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Distance protection with tele-protection on an OHL feeder

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SIPROTEC 5 Application

Distance protection with tele-protection (pilot protection) on an OHL feeder

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Content

1 Distance protection with tele-protection (pilot protection) on an OHL feeder

1.1 Introduction

This application note provides a graphic road map for a typical application of the distance protection with tele-protection (pilot protection) on an OHL feeder. Numerous screen shots from DIGSI are used to help the reader apply the information to his own project.

The general configuration of SIPROTEC 5 is described in the overview separately.

The applicable SIPROTEC5 device Manual should be consulted for detailed information.

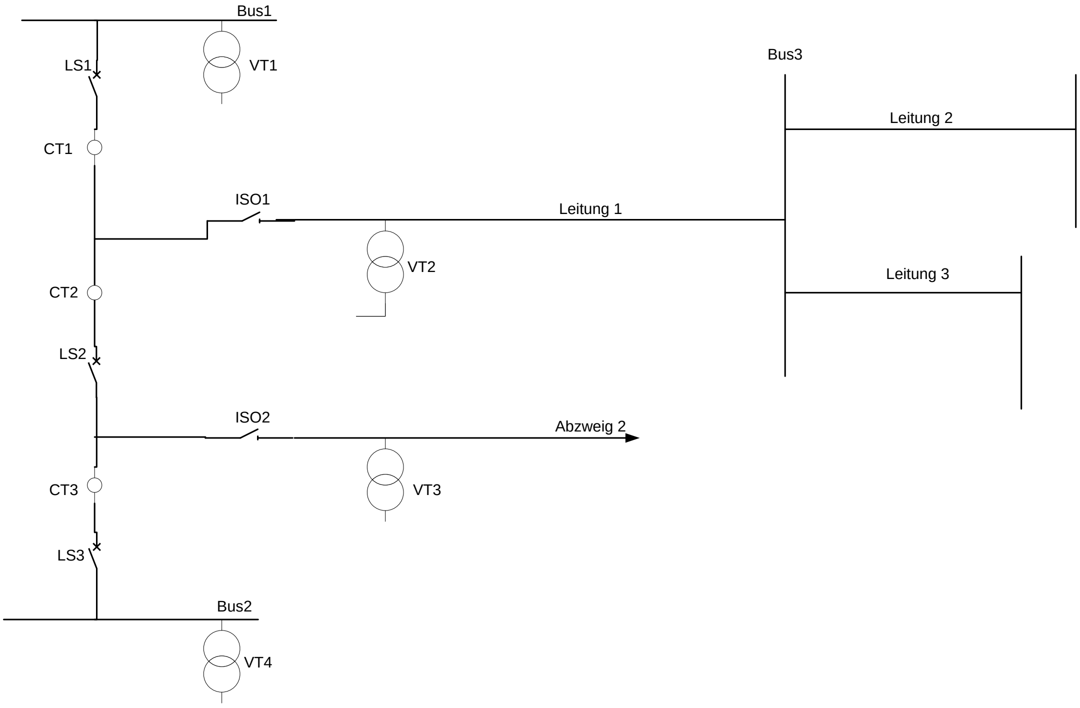
This application example covers the details with regard to distance protection only. Related subjects such as e.g. auto re-close, sync check and breaker fail are covered in separate application descriptions.

1.2 Overview

Every protection engineer has his own preference when calculating settings. Some prefer calculations in primary, others secondary and some in per unit quantities. The finer details of distance protection setting co-ordination are also not addressed here as this is typically obtained with special software tools. The zone reaches are therefore predefined in Table 1 without further calculation.

Single pole tripping will be permitted for faults cleared by the under-reaching zone 1 and the tele-protection.

For the tele-protection the forward over-reaching time delayed Zone 2 will be applied with a POTT scheme.



The distance protection is applied to protect Line1 in Figure 1 above with the zone reaches defined in Table 1 below.

The values given in the table below are typically obtained by protection co-ordination studies using software tools (e.g. PSS®SINCAL). For this application example the zone reaches as defined below will be used:

Zone number	Function	Reach	Time delay
Zone 1	Fast underreach protection for Line 1	80% Line 1	0.00 sec
Zone 2	Forward time delay backup, overreach	20% less than Z1 reach on Line 3	1 time step
Zone 3	Reverse time delay backup	50% Z Line 1	2 time steps
Zone 5	Non-directional	120% Line 2	3 time steps

Table 1

Although the configuration in Figure 1 shows a breaker-and-a-half application, this has no significant impact on the general application of distance protection as explained in this example. For this general case it is assumed that the two CT's are identical so that they may be replaced by a single CT which is equivalent to the double busbar application with only one CT. The allocation of the CT's and VT's to the various measuring points as well as the circuit breakers to the relevant function groups is covered in a separate application description.

1.3 Application Data

The application data below, consisting of the line parameters as well as instrument transformer data are required. In order to calculate the settings some values with regard to load and short circuit levels are also needed. The following table lists the data for this application:

	Parameter	Value
System data	Nominal system voltage phase-phase	400 kV
	Power system frequency	50 Hz
	Maximum positive sequence source impedance	10 + j100
	Maximum zero sequence source impedance	25 + j200
	Minimum positive sequence source impedance	1 + j10
	Minimum zero sequence source impedance	2.5 + j20
	Maximum ratio remote infeed / local infeed (I_{Rem}/I_{Loc})	3
Instrument transformers	Voltage transformer ratio (LINE) (VT2)	380 kV / 100 V
	Voltage transformer ratio (BUS) (VT1)	400 kV / 110 V
	CT1 and CT2: Current transformer ratio	1000 A / 1 A
	CT1 and CT2: Current transformer data	5P20 20VA P_i=3VA
	CT1 and CT2 secondary connection cable	2.5 mm² 50m
	CT ratio / VT ratio for impedance conversion	0.2632
	Line 1 - length	80 km
	Maximum load current	250% of full load
Line data	Minimum operating voltage	85% nominal voltage
	Sign convention for power flow	Export = negative
	Full load apparent power (S)	600 MVA
	Line 1 – positive seq. impedance per km Z1	0.025 + j0.21 Ω/km
	Line 1 – zero seq. impedance per km Z0	0.13 + j0.81 Ω/km
	Line 2 – total positive seq. impedance	3.5 + j39.5 Ω
	Line 2 – total zero seq. impedance	6.8 + j148 Ω
	Line 3 – total positive seq. impedance	1.5 + j17.5 Ω
	Line 3 – total zero seq. impedance	7.5 + j86.5 Ω
	Maximum fault resistance, Ph-E	250 Ω
	Average tower footing resistance	15 Ω
	Earth Wire	60 mm² steel
Tower data	Distance: Conductor to tower (ground)	5 m
	Distance: Conductor to conductor (phase-phase)	12 m
Circuit breaker 1 and 2	Trip operating time	60 ms
	Close operating time	70 ms

Table 2: Power system and line parameters

Based on the source and line impedance, the following minimum fault current levels can be calculated for faults on Line 1:

$$I_{fault} = \frac{U_{source}}{\sqrt{3} \cdot Z_{tot}}$$ with U_{source} = 400 kV

If fault resistance is neglected for 3 phase faults:

Z_{tot} = sum of positive sequence source and line impedance (as only current magnitudes are being calculated, only the magnitude of the impedance is relevant)

$$|Z_{tot}| = |(10 + 80 \cdot 0.025) + j(100 + 80 \cdot 0.21)|$$
$$|Z_{tot}| = |12 + j116.8|$$
$$|Z_{tot}| = 117.4\Omega$$

The minimum three phase fault current is therefore:

$$I3ph_{\min} = \frac{400kV}{\sqrt{3} \cdot 117.4}$$
$$I3ph_{\min} = 1967A$$

If **fault resistance is neglected** then for single phase faults:

Z_{tot} = 1/3 (sum of positive, negative and zero sequence source and line impedance)

$$|Z_{tot}| = \frac{|2 \cdot [(10 + 80 \cdot 0.025) + j(100 + 80 \cdot 0.21)] + (25 + 80 \cdot 0.13) + j(200 + 80 \cdot 0.81)|}{3}$$
$$|Z_{tot}| = |19.8 + j166.1|$$
$$|Z_{tot}| = 167.3$$

The minimum single phase fault current without fault resistance is therefore:

$$I1ph_{\min} = \frac{400kV}{\sqrt{3} \cdot 167.3}$$
$$I1ph_{\min} = 1380A$$

If **fault resistance is included** then for single phase faults:

$Z_{tot\_R} = Z_{tot} + R_F$

$$|Z_{tot\_R}| = |R_F + Z_{tot}|$$
$$|Z_{tot}| = |250 + 19.8 + j166.1|$$
$$|Z_{tot}| = 316.8$$

The minimum single phase fault current with high resistance is therefore:

$$I1ph_{\min\_R} = \frac{400kV}{\sqrt{3} \cdot 316.8}$$

$$I1ph_{\min\_R} = 729A$$

1.4 General Settings

The creation of a project, adding devices to the project and selection of templates is described in a separate application note. For the explanations in this application note the Function Groups Line1 and Circuit breaker 1 are used.

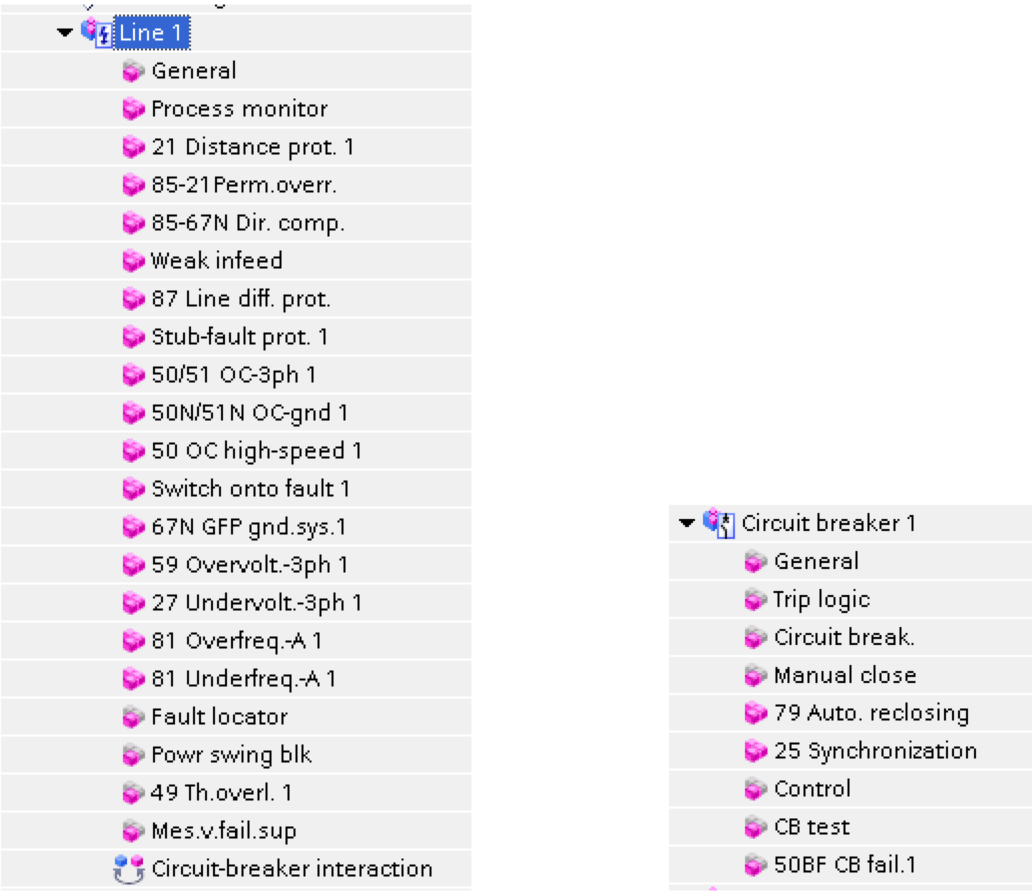


Figure 1: Typical scope of function included in template

In this application note only the following will be covered in detail:

- 21 Distance prot. 1 Distance protection
- 85-21 Perm.overr. Tele-protection with POTT

Before the settings for the individual functions are applied the general settings such as Device Settings and Power System data must be applied.

1.4.1 Device Settings

The device settings are the first item under settings and include some parameters that are relevant to the distance protection application:

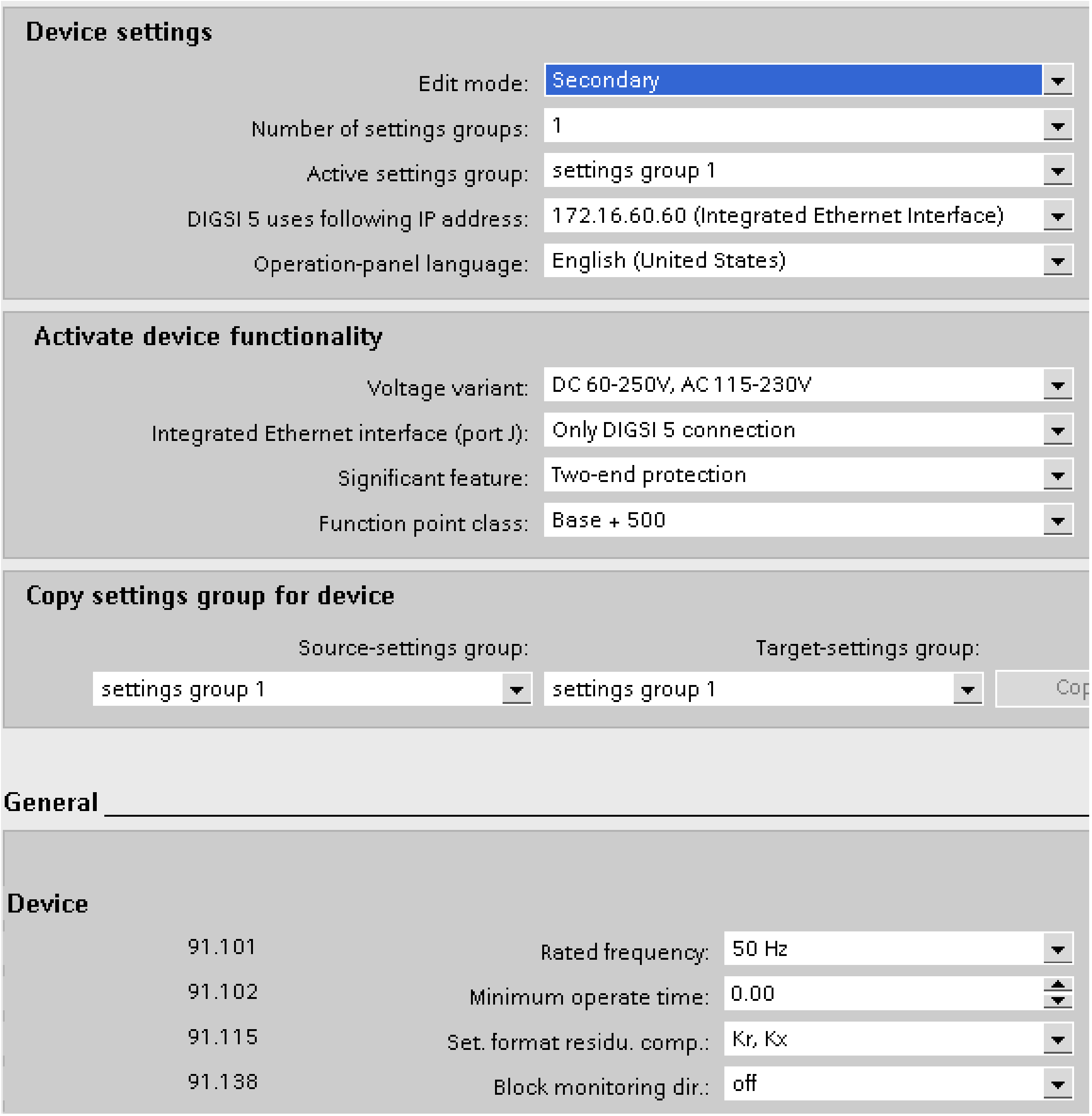


Figure 2: Device Settings

In the Edit mode the selection “Primary”, “Secondary” or “Percent” is made. In order to maintain default settings that are in relation to the rated secondary current/voltage, it is recommended to select “Secondary” before CT and VT parameters are changed. This prevents overwriting all current/voltage threshold settings when the CT/VT ratios are set. When the CT/VT data has been entered the Edit mode can be set according to the individual preference (it may also be changed at any time during application of the settings).

The minimum operating time has a default setting of 0 s. This does not have to be changed. Only in applications where the “operate” of a protection function is intentionally not associated with a configured Circuit Breaker can this time be changed to obtain a defined minimum operate time. The minimum tripping time for the trip command to the circuit breaker is set in the FG Circuit breaker.

For the distance protection the residual compensation factors “Kr and Kx” must be set for the ground loop measurement. The default setting format “Kr, Kx” is used in this application note. Alternatively the complex “K0” factor may also be used.

The setting of “Block monitoring dir.” should remain “off”. It can be changed to “on” during testing and commissioning to avoid a flood of test related signals arriving in the control centre. This blocking can also be activated via binary input.

1.4.2 Power System Settings

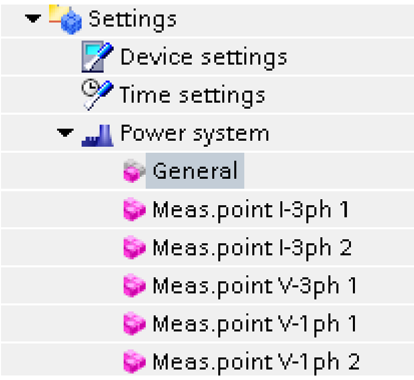


Figure 3: Initial Settings in the setting tree

The CT and VT parameters are part of the settings under Power system. These must be set according to the given data. Please note that the device may have several current and voltage measuring points. Be sure to select the correct one for the application of the following settings.

Meas. point CT Settings

he setting mask for the CT parameters (e.g. Meas. Point I-3ph 1) is as follows (refer to the comment above regarding “Edit mode” – it is recommended to be in “secondary” when changing CT ratio parameters):

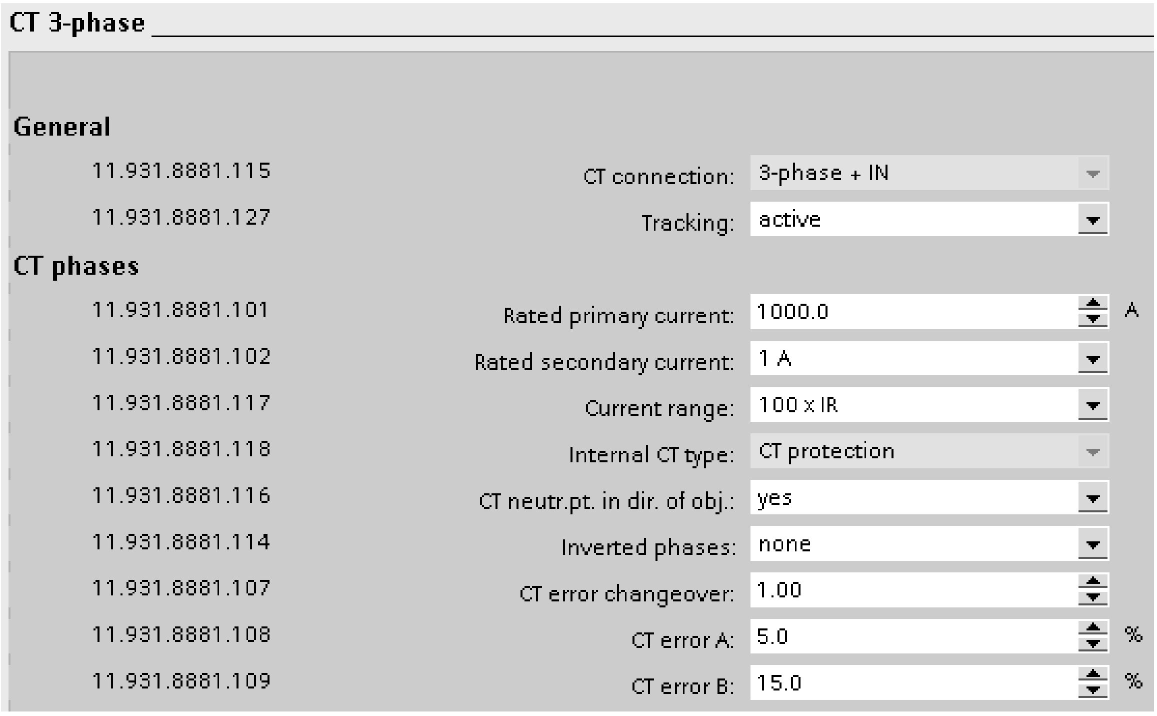


Figure 4: CT setting entry

Tracking is set to active if the signals measured at this measuring point may be used to determine the power system frequency. The power system frequency determined in this manner is used to establish the re-sampling frequency so that a fixed number of samples per cycle are available. Although the distance protection does not use re-sampling the tracking is set to "active" for the line current measurement because other functions in the device may use frequency tracking.

The rated primary and secondary current are set according to the application data given in Table 2.

The Current range setting for distance protection is fixed at 100 x IR.

The CT polarity is selected by correct application of the star point. This is done with the selection of the CT neutral point direction which may be towards the protected object (line) or not. The correct setting must be checked during commissioning or with "on-load" direction check.

The setting "Inverted phases" is only relevant when a there is the possibility of reversed phase rotation. For example the phase sequence in the generator bay of a pumped storage plant has a phase sequence change when it switches from pumping to generating. In this application the phase sequence is fixed so that this parameter is set to "none"

The other settings such as e.g. CT error are not applicable to this application. For Line Differential protection these have significance.

The settings for the 2nd CT, Meas.point I-3ph 2, are exactly the same as the CT's are identical.

Meas. Pont VT Settings

For the VT the mask for applying the settings is as follows:

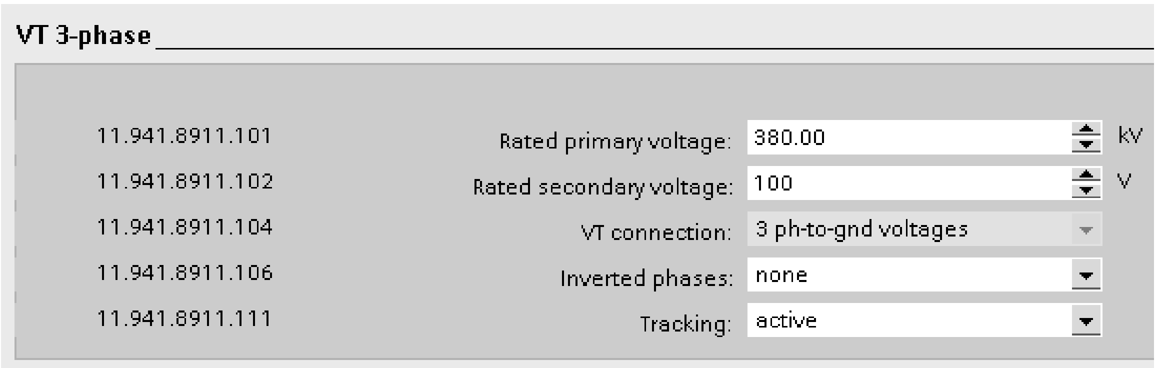


Figure 5: Line VT setting entry

For the line side VT the settings are entered as shown in Figure 9. Here the primary rated voltage is 380kV. The sync check VT has a different primary rated voltage in this example so that it will have a different setting.

1.4.3 Recording

The fault recording in SIPROTEC 5 is in the first place provided by the fault log. In the Information Routing the selection for the fault log can be applied. The oscillographic recording (records) also contain bimary traces that are selectable in the Information Routing matrix. The following settings cn be applied for the Fault recorder:

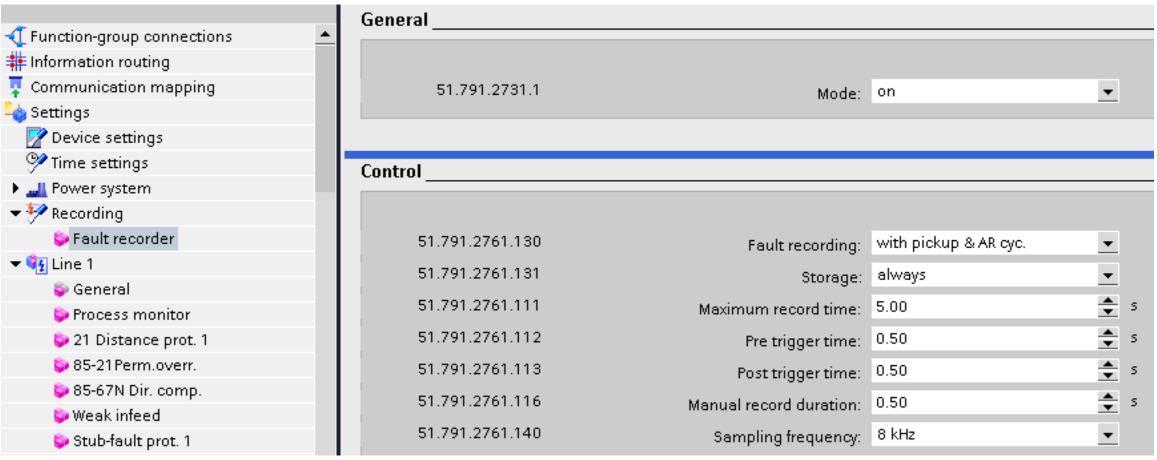


Figure 6: Settings for Fault Recording

Setting the Fault recording with AR cycle (with pickup & AR cyc.) ensures that both the Fault Log and Recorder covers the fault from pre-fault through to the close command following the AR-cycle under a single entry number.

The SIPROTEC 5 devices can store long records in the internal memory so that in general all events (even those that do not result in a trip output) are stored. If the risk exists that, due to high fault incidence or long intervals before extracting the records from the device, records that resulted in trip and reclose are overwritten by other events, the storage mode can be changed to “with trip” instead of “always”. Alternatively the sampling rate can be reduced to less than 8kHz for longer fault recordings – refer to manual for details on the storage capacity.

1.5 Function Group Line

In the function group line the individual function are grouped. Here there are also some general settings that are located under the heading *General* and *Process monitor:*

General

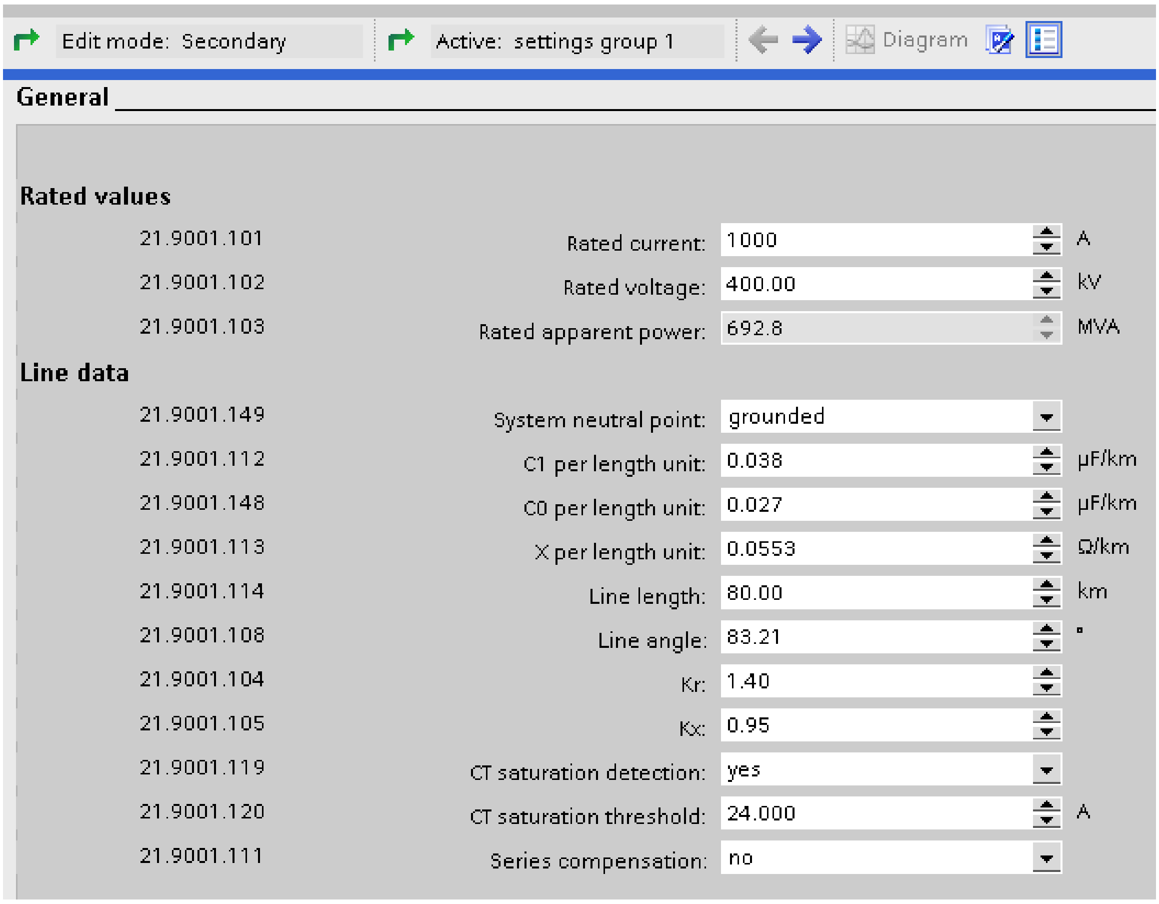


Figure 7: General Settings for FG Line

The Rated current and voltage should be set to the nominal value of the line. In most cases these parameters are set the same as the primary rating of the CT and VT. The rated power is automatically derived from these two settings. All FG Line settings and indications in percent are related to these settings. Protection settings are not affected unless they are applied in percent.

The further settings in this window should be set according to the line data. The line capacitance (C1 and C0) are only required if 2-ended fault location or charge compensation are applied together with line differential protection. The X per length unit is also required by the fault location and should be set according to the line data in Table 2.

The Line angle setting is calculated from the positive sequence line impedance data. In this example:

$\underline{Z1} = 0.025 + j0.21$

$$Line\_angle = \arctan\left(\frac{X_L}{R_L}\right)$$

Line angle = **83.21°**

Although the residual compensation factors can be set for each zone separately, the setting based on the line data should be set here.

$$\frac{R_E}{R_L} = \frac{1}{3} \cdot \left(\frac{R_0}{R_1} - 1 \right) \qquad \frac{X_E}{X_L} = \frac{1}{3} \cdot \left(\frac{X_0}{X_1} - 1 \right)$$

$$\frac{R_E}{R_L} = \frac{1}{3} \cdot \left(\frac{0.13}{0.025} - 1 \right) \qquad \frac{X_E}{X_L} = \frac{1}{3} \cdot \left(\frac{0.81}{0.21} - 1 \right)$$

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$$\frac{R_E}{R_L} = 1.4 \qquad \frac{X_E}{X_L} = 0.95$$

Apply setting RE/RL equal to **1.40,** and XE/XL equal to **0.95**

If the fault current (with transients) can cause CT saturation, the setting for CT saturation detection should be set to yes. This ensures that appropriate stabilization measures are applied to prevent mal-operation due to CT saturation during faults. When this setting is "yes" the CT saturation threshold must be set. This current level can be calculated with the given CT data:

$$CT\_Saturation\_Threshold = \frac{n'}{5} \cdot I_{nom}$$

with: $n' = n \cdot \frac{P_N + P_i}{P' + P_i} = actual\_overcurrent\_factor$

P' = the actual burden connected to the CT secondary

P' = relay burden + CT secondary connection cable burden

In this example only the 7SA52 relay is connected to the CT, so that the relay burden is 0.05 VA per phase. Due to the Holmgreen connection, the maximum burden for earth currents is therefore twice 0.05VA =0.1VA.

The CT secondary cable connection burden is calculated as follows:

$$R_{cable} = \frac{2 \cdot l_{cable} \cdot \rho_{CU}}{a_{cable}}$$

l_{cable} = 50 m
ρ_{cu} = 0,0179 $\Omega mm^2/m$
a_{cable} = 2,5 mm^2

therefore:

$$R_{cable} = \frac{2 \cdot 50 \cdot 0.0179}{2.5}$$
$$R_{cable} = 0.72$$

at 1 A nominal secondary current, this relates to:

$$P' = R_{cable} \cdot Inom_{CT}{}^{2} + P_{relay}$$
$$P' = 0.72 \cdot 1^{2} + 0.1$$
$$P' = 0.82VA$$

From Table 2, the CT data is 5P20 20VA, therefore:

$$n' = 20 \cdot \frac{20+3}{0.82+3}$$
$$n' = 120$$

with this value, the setting can then be calculated:

$$CT\_Saturation\_Threshold = \frac{120}{5} \cdot 1A$$
$$CT\_Saturation\_Threshold = 24A$$

The applied setting in this case is therefore **24.0A**

Process monitor

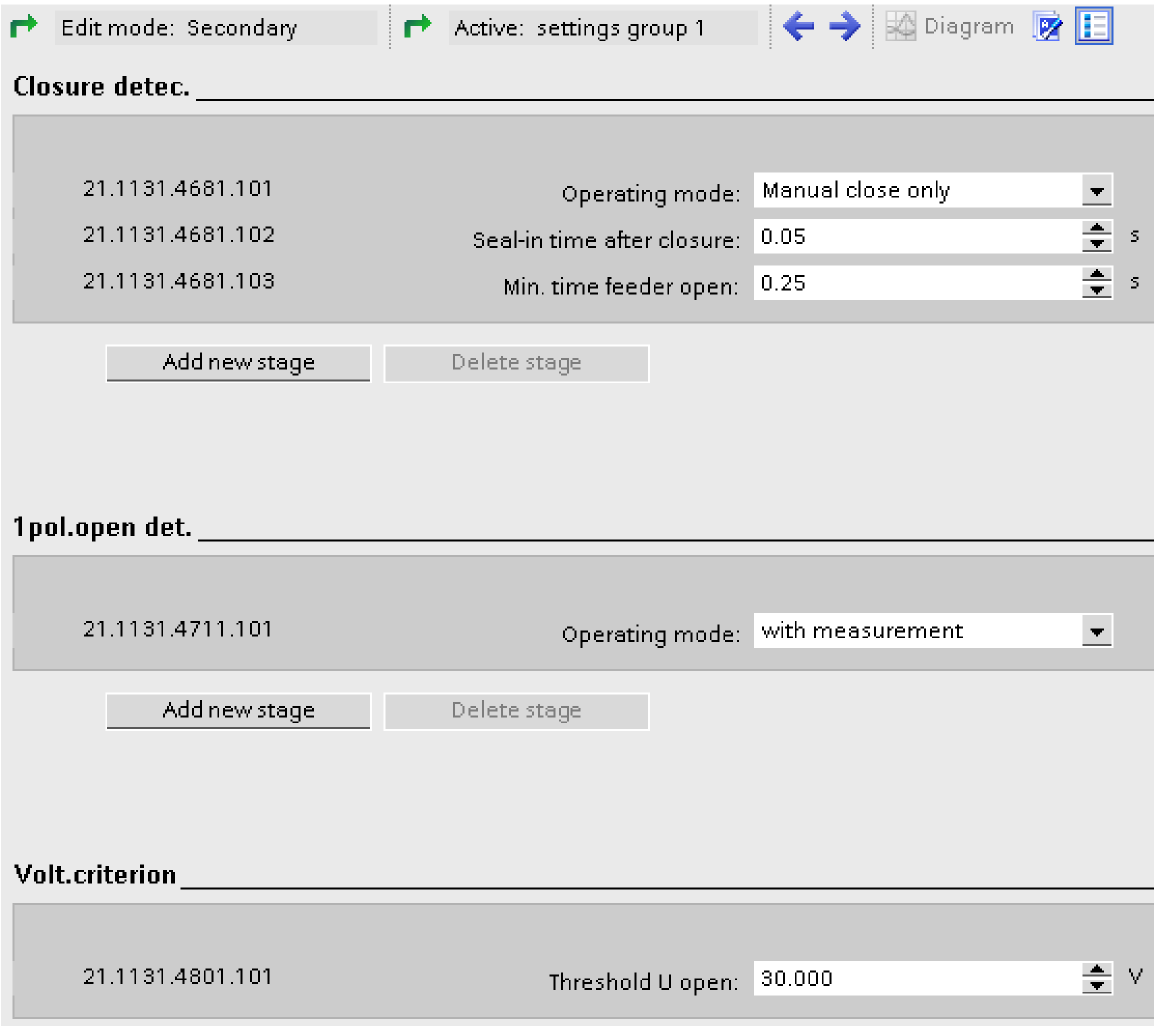


Figure 8: Process monitor Settings for FG Line

The Closure detection settings relate to the “Switch On To Fault” function. For most applications the default settings can be applied.

The 1-pole open detection is important when single pole tripping is possible. During the single pole dead time some protection functions are blocked (stabilized). The default setting “with measurement” is recommended. In this context the settings for the Voltage Criterion arise. To illustrate this the following diagram from the manual is shown below:

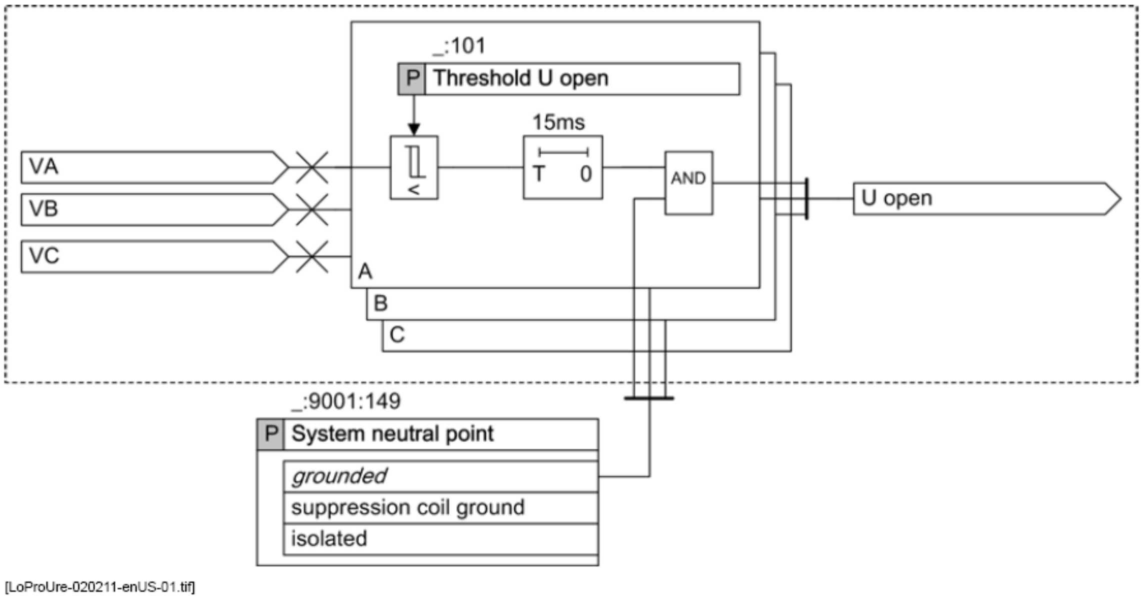
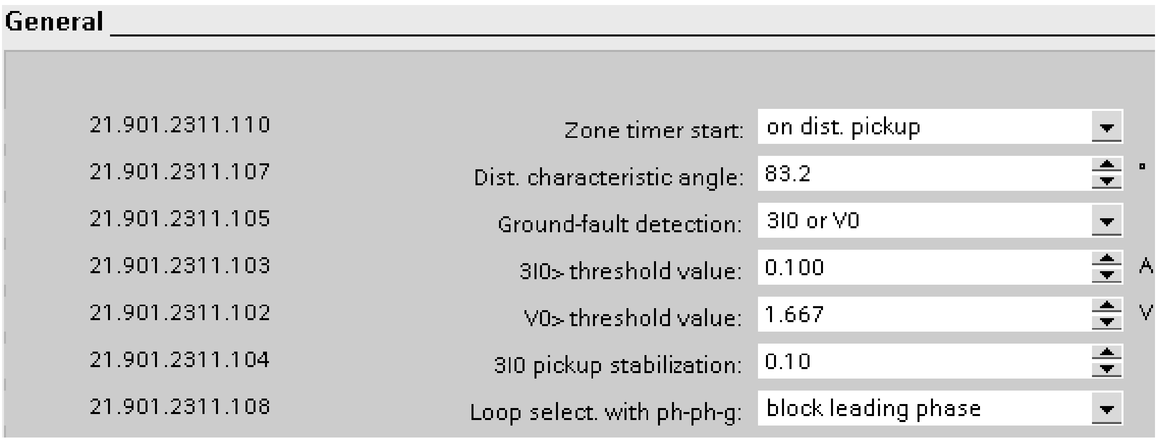


Figure 9: General Settings for FG Liner

The voltage criterion should only be used for line/pole open detection if the voltage transformers are located on the line side of the circuit breakers – as is the case in this example.

1.6 Distance Protection

The distance protection settings start off with a general setting block:


General

21.901.2311.110	Zone timer start:	on dist. pickup	
21.901.2311.107	Dist. characteristic angle:	83.2	°
21.901.2311.105	Ground-fault detection:	3I0 or V0	
21.901.2311.103	3I0> threshold value:	0.100	A
21.901.2311.102	V0> threshold value:	1.667	V
21.901.2311.104	3I0 pickup stabilization:	0.10	
21.901.2311.108	Loop select. with ph-ph-g:	block leading phase	

Figure 10: Distance Protection General Settings

The "Zone timer start" is set to "on dist. pickup" so that the timers are all triggered at the same time when the distance protection picks-up in any zone. This ensures tripping with the correct (shortest allowed) time delay during remote faults with fault resistance. See example below:

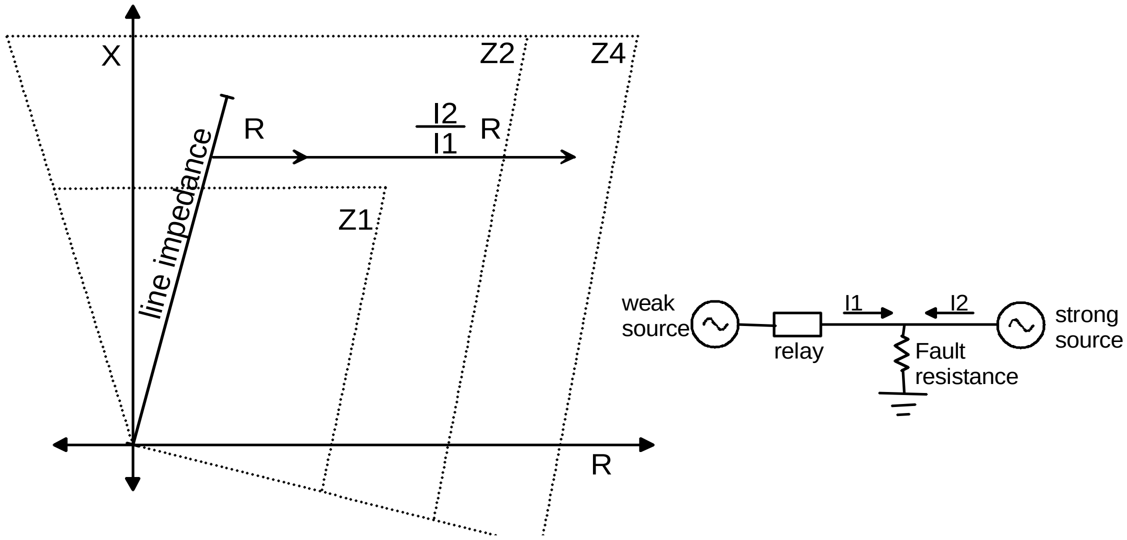


Figure 11: Example, sequential tripping with back-up stage during remote faults

Although the fault is in the Zone 2 range (according to reach co-ordination) it is initially not seen in zone 2 due to the fault resistance and strong remote infeed. The remote end with strong infeed will trip according to its setting (reach and time delay). When the remote infeed is open the current (I2) resets so that the fault impedance is seen in Zone 2. With the applied setting, the zone 2 timer was already started on distance pickup, and zone 2 will trip in the desired time although the fault was initially outside zone 2.

The Line Angle setting must be calculated from the positive sequence line parameters:

Z1 = 0.025 + j0.21

$$Line\_angle = \arctan\left(\frac{X_L}{R_L}\right)$$

Line angle = 83.2°

The remaining settings in Figure 10 can remain on the default values. For details refer to the manual or online help function.

The distance protection has a Z< pickup characteristic:

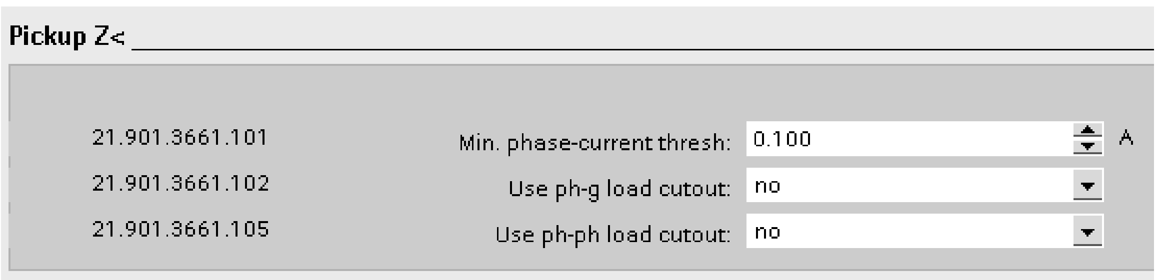


Figure 12: Distance Protection Pickup Settings

For the distance protection a minimum current is required for operation. It is typically left unchanged on the default value corresponding to 10% of secondary nominal current. As this setting is not relevant for the reach grading and is generally much smaller than typical load current it is not based on a fault current calculation. If however weak in-feed conditions exist which may result in internal faults having fault current flow below this threshold, a special "Weak In-Feed" protection may have to be applied.

The load cut-out is typically only required on long lines where the set zone reaches may include load impedances. If this is the case the load cut-out should be activated – not the case in this example.

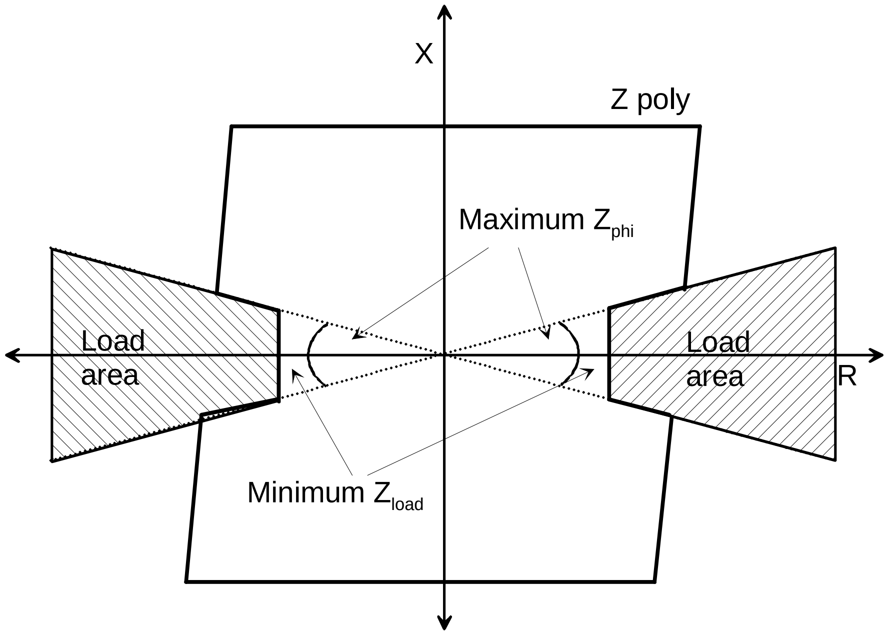


Figure 13: Load Cut-out area

In this application 4 Zones are applied, Zone 1, 2, 3 and 5. The Zone 2 is a forward overreach zone and will also be used by the tele-protection POTT scheme.

Zone number	X reach	Reach	Time delay
Zone 1	80% XLine	80% Line 1	0.00 sec
Zone 2	20% less than Z1 reach on Line 3	20% less than Z1 reach on Line 3	1 time step
Zone 3	50% Z Line 1	50% Z Line 1	2 time steps
Zone 5	120% Line 2	120% Line 2	3 time steps

Table 3

The applied template is pre-configured with the following distance protection zones:

Z1, Z1B, Z3 and Z4. These can be renamed, deleted or supplemented with additional inserted stages. In this case the zones will be renamed by entering the desired name in the "Details" window as shown below:

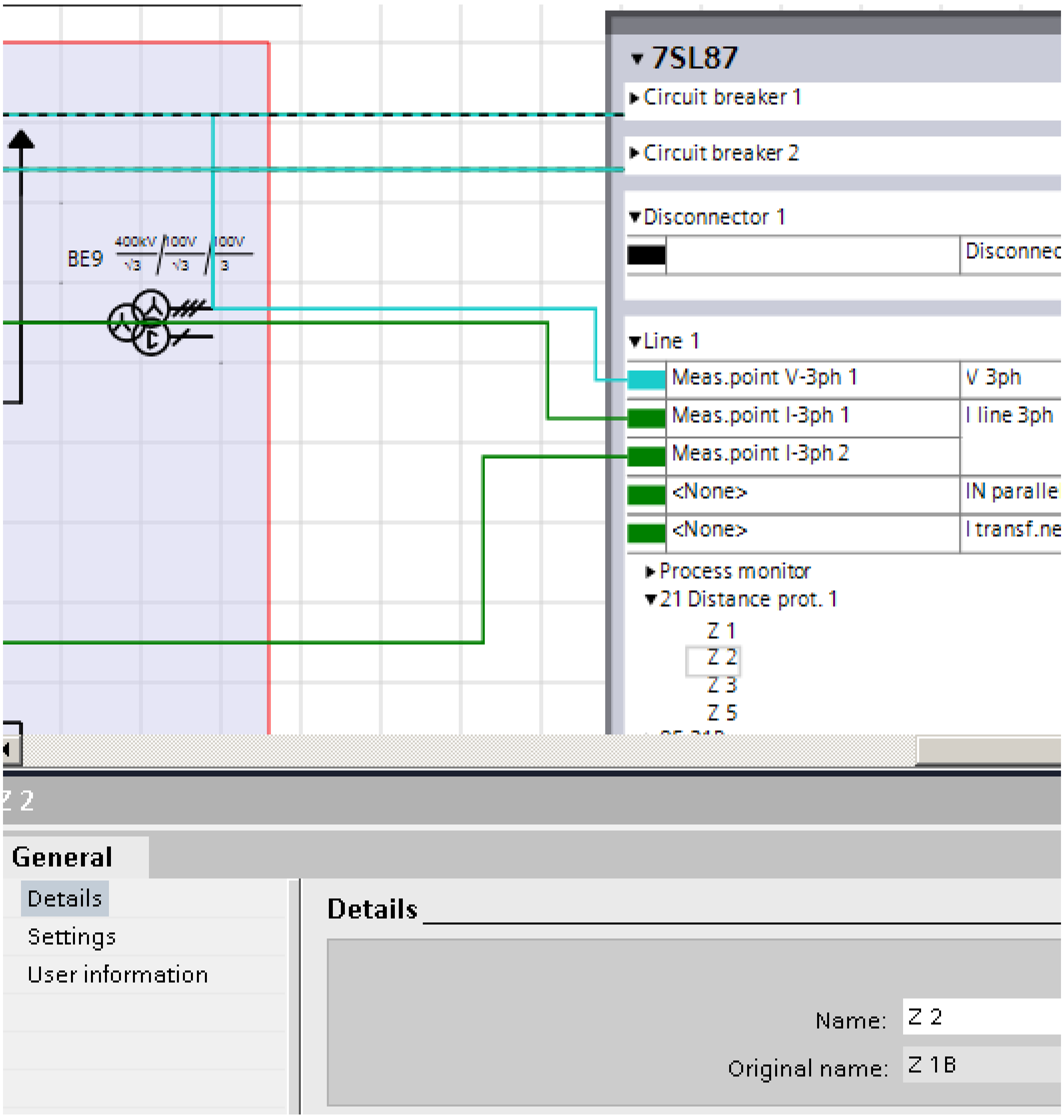


Figure 14: Rename Z1B to Z2

The distance protection zones are treated as stages of the distance protection function. All stages (zones) have the same setting options.

1.6.1 Zone 1 Settings

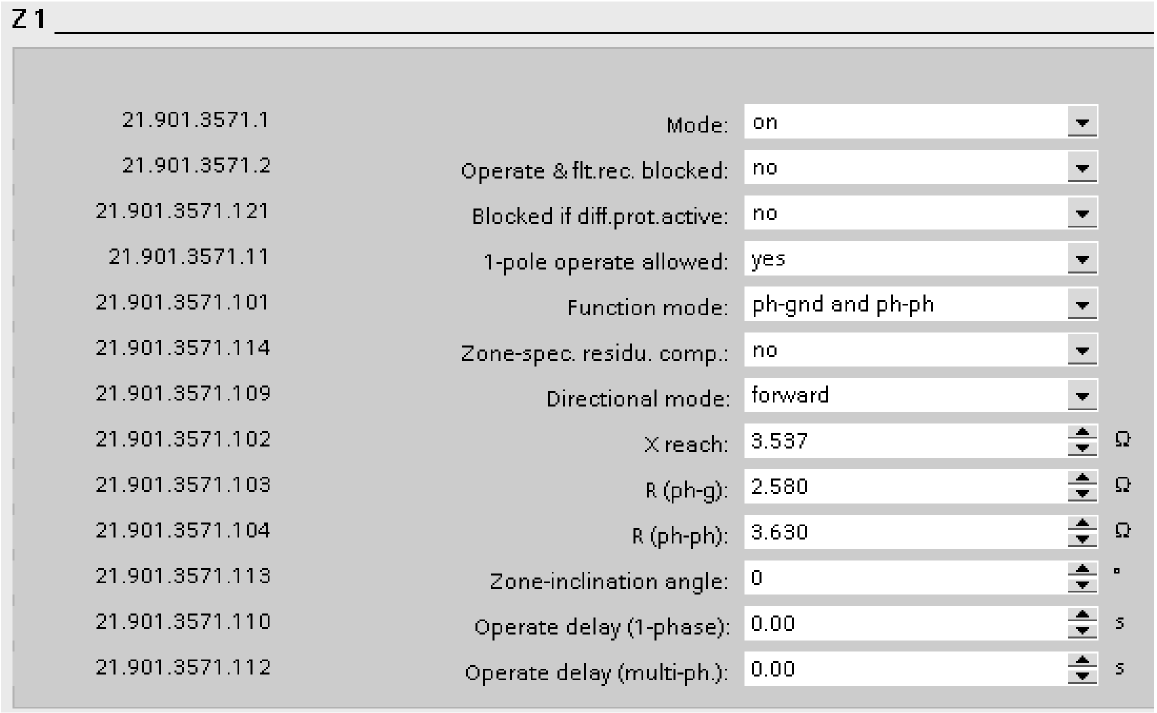


Figure 15: Settings for Zone 1

The Zone 1 (Z1) is set as non delayed selective zone in forward direction with a reach of 80% of the line length. It will trip single pole for ph-gnd faults and three pole for ph-ph faults. As under-reaching zone it will not use Zone specific residual compensation factors because the parameters set for the line can be applied.

The reactance reach is calculated based on the grading margin of Z1 (80%):

$$X(Z1) = 0.8 \cdot X_{Line1}$$
$$X(Z1) = 0.8 \cdot 80 \cdot 0.0.21$$
$$X(Z1) = 13.44\Omega(prim)$$

This is converted to a secondary value by multiplying with the conversion factor in Table 2:

$$X(Z1) = 13.44 \cdot 0.2632$$
$$X(Z1) = 3.537\Omega(\text{sec})$$

The setting for Z1 X reach is therefore 3.537 Ohm secondary.

A separate resistance reach setting is available for ph-ph measured loops and ph-g measured loops. With the “Distance characteristic angle” under **General** above the angle of inclination of the distance characteristic is set equal to the line angle. The resistance settings of the individual zones therefore only have to cover the fault resistance at the fault location (faults on the protected line). For the Z1 setting only arc faults will be considered. For this purpose the arc resistance will be calculated with the following equation.

$$R_{arc} = \frac{U_{arc}}{I_F}$$

The arc voltage (U_{arc}) will be calculated using the following rule of thumb which provides a very conservative estimate (estimated R_{arc} is larger than actual value):

$$U_{arc} = 2500V \cdot l_{arc}$$ whereby l_{arc} is the length of the arc.

The length of the arc is greater than the spacing between the conductors (ph-ph) because the arc is blown into a curve due to thermal and magnetic forces. For estimation purposes it is assumed that l_{arc} is 1.5 times the conductor spacing. To obtain the largest value of R_{arc} , which is required for the setting, the smallest value of fault current must be used (calculated earlier):

For the earth fault, not only the arc voltage must be considered, but also the tower footing resistance. From the graph in Figure 20 it is apparent that although the individual tower footing resistance is 15 Ω (Table 2) the resultant value due to the parallel connection of multiple tower footing resistances is less than 1.5 Ω.

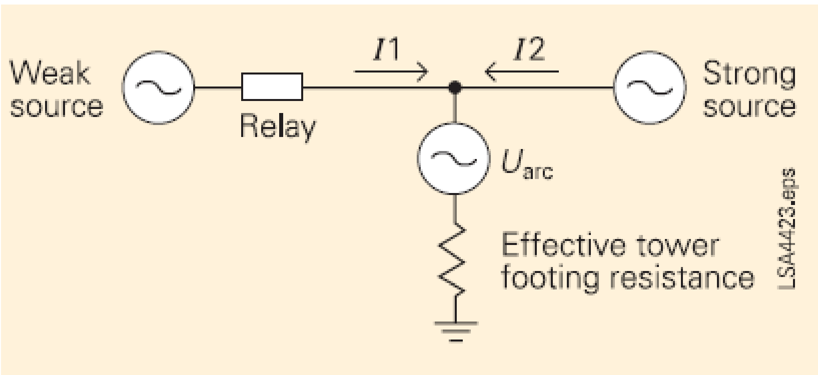


Figure 16: Combination of arc voltage and tower footing resistance

From Figure 16: Combination of arc voltage and tower footing resistance it can be seen that the remote in-feed (I2) will introduce an additional voltage drop across the "effective tower footing resistance" which will be measured in the fault loop by the relay (this effect is also shown in Figure 15). To make allowance for this the maximum value (not weak in-feed conditions) of the ratio of I2/I1 is required. This is provided for this application in Table 2 with the value 3. The maximum tower footing resistance that is measured by the relay (with consideration of remote in-feed) in the fault loop is therefore:

$$R_{TF} = \left(1 + \frac{I2}{I1}\right) \cdot effective\_tower\_footing\_R$$

$$R_{TF} = (1+3) \cdot 1.5$$

$$R_{TF} = 6\Omega(prim)$$

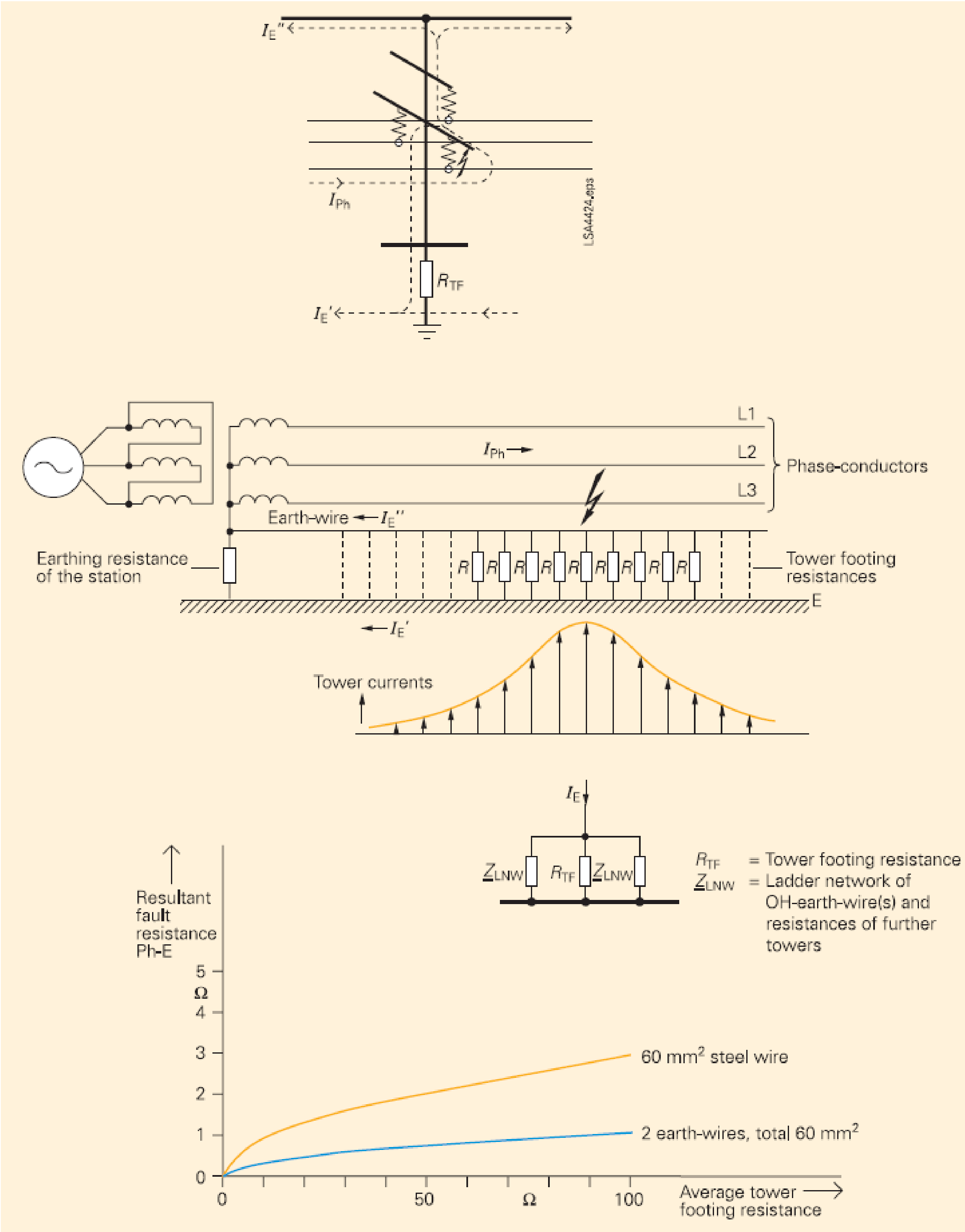


Figure 17: Effective tower footing resistance

The arc voltage for the earth faults is calculated as follows using the conductor to tower/ground spacing given inTable 2:

$$U_{arc} = 2500V \cdot l_{arc}$$
$$U_{arc} = 2500V \cdot 1.5 \cdot 5m$$
$$U_{arc} = 18.75kV$$

To obtain the largest value of R_{arc} , which is required for the setting, the smallest value of fault current must be used (calculated earlier):

$$R_{arc} = \frac{18.75kV}{1380A}$$
$$R_{arc} = 13.6\Omega$$

The total resistance that must be covered during earth faults is the sum of R_{arc} and R_{TF} . A safety factor of 20% is included and the result is converted to secondary values (division by factor (1 + RE/RL) because R_{arc} and R_{TF} appear in the loop measurement while the setting is done as phase impedance or positive sequence impedance). :

$$RE(Z1) = \frac{1.2 * (13.6 + 6) * 0.2632}{(1 + 1.4)}$$
$$RE(Z1) = 2.58\Omega(\sec)$$

The setting for Z1 R(ph-g) is therefore 2.58 Ohm secondary.

The phase to phase fault resistance reach is calculated along the same lines as the setting for ph-ph resistance. Initially calculate the ph-ph arc resistance

$$R_{arc} = \frac{2500V \cdot 1.5 \cdot 12m}{1967A}$$
$$R_{arc} = 23\Omega$$

By addition of a 20% safety margin and conversion to secondary impedance (factor from Table2) the following minimum setting is calculated (division by 2 because R_{arc} appears in the loop measurement while the setting is done as phase impedance or positive sequence impedance):

$$R(Z1) = \frac{1.2 * 23 * 0.2632}{2}$$
$$R(Z1) = 3.63\Omega(\sec)$$

The setting for Z1 R(ph-ph) is therefore 3.63 Ohm secondary.

1.6.2 Zone 2,3 and 5 Settings

The settings for zones 2 to 5 are done in a similar manner. The zone reach as defined in Table 1 is used with the line data from Table 2 to calculate the various zone reaches:

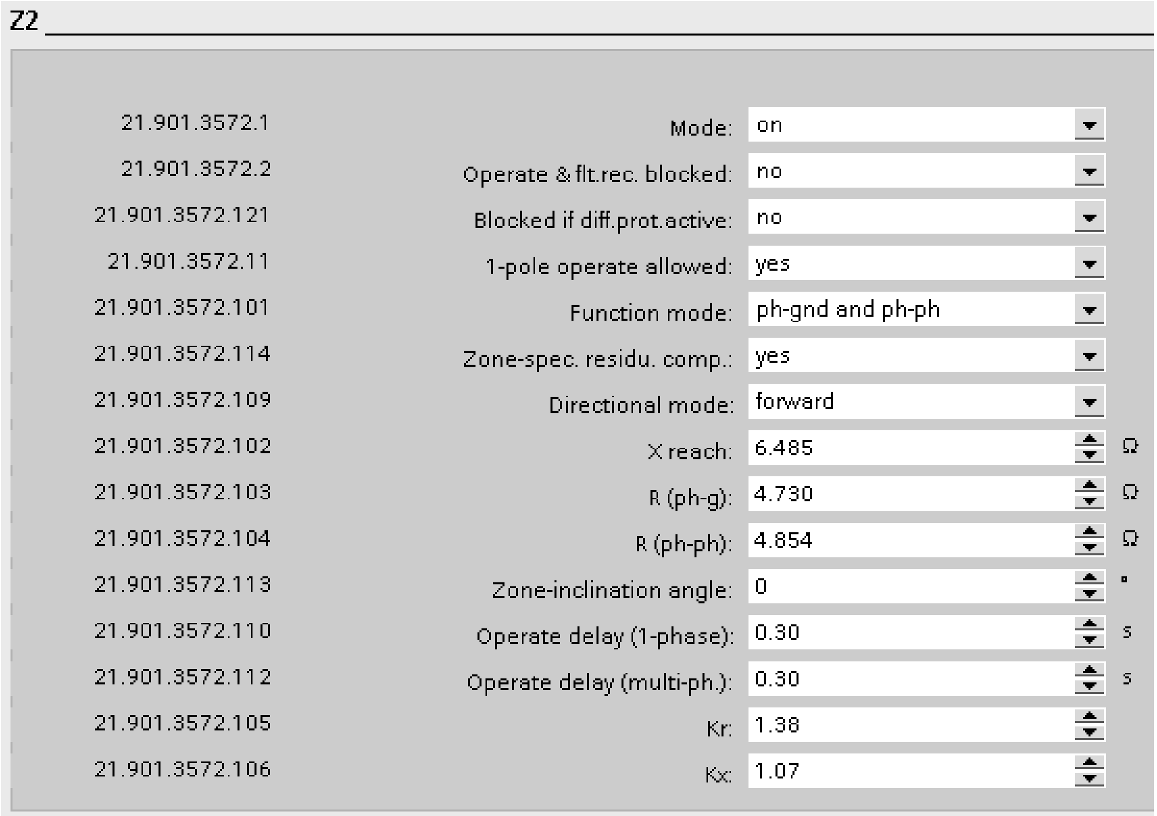
	X reach Calculation		
	Definition	Calculation	Result
			Ohm (sec)
Z1	0.8 x Xline1	0.8 x 80 x 0,21 x 0,2632	3,537
Z2	0.8 x (Xline1 + 0.8 x Xline3)	0.8 x(80 x 0,21 + 0.8 x 4.606) x 0.2632	6,485
Z3	0.5 x XLine1	0.5 x 80 x 0,21 x 0,2632	2,211
Z5	1.2 x (XLine1 + XLine2)	0.8 x 80 x 0,21 x 0,2632	17,78

The resistance reaches are simply increased proportional to the resistance reaches calculated for Zone Z1:

	R reach Calculation (ph-G)		
	Definition	Calculation	Result
			Ohm (sec)
Z1	Calculated from arc voltage + Rtf	see above	2,580
Z2	(X2 / X1) x R1G	(6.485 / 3,537) x 2,58	4,730
Z3	(X3 / X1) x R1G	(2.211 / 3,537) x 2,58	1,613
Z5	(X5 / X1) x R1G	(17.78 / 3,537) x 2,58	12,97

	R reach Calculation (ph-ph)		
	Definition	Calculation	Result
			Ohm (sec)
Z1	Calculated from arc voltage	see above	3,63
Z2	(X2 / X1) x R1	(6.485 / 3,537) x 3.63	4,854
Z3	(X3 / X1) x R1	(2.211 / 3,537) x 3.63	1,655
Z5	(X5 / X1) x R1	(17.78 / 3,537) x 3.63	13,31

For the Z2 zone specific residual compensation factors will be used. If the parameter is selected for this purpose, the required settings are accessible:



Z2

21.901.3572.1	Mode:	on	
21.901.3572.2	Operate & flt.rec. blocked:	no	
21.901.3572.121	Blocked if diff.prot.active:	no	
21.901.3572.11	1-pole operate allowed:	yes	
21.901.3572.101	Function mode:	ph-gnd and ph-ph	
21.901.3572.114	Zone-spec. residu. comp.:	yes	
21.901.3572.109	Directional mode:	forward	
21.901.3572.102	X reach:	6.485	Ω
21.901.3572.103	R (ph-g):	4.730	Ω
21.901.3572.104	R (ph-ph):	4.854	Ω
21.901.3572.113	Zone-inclination angle:	0	°
21.901.3572.110	Operate delay (1-phase):	0.30	s
21.901.3572.112	Operate delay (multi-ph.):	0.30	s
21.901.3572.105	Kr:	1.38	
21.901.3572.106	Kx:	1.07	

Figure 18: Z2 settings with Zone specific residual compensation

The residual compensation for Z2 is calculated with the positive and zero sequence impedance of line 1 plus line 3 up to the Z2 reach. The following calculations are done with primary impedances:

Positive sequence reactance of Z2 reach (Line 1 + 80% Line3):

$$X2_1 = 0.8 \cdot (X_{Line1} + 0.8 \cdot X_{Line3})$$
$$X2_1 = 0.8 \cdot (80 \cdot 0.21 + 0.8 \cdot 17.5)$$
$$X2_1 = 24.64$$

The corresponding positive sequence resistance:

$$R2_1 = R_{Line1} + \frac{(X2_1 - X_{Line1})}{X_{Line3}} \cdot R_{Line3}$$

$$R2_1 = 80 \cdot 0.025 + \frac{24.64 - 80 \cdot 0.21}{17.5} \cdot 1.5$$

$$R2_1 = 2.672$$

The corresponding zero sequence reactance and resistance:

$$X2_0 = X0_{Line1} + \frac{(X2 - X_{Line1})}{X_{Line3}} \cdot X0_{Line3} \qquad R2_0 = R0_{Line1} + \frac{(X2 - X_{Line1})}{X_{Line3}} \cdot R0_{Line3}$$

$$X2_0 = 80 \cdot 0.81 + \frac{24.64 - 80 \cdot 0.21}{17.5} \cdot 86.5 \qquad R2_0 = 80 \cdot 0.13 + \frac{24.64 - 80 \cdot 0.21}{17.5} \cdot 7.5$$

$$X2_0 = 103.4 \qquad R2_0 = 13.76$$

This is shown below in graphic form:

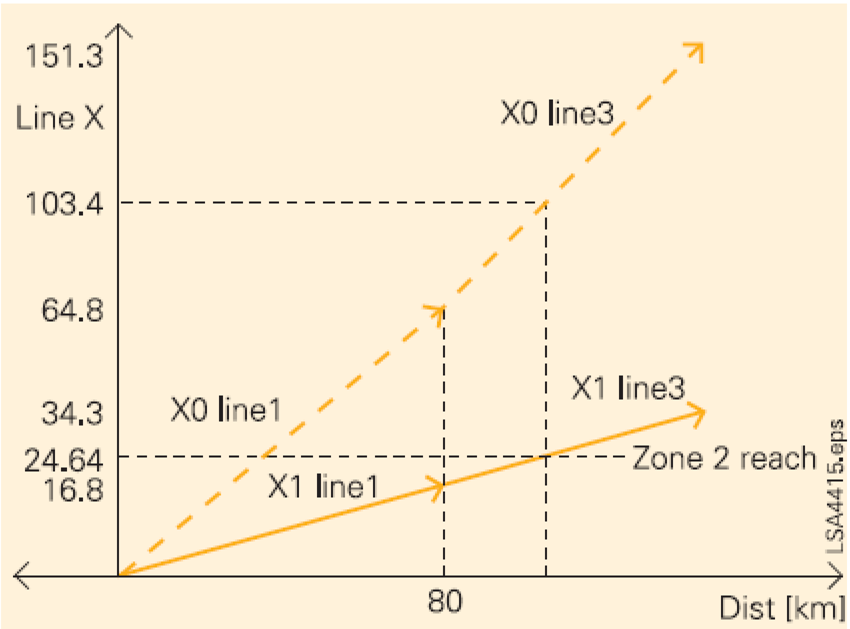


Figure 19: Graphic illustration of positive and zero sequence impedance for Z2

The Kr and Kx factors for Z2 can then be directly calculated using the above results:

$$K_r = \frac{1}{3} \cdot \left(\frac{R_0}{R_1} - 1 \right) = \frac{1}{3} \cdot \left(\frac{13.76}{2.672} - 1 \right) = 1.38$$

$$K_x = \frac{1}{3} \cdot \left(\frac{X_0}{X_1} - 1 \right) = \frac{1}{3} \cdot \left(\frac{103.4}{24.64} - 1 \right) = 1.07$$

Graphic output of the set zones:

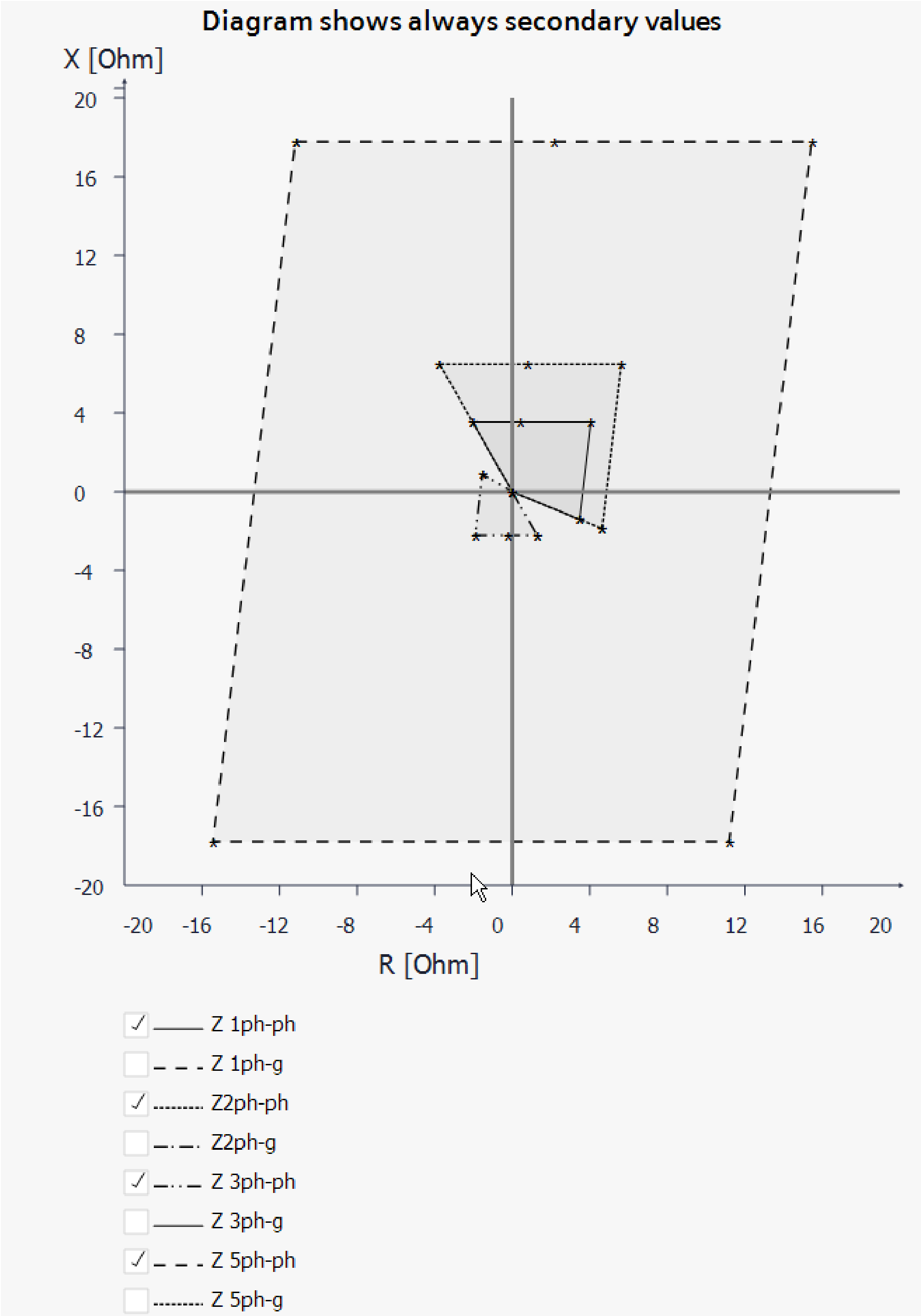


Figure 20: Graphic illustration of the set zone reaches

It is recommended to check the zone graphic shown in Figure 20 to make sure there are no severe setting errors

1.7 Tele-Protection POTT (85-21)

With SIPROTEC 5 the 85-21 does not require a dedicated zone it can use any of the applied distance protection zones. For POTT an over-reaching forward zone is required. In this application Z2 will be used as shown in Figure 24:

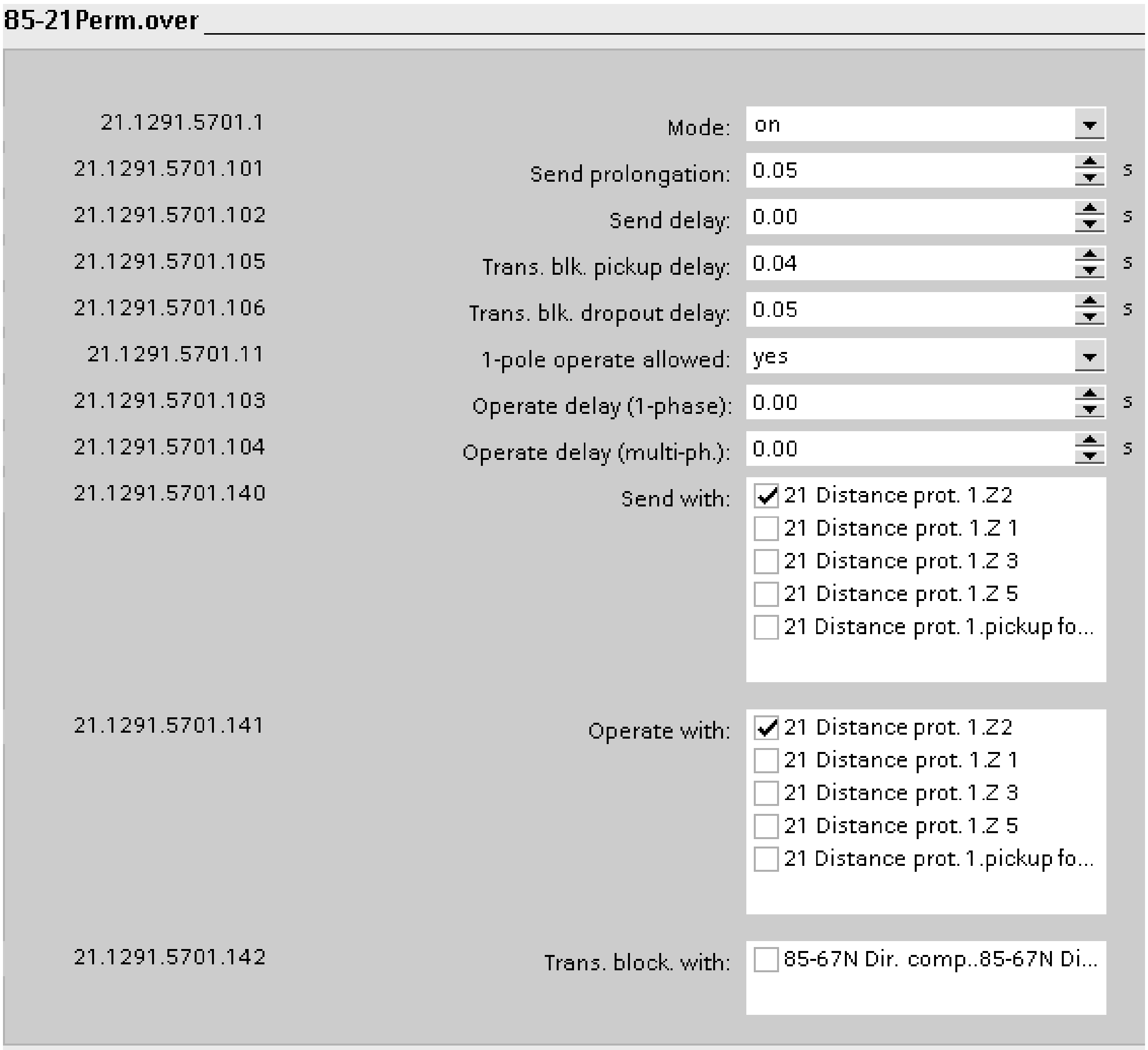


Figure 21: Setting window for 85-21

A send prolongation is used to ensure that the send signal is maintained long enough following a trip to allow the remote end to securely pick-up and trip with the received signal in case of weak in-feed at remote end.

As the application is not on a parallel line the transient blocking does not need special consideration. The default settings can be left unchanged.

The 85-21 is a selective protection, clearing internal faults without delay. It should therefore be set to trip single pole is single pole auto re-closure is possible.

The 85-21 is generally set without any intentional operate delay. Only special back-up constellations require a time delay setting here.

If the 85-67N scheme is sharing the same communication channel with 85-21, the transient block condition from 85-67N should be applied to prevent maloperation of the 85-21 when there is a ground fault on a parallel line followed by current reversal. As there is no parallel line in this application this selection is not made.

1.8 Auto re-close

The auto re-close function on the breaker-and-a-half configuration requires special attention. In this application fixed leader/follower logic is implemented. The bus circuit breaker (CB1) is Leader while the Tie circuit breaker (CB2) is Follower. The following table defines the required AR response:

Pre fault state		Description	AR response	
CB1	CB2		CB1	CB2
Closed	Closed	Normal Operation with both CB closed prior to fault	Close with set dead time as leader and then release Follower	Run normal dead time then wait for release by leader before AR close
Closed	Open	Tie breaker (follower) is open prior to fault	Close with set dead time as leader and then release Follower	AR detects CB open and does not start = no AR close
Open	Closed	Bus breaker (leader) is open prior to fault	AR detects CB open and does not start = no AR close	Close with set dead time as leader does not block the follower
Closed	Closed	Normal Operation with both CB closed prior to fault – **AR not successful –** permanent fault	Close with set dead time - **Trip** – definite trip no further AR	Run normal dead time then wait – no release by Leader – then new trip indication – no AR and definite trip

Table 4

A simple logic will be applied in the Function charts to achieve the above response:

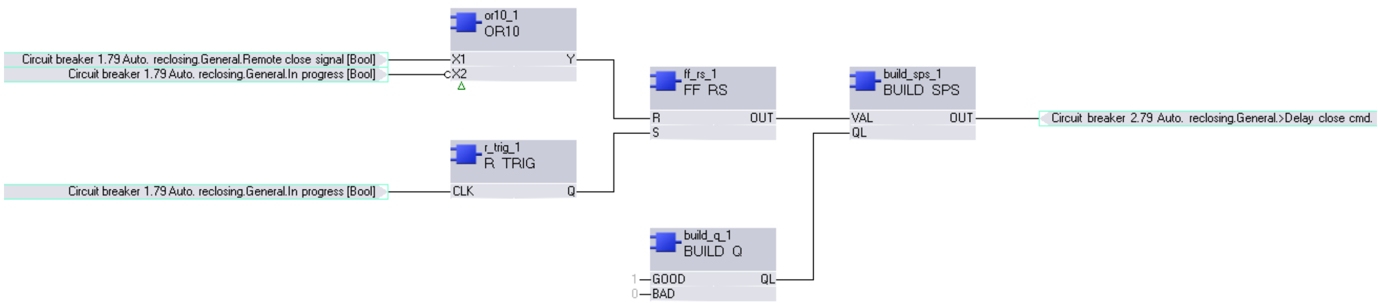


Figure 22: CFC Logic to delay Follwer Re-Close command

The above logic is implemented in the Function Charts. The Flip-Flop is set when the Auto re-close function in the Leader = Circuit Breaker 1 (Bus Circuit breaker – CB1) is in progress. As the initiation of the AR function in both circuit breakers is at the same time from the same source (the protection functions in FG Line), the AR in progress of CB1 is a clear indication that CB1 is in service and taking the role as leader. Is CB1 is open for maintenance or the AR function is selected Off, the AR in progress will not assert.

When the Flip-flop is set, the output sets (via the Build SPS block) the signal Delay Close Command in CB2 the Follower. The AR function in CB2 will go through all the normal states until the AR Close command is due. If the signal Delay Close Command is active the AR close will not be issued until this signal resets. If the maximum dead time extension (Setting Parameter) has expired before the release is given the AR will be terminated with a definite trip.

The Leader will reset the Flip-Flop when the leader Cycle is successful. This is indicated with the Remote Close Command from CB1 which is issued when there is no further protection operation within a set time after the re-close of CB1.

General

General

302.1361.6601.1	Mode:	on	
302.1361.6601.101	79 operating mode:	with op., with act. time	
302.1361.6601.102	CB ready check bef. start:	no	
302.1361.6601.103	Reclai. time aft.succ.cyc.:	3.00	s
302.1361.6601.104	Block. time aft. man.close:	1.00	s
302.1361.6601.105	Start signal supervis.time:	0.25	s
302.1361.6601.106	CB ready superv. time:	3.00	s
302.1361.6601.107	3-pole operate by 79:	yes	
302.1361.6601.108	Evolving-fault detection:	with trip	
302.1361.6601.109	Response to evolv. faults:	blocks 79	
302.1361.6601.110	Max. dead-time delay:	0.50	s
302.1361.6601.111	Max. dead-time extension:	1.20	s
302.1361.6601.112	Send delay f. remot. close:	0.05	s

Figure 23: AR Function General Settings

The General settings for the AR function in both circuit breakers can be the same. The Leader must have a set time for “Send delay for remote close” as this determines how long after the Leader close command the follower is released.

In the Follower the “Max. dead time extension” must be set longer than the release delay from the leader as set above.

1.8.1 Single Pole Trip / Operate

As the two circuit breakers execute their AR cycles independently, they can be individually set to trip and AR: 1-pol, 3-pol or 1- and 3-pol.

1.9 Conclusion

The breaker-and-a-half application with SIPROTEC5 can be achieved with flexible combination of the available functions. A logical grouping of protection and control functions is possible to cover the special requirements of all users.

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