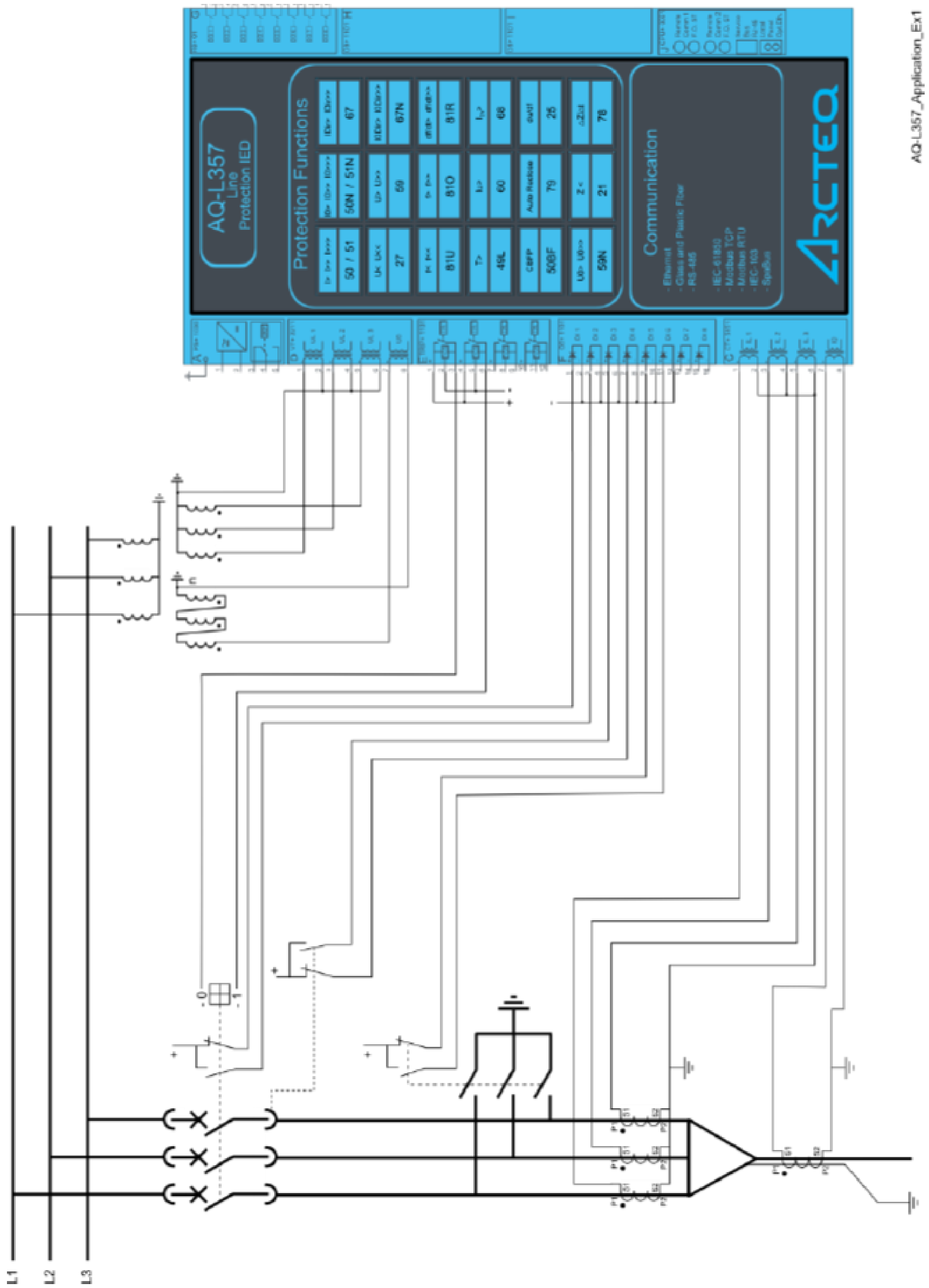


Figure 5-3 Connection example of AQ-L357 line protection IED. The AQ-L397 (full rack version) can be connected in the same way.

6 CONSTRUCTION AND INSTALLATION

The Arcteq AQ-L3x7 line 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-L357 and AQ-L397 is shown in the figures below. Visit https://configurator.arcteq.fi/ to see all of the available options.

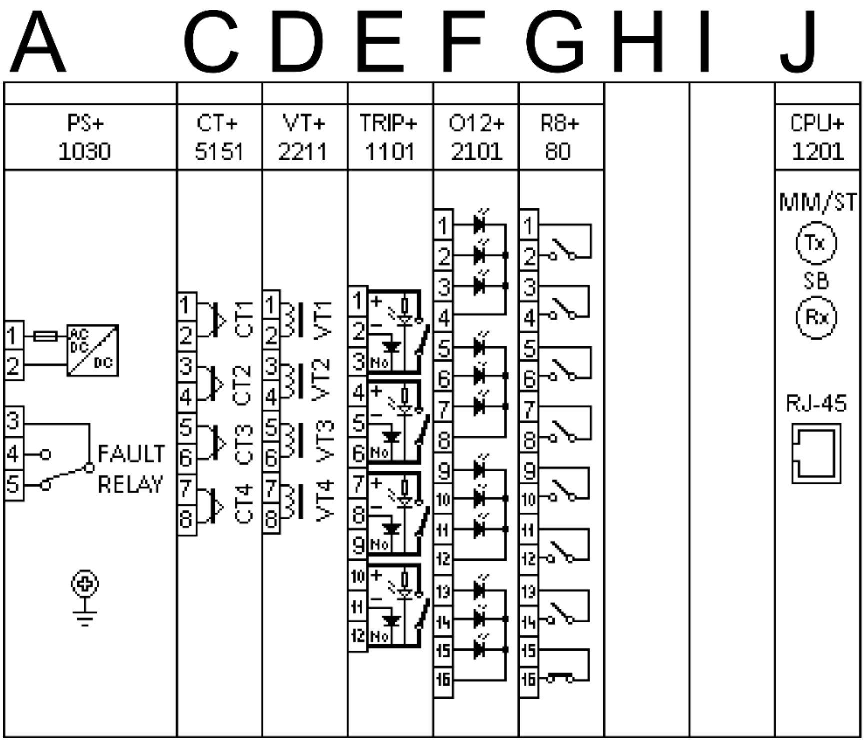


Figure 6-1. An example module arrangement configuration of the AQ-L357 IED.

Table 6-1. Hardware modules description.

Position	Module identifier	Explanation
A-B	PS+ 1030	Power supply unit, 85-265 VAC, 88-300 VDC
C	CT + 5151	Analog current input module
D	VT+ 2211	Analog voltage input module,
E	TRIP+ 1101	Trip relay output module, 4 tripping contacts
F	O12+ 2101	Binary input module, 12 inputs, threshold 110 VDC
G	R8+ 1101	Signaling output module, 8 output contacts (7NO+1NC)
H	Spare	-
I	Spare	-
J	CPU+ 1201	Processor and communication module

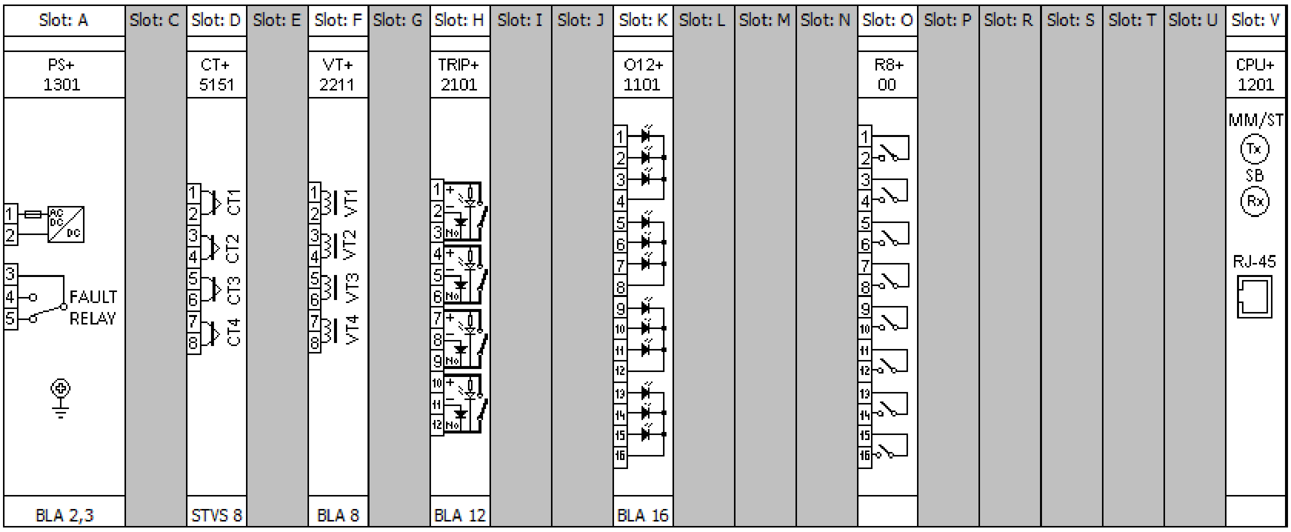


Figure 6-2. An example module arrangement configuration of the AQ-L397 IED.

Table 6-2. Hardware modules description.

Position	Module identifier	Explanation
A-B	PS+ 1030	Power supply unit, 85-265 VAC, 88-300 VDC
D	CT + 5151	Analog current input module
F	VT+ 2211	Analog voltage input module,
H	TRIP+ 2101	Trip relay output module, 4 tripping contacts
K	O12+ 1101	Binary input module, 8 inputs, threshold 110 VDC
O	R8+ 00	Signaling output module, 8 output contacts (7NO+1NC)
...U	Spare	Empty slots which can be used for additional DI or DO slots.
V	CPU+ 1201	Processor and communication module

6.1 CPU MODULE

The CPU module contains all the protection, control and communication functions of the AQ 3xx 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 IEC61850 software stack.

The built-in 5- port Ethernet switch allows AQ 3xx 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

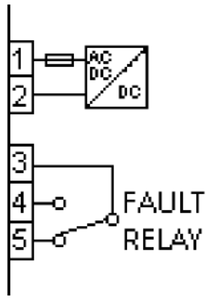
- RS422/RS485/RS232 interfaces
- Plastic or glass fiber interfaces to support legacy protocols
- Process-bus communication controller on COM+ card

6.2 POWER SUPPLY MODULE

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

Figure 6-1 Connector allocation of the 30W power supply unit

"A" "B"	PS+/1030
No.	Name
1	AuxPS+
2	AuxPS-
3	Fault Relay Common
4	Fault Relay NO
5	Fault Relay NC



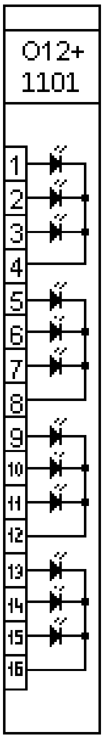
Main features of the power supply module

- 30W input
- Maximum 100ms 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 80V-300VDC 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

6.3 BINARY INPUT MODULE

The inputs are galvanic isolated and the module converts high-voltage signals to the voltage level 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.

"F"	O12+/1101
No.	Name
1	BIn_F01
2	BIn_F02
3	BIn_F03
4	Opto-(1-3)
5	BIn_F04
6	BIn_F05
7	BIn_F06
8	Opto-(4-6)
9	BIn_F07
10	BIn_F08
11	BIn_F09
12	Opto-(7-9)
13	BIn_F10
14	BIn_F11
15	BIn_F12
16	Opto-(10-12)



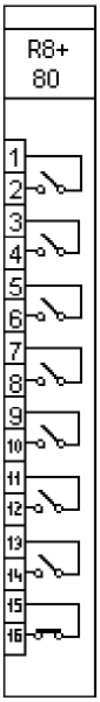
The binary input modules are

- Rated input voltage: 110/220Vdc
- Clamp voltage: falling 0.75Un, rising 0.78Un
- Digitally filtered per channel
- Current drain approx.: 2 mA per channel
- 12 inputs.
- IRIG-B timing and synchronization input

6.4 BINARY OUTPUT MODULES FOR SIGNALING

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

"H"	R8+/80
No.	Name
1	BOut_H01 Common
2	BOut_H01 NO
3	BOut_H02 Common
4	BOut_H02 NO
5	BOut_H03 Common
6	BOut_H03 NO
7	BOut_H04 Common
8	BOut_H04 NO
9	BOut_H05 Common
10	BOut_H05 NO
11	BOut_H06 Common
12	BOut_H06 NC
13	BOut_H07 Common
14	BOut_H07 NO
15	BOut_H08 Common
16	BOut_H08 NC

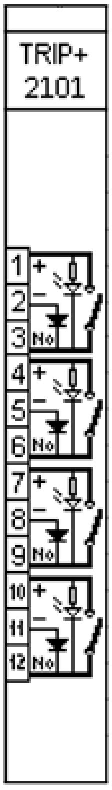


- Rated voltage: 250 V AC/DC
- Continuous carry: 8 A
- Breaking capacity, (L/R=40ms) at 220 V DC: 0,2 A
- 8 contacts, 7 NO and 1 NC

6.5 TRIPPING MODULE

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

"E"	TRIP+/2101
No.	Name
1	Trip1 +
2	Trip1 -
3	Trip1 NO
4	Trip 2 +
5	Trip 2 -
6	Trip 2 NO
7	Trip 3 +
8	Trip 3 -
9	Trip 3 NO
10	Trip 4 +
11	Trip 4 -
12	Trip 4 NO



The main characteristics of the trip module:

- 4 independent tripping circuits
- High-speed operation
- Rated voltage: 110V, 220V DC
- Continuous carry: 8 A
- Making capacity: 0.5s, 30 A
- Breaking capacity: (L/R=40ms) at 220 VDC: 4A
- Trip circuit supervision for each trip contact

6.6 VOLTAGE MEASUREMENT MODULE

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.

"D"	VT+/2211
No.	Name
1	U L1->
2	U L1<-
3	U L2->
4	U L2<-
5	U L3->
6	U L3<-
7	U Bus->
8	U Bus<-

The main characteristics of the voltage measurement module:

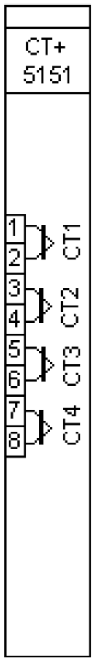
- Number of channels: 4
- Rated frequency: 50Hz, 60Hz
- Selectable rated voltage (Un): 100/√3, 100V, 200/√3, 200V by parameter
- Voltage measuring range: 0.05 Un – 1.2 Un
- Continuous voltage withstand: 250 V
- Power consumption of voltage input: ≤1 VA at 200V (with special CVT module the burden is < 50 mVA for VT4 channel)
- Relative accuracy: ±0,5 %
- Frequency measurement range: ±0,01 % at Ux 25 % of rated voltage
- Measurement of phase angle: 0.5º Ux 25 % of rated voltage

6.7 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.

Table 6-3: Connector allocation of the current measurement module I

"C"	CT+/515
No.	Name
1	I L1->
2	I L1<-
3	I L2->
4	I L2<-
5	I L3->
6	I L3<-
7	I4->
8	I4<-



- Number of channels: 4
- Rated frequency: 50Hz, 60Hz
- Electronic iron-core flux compensation
- Low consumption: ≤0,1 VA at rated current
- Current measuring range: 35 x In
- Selectable rated current 1A/5A 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

6.8 INSTALLATION AND DIMENSIONS

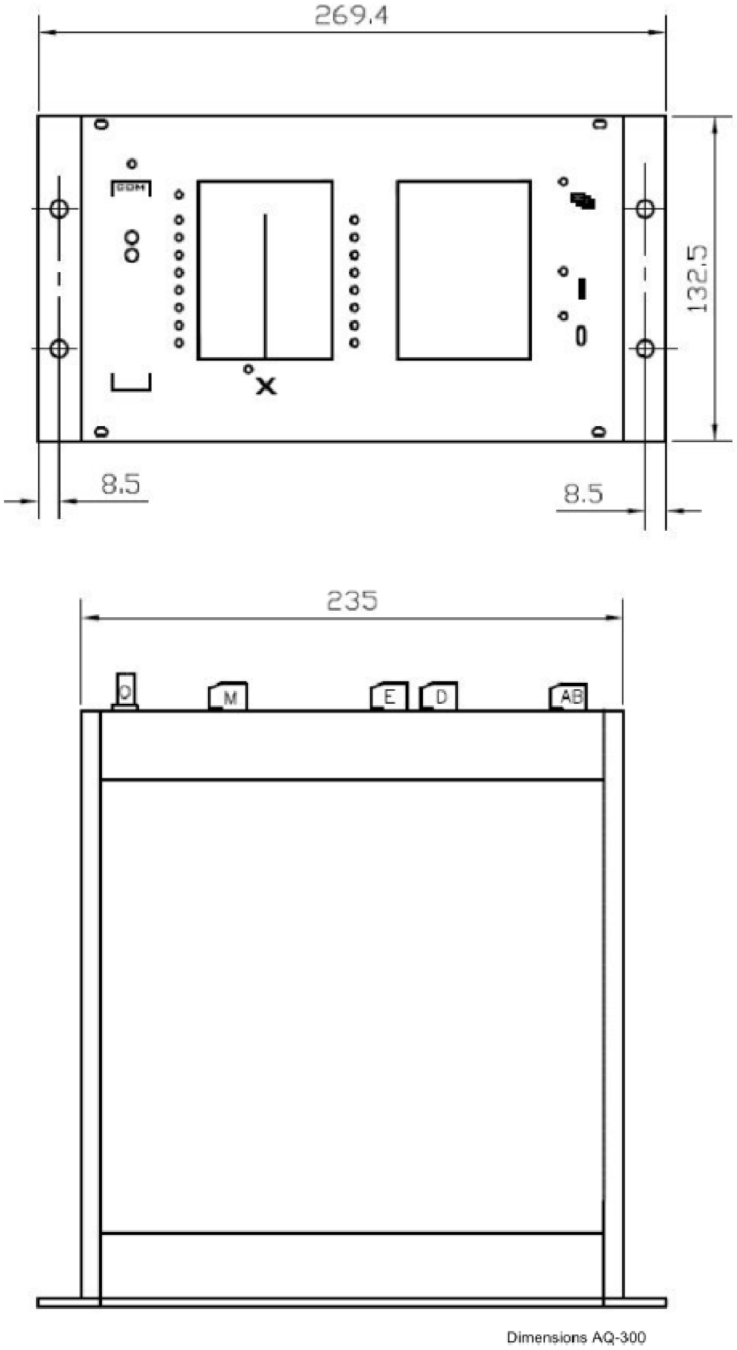


Figure 6-2: Dimensions of AQ-35x IED.

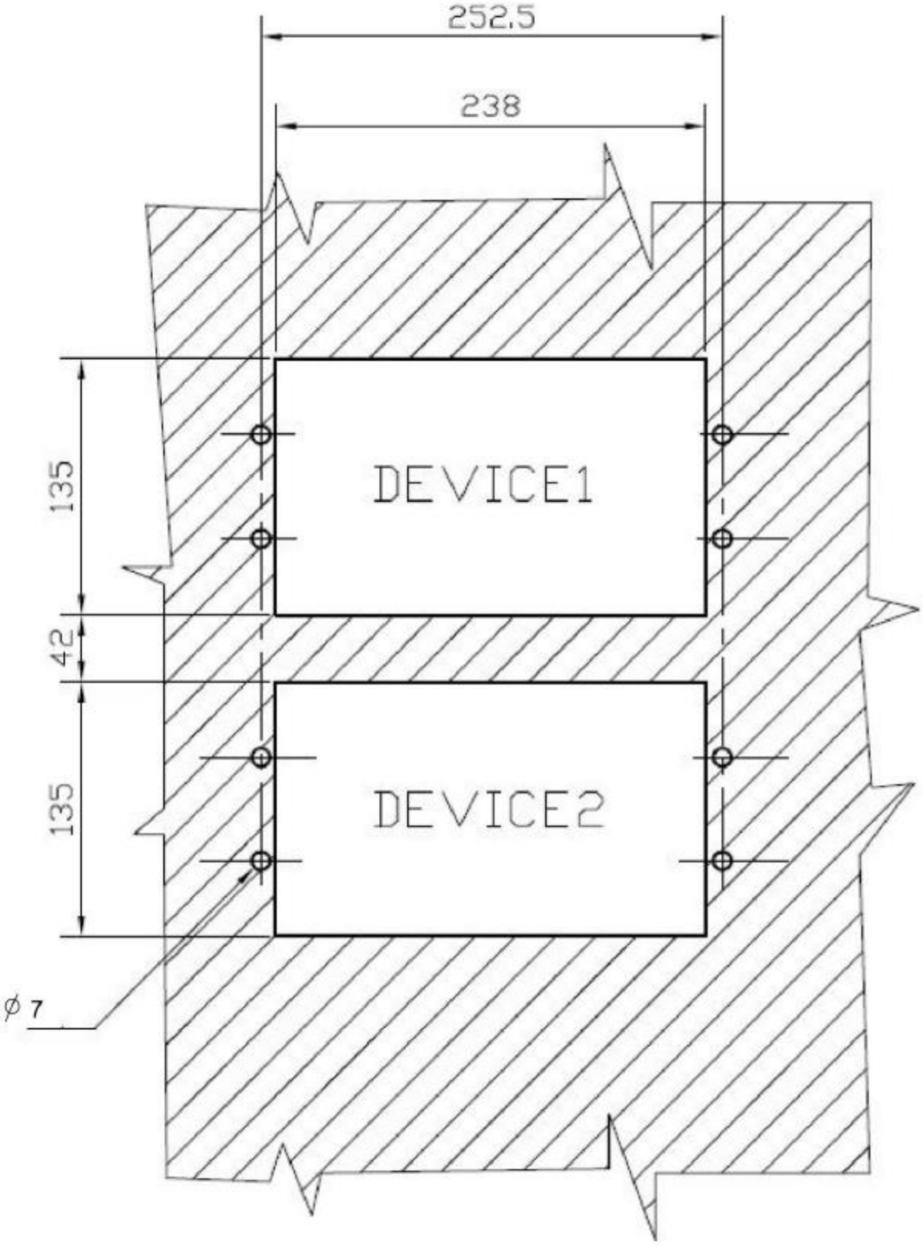


Figure 6-3: Panel cut-out and spacing of AQ-35x IED.

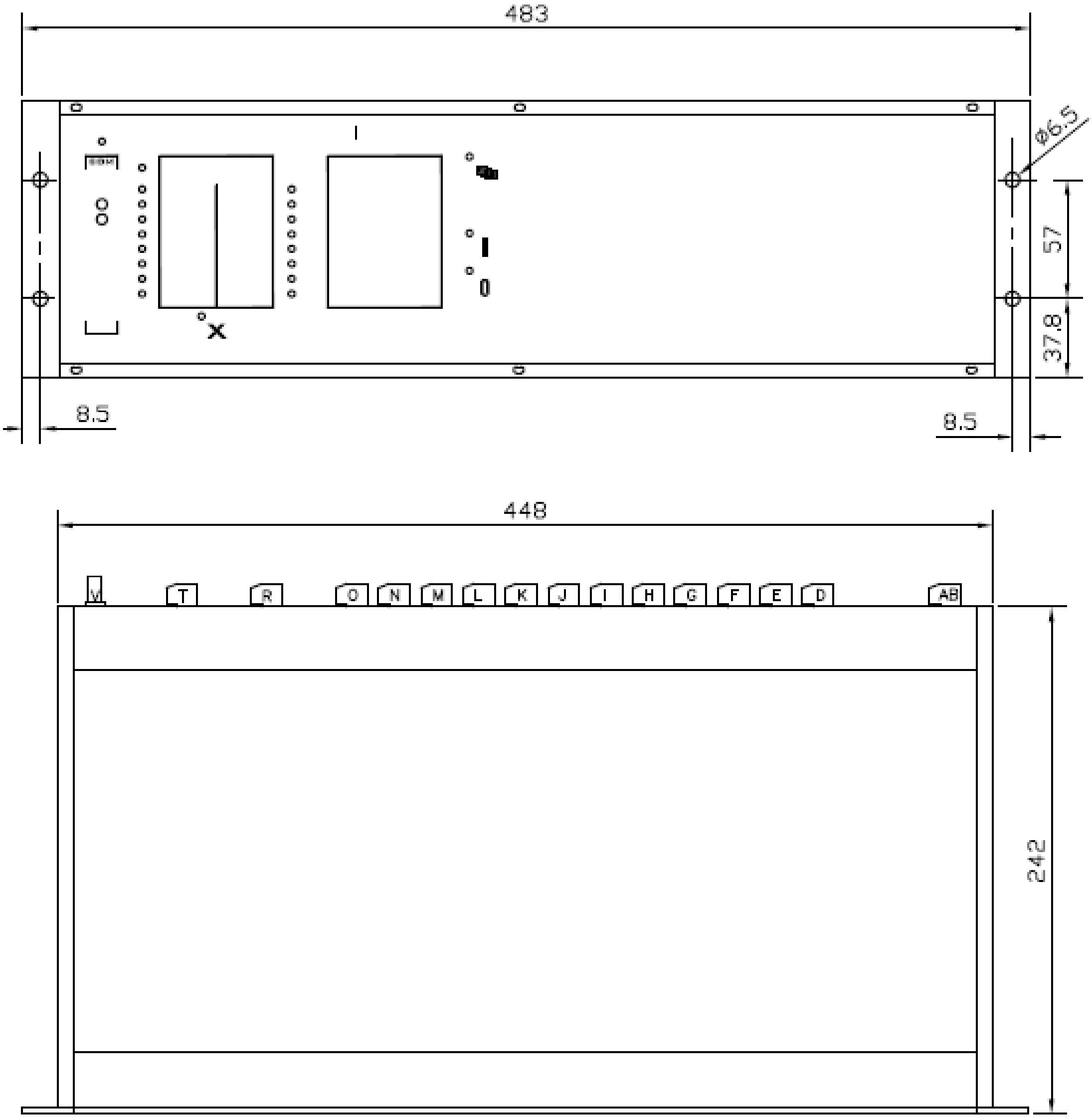


Figure 6-4: Dimensions of AQ-39x IED.

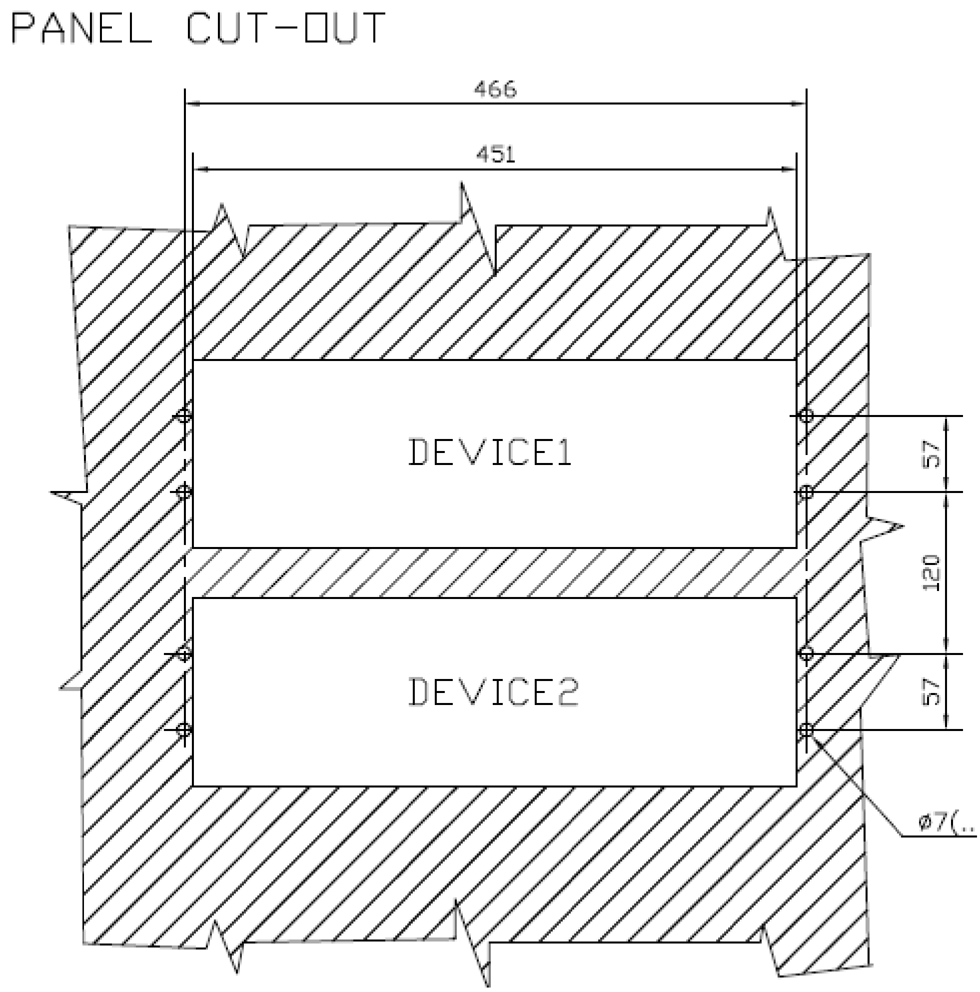


Figure 6-5: Panel cut-out and spacing of AQ-39x IED.

7 TECHNICAL DATA

7.1 PROTECTION FUNCTIONS

7.1.1 DISTANCE PROTECTION FUNCTIONS

Distance protection Z> (21)	
Number of zones	5
Current effective range	20…2000% of In
Voltage effective range	2…110% of Un
Operation inaccuracy (current & voltage)	±1%
Impedance effective range	0.1 – 200 Ohm (In =1A) 0.1 – 40 Ohm (In = 5A)
Impedance operation inaccuracy	±5%
Zone static range	48…52Hz 49.5…50.5Hz
Zone static inaccuracy	±5% (48..52Hz) ±2% (49.5…50.5Hz)
Zone angular inaccuracy	±3 °
Minimum operate time	<20ms
Typical operate time	25ms
Operate time inaccuracy	±3ms
Reset time	16-25ms
Reset ratio	1.1
Teleprotection (85)	
Operate time accuracy	±5% or ±15 ms, whichever is greater

7.1.2 OVERCURRENT PROTECTION FUNCTIONS

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 %

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 %

Three-phase time overcurrent protection I>, 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 time overcurrent protection I0>, 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

7.1.3 Directional overcurrent protection functions

Three-phase directional overcurrent protection function IDir>, IDir>> (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>, 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°

7.1.4 Voltage protection functions

Overvoltage protection function U>, U>> (59)	
Pick-up starting inaccuracy	< 0,5 %
Reset time	
U> → Un	50 ms
U> → 0	40 ms
Operation time inaccuracy	+ 15 ms

Undervoltage protection function U<, U<< (27)	
Pick-up starting inaccuracy	< 0,5 %
Reset time	
U> → Un	50 ms
U> → 0	40 ms
Operation time inaccuracy	+ 15 ms

Residual overvoltage protection function U0>, U0>> (59N)	
Pick-up starting inaccuracy	< 0,5 %
Reset time	
U> → Un	50 ms
U> → 0	40 ms
Operate time inaccuracy	+ 15 ms

7.1.5 Frequency protection functions

Overfrequency protection function f>, f>>, f>>>, f>>>> (81O)	
Operating range	40 - 70 Hz
Operating range inaccuracy	30mHz
Effective range inaccuracy	2mHz
Minimum operating time	140ms
Operation time inaccuracy	+ 10ms
Reset ratio	0,99

Underfrequency protection function f<, f<<, f<<<, f<<<< (81U)	
Operating range	40 - 70 Hz
Operating range inaccuracy	30mHz
Effective range inaccuracy	2mHz
Minimum operating time	140ms
Operation time inaccuracy	+ 10ms
Reset ratio	0,99

Rate of change of frequency protection function df/dt>, df/dt>>, df/dt>>>, df/dt>>>> (81R)	
Effective operating range	-5 - +5Hz/sec
Pick-up inaccuracy	0,01Hz/sec

Minimum operating time	140 ms
Operation time inaccuracy	+ 15ms

7.1.6 Other protection functions

Current unbalance protection function (60/46)	
Pick-up starting inaccuracy at In	< 2 %
Reset ratio	0,95
Operate time	70 ms

Thermal overload protection function T>, (49L)	
Operation time inaccuracy at I>1.2*Itrip	3 % or + 20ms

Breaker failure protection function CBFP, (50BF)	
Current inaccuracy	<2 %
Re-trip time	Approx. 15ms
Operation time inaccuracy	+ 5ms
Current reset time	20ms

Inrush current detection function INR2, (68)	
Current inaccuracy	<2 %
Reset ratio	0,95
Operating time	Approx. 20 ms

7.1 Monitoring functions

Voltage transformer supervision function VTS, (60)	
Pick-up voltage inaccuracy	1%
Operation time inaccuracy	<20ms
Reset ratio	0.95

Current transformer supervision function	
Pick-up starting inaccuracy at In	<2%
Minimum operation time	70ms
Reset ratio	0.95

Sag and swell (Voltage variation)	
Voltage measurement inaccuracy	±1% of Un

Timer inaccuracy	±2% of setting value or ±20ms

7.1 CONTROL FUNCTIONS

Synchrocheck 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

Autoreclosing function, (79)	
Operating time inaccuracy	±1% of setting value or ±30ms

7.2 HARDWARE

7.2.1 POWER SUPPLY MODULE

Rated voltage	80-300Vac/dc
Maximum interruption	100ms
Maximum power consumption	30W

7.2.2 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

7.2.3 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)
Voltage measurement range	0.05-1.2xUn

7.2.4 High speed trip module

Rated voltage Un	110/220Vdc
Number of outputs per module	4
Continuous carry	8A
Making capacity	30A (0.5s)
Breaking capacity	4A (L/R=40ms, 220Vdc)

7.2.5 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)

7.2.6 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)

7.3 Tests and environmental conditions

7.3.1 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) - Surge (According to EN61000-4-5 [09/96], level 4) - RF electromagnetic field test (According. to EN 61000-4-3, class III) - Conducted RF field (According. to EN 61000-4-6, class III)	Power supply input 4kV, 5/50ns other inputs and outputs 4kV, 5/50ns Between wires 2 kV / 1.2/50µs Between wire and earth 4 kV / 1.2/50µs f = 80….1000 MHz 10V /m f = 150 kHz….80 MHz 10V

7.3.2 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

7.3.3 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.

7.3.4 CASING AND PACKAGE

Protection degree (front)	IP 54 (with optional cover)
Weight	5kg net 6kg with package

7.3.5 ENVIRONMENTAL CONDITIONS

Specified ambient service temp. range	-10…+55°C
Transport and storage temp. range	-40…+70°C

8 ORDERING INFORMATION

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

9 Reference information

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