

Application Note

Distance protection



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1 DOCUMENT INFORMATION

This document uses the following notation for the various sections in the AQtivate configuration and setting software as well as the keyboard:

- Navigation paths are in italics (e.g. *Tools → Events and Logs → Event History*).
- Buttons and keys are in bold (e.g. the **Enter** key).
- AQtivate main menus are in all caps (e.g. the PROTECTION menu).
- Tabs are in italics (e.g. the *Line Protection Module* tab).
- Section names within tabs are in single quotation marks (e.g. the 'CB control block' support functionality)
- Parameter names are in bold and italics (e.g. the ***Master node status*** parameter).
- Parameter drop-down menu items and text values are in double quotation marks (e.g. "Sub-unit").

Additionally, this document uses the following notices, cautions, and warnings to highlight information that is especially important for the user.

Table 1. Highlighting symbols that can be used in this document.

Symbol	Description
	NOTICE! These messages indicate relevant factors and conditions to the concept discussed in the text, as well as other relevant advice.
	CAUTION! These messages indicate a potentially hazardous situation which, if not avoided, <u>could</u> result in personal injury, equipment/property damage, or software corruption.
	DANGER! These messages indicate a hazardous situation which, if not avoided, <u>could</u> result in serious personal injury or death.

2 INTRODUCTION

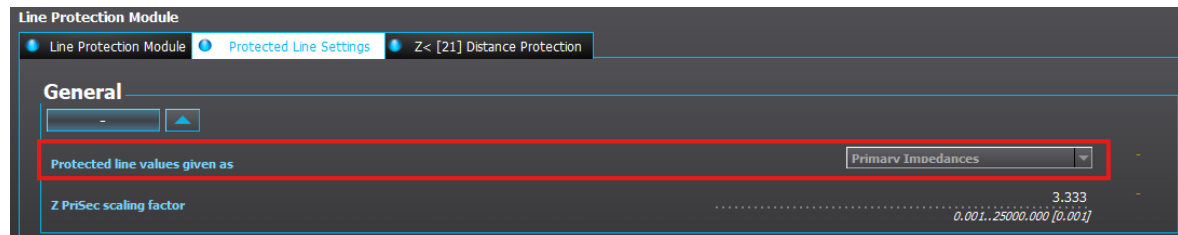
This document provides technical guidance on how to commission a distance protection device. Distance protection is an impedance-based function that provides fast and selective operation, as its setting is not dependent on the current or voltage magnitudes but on the voltage-to-current ratio.

This document goes through the details of setting up the distance function and what the user should take into consideration in the configurations. Transfer trip functionality as well as commissioning tips are also presented in this document.

3 PROTECTED LINE SETTINGS

To start the distance protection configuration, open the AQtivate configuration tool. Then, head to the PROTECTION menu and activate the distance stage in the *Stage activation* tab. Then, open the *Line Protection Module* tab and select the *Protected Line Settings* tab. The protected line settings are given in primary impedances as indicated by the parameter **Protected line values given as** (see Figure 1 below).

Figure 1. 'Protected line values given as' indication.



The primary to secondary scaling factor can be seen in the 'General' section as well. The scaling factor is calculated using the ratios of the voltage transformers (VTs) and current transformers (CTs). This requires that the transformer settings are set correctly in the MEASUREMENT menu. Please refer to the device manuals for more details on the VTs and CTs, available on our website at arcteq.com/documents-and-software. Secondary impedances can be converted to primary by multiplying the secondary values with the scaling factor.

Line parameters can be configured to both forward and reverse directions separately. Both directions can be divided into 5 separate segments, each having their own positive sequence impedance values. Each segment impedance values can be given in three different formats (displayed in Figure 2). These include R/X which are the line segment total resistance and reactance values, (R/X) / km which are the line segment resistance and reactance values per kilometer, and Z/angle which are the line segment impedance magnitude and angle.

Figure 2. Positive sequence line setting formats.

Forward Line Settings

Positive Sequence Line Settings

Forward Line segmenting settings: Equal Segments (Line and Ground)

Forward Line Segments: 1 Segment

Forward Segment 1 values in: Z / Angle

Fwd. Line seg. 1 Length: (R/X) / km

Figure 3 displays an example line configuration.

Figure 3. Example line configuration.

Forward Line Settings

Positive Sequence Line Settings

Forward Line segmenting settings: Equal Segments (Line and Ground)

Forward Line Segments: 3 Segments

Forward Segment 1 values in: (R/X) / km

Fwd. Line seg. 1 Length: 45.000 km

Fwd. Line seg. 1 Pos.Seq. Resistance (RL+) / km: 0.267 ohm/km

Fwd. Line seg. 1 Pos.Seq. Reactance (XL+) / km: 0.330 ohm/km

Forward Segment 2 values in: (R/X) / km

Fwd. Line seg. 2 Length: 45.000 km

Fwd. Line seg. 2 Pos.Seq. Resistance (RL+) / km: 0.089 ohm/km

Fwd. Line seg. 2 Pos.Seq. Reactance (XL+) / km: 0.467 ohm/km

Forward Segment 3 values in: (R/X) / km

Fwd. Line seg. 3 Length: 75.000 km

Fwd. Line seg. 3 Pos.Seq. Resistance (RL+) / km: 0.480 ohm/km

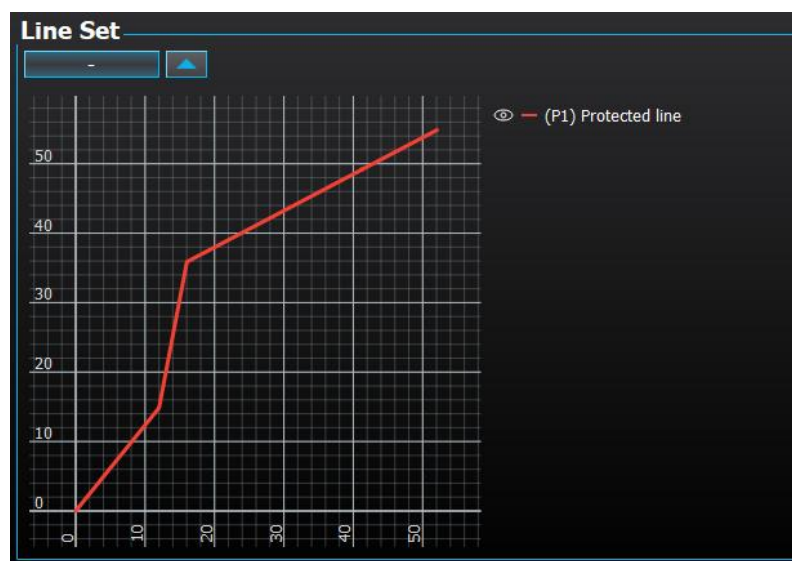
Fwd. Line seg. 3 Pos.Seq. Reactance (XL+) / km: 0.253 ohm/km

The line settings can be verified in the 'Line Settings Verified' section (shown in Figure 4). Figure 5 displays the graph of the verified line configuration.

Figure 4. Verified line settings.

Line Settings Verified		
Forward Line Settings		
Set total line length forward	165.000 km	-
	0.001..1800.000 [0.001]	
Forward Line Segment 1 Resistance (R)	12.015 ohm	-
	0.000..1800.000 [0.001]	
Forward Line Segment 1 Reactance (X)	14.850 ohm	-
	0.000..1800.000 [0.001]	
Forward Line Segment 1 Length	45.000 km	-
	0.001..1800.000 [0.001]	
Forward Line Segment 2 Resistance (R)	16.020 ohm	-
	0.000..1800.000 [0.001]	
Forward Line Segment 2 Reactance (X)	35.865 ohm	-
	0.000..1800.000 [0.001]	
Forward Line Segment 2 Length	90.000 km	-
	0.001..1800.000 [0.001]	
Forward Line Segment 3 Resistance (R)	52.020 ohm	-
	0.000..1800.000 [0.001]	
Forward Line Segment 3 Reactance (X)	54.840 ohm	-
	0.000..1800.000 [0.001]	
Forward Line Segment 3 Length	165.000 km	-
	0.001..1800.000 [0.001]	

Figure 5. Graph of the set line.



The zero sequence compensation setting can be set individually for forward and reverse directions. But the compensation factor for the respective direction is equal for all the line segments. The zero sequence compensation factor (k_0) for Phase to Earth impedances is calculated with the following formula.

$$k_0 = \frac{Z_0 - Z_1}{3 * Z_1} = |k_{0Z}| \angle k_{0ang} = k_{0R} + jk_{0X}$$

The zero sequence settings can be applied in three different formats (displayed in Figure 6). “K0” is the compensation factor itself. In “Line Z0 values” format, the compensation factor is calculated using the given zero sequence and positive sequence impedance values. In “Estimate” format, the user can give estimate of the ratio between the line zero sequence and positive sequence impedances which is then used to calculate the compensation factor.

Figure 6. Zero Sequence Line Setting formats.

Zero Sequence Line Settings

Forward Zero Seq. k0 ***

Forward k0 given in k0 ***

Fwd. Line Zero.Seq. k0 Z 1.000 ohm ***

-10000.000..10000.000 [0.001]

The calculated compensation factor values are displayed under the settings (Figure 7).

Figure 7. Calculated compensation factor values.

Zero Sequence Line Settings

Forward Zero Seq. k0 ***

Forward k0 given in Z/Angle ***

Fwd. Line Zero.Seq. k0 Z 1.000 ohm ***

-10000.000..10000.000 [0.001]

Fwd. Line Zero.Seq. k0 angle 0.000 deg ***

-360.000..360.000 [0.001]

Fwd. Line k0 factor R set 1.000

-10000.000..10000.000 [0.001]

Fwd. Line k0 factor X set 0.000

-10000.000..10000.000 [0.001]

Fwd. Line k0 factor Z set 1.000 ohm

-10000.000..10000.000 [0.001]

Fwd. Line k0 factor Angle set 0.000 deg

-360.000..360.000 [0.001]

4 DISTANCE PROTECTION

4.1 Distance Protection General Settings

The distance function continuously calculates phase-to-phase and phase-to-earth impedance loops as a ratio between voltage and current. The loop calculation formulas are presented in Table 2 below.

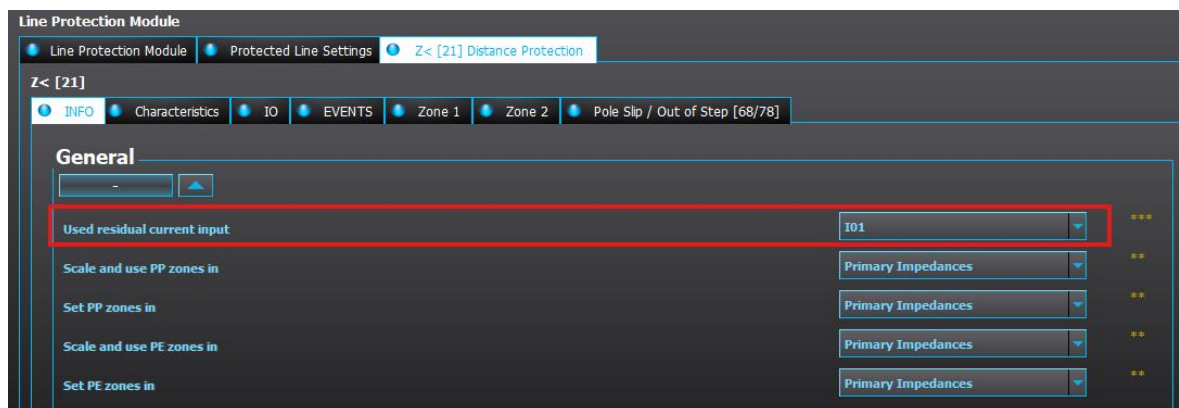
Table 2. Impedance loop calculation formulas.

Phase-to-Phase loops	Phase-to-Earth loops
$Z_{L12} = \frac{U_{L1} - U_{L2}}{I_{L1} - I_{L2}}$	$Z_{L1} = \frac{U_{L1}}{I_{L1} + k0 * I_0}$
$Z_{L23} = \frac{U_{L2} - U_{L3}}{I_{L2} - I_{L3}}$	$Z_{L2} = \frac{U_{L2}}{I_{L2} + k0 * I_0}$
$Z_{L31} = \frac{U_{L3} - U_{L1}}{I_{L3} - I_{L1}}$	$Z_{L3} = \frac{U_{L3}}{I_{L3} + k0 * I_0}$

The k0 factor in the phase-to-earth formulas is the earlier presented zero sequence compensation factor and I_0 is the calculated or measured residual current.

The user can select the used residual current input from the *Distance protection* 'General' section in the *INFO* tab. The input can be either the measured "I01" or "I02" channel or the calculated "I0calc".

Figure 8. Residual current selection.



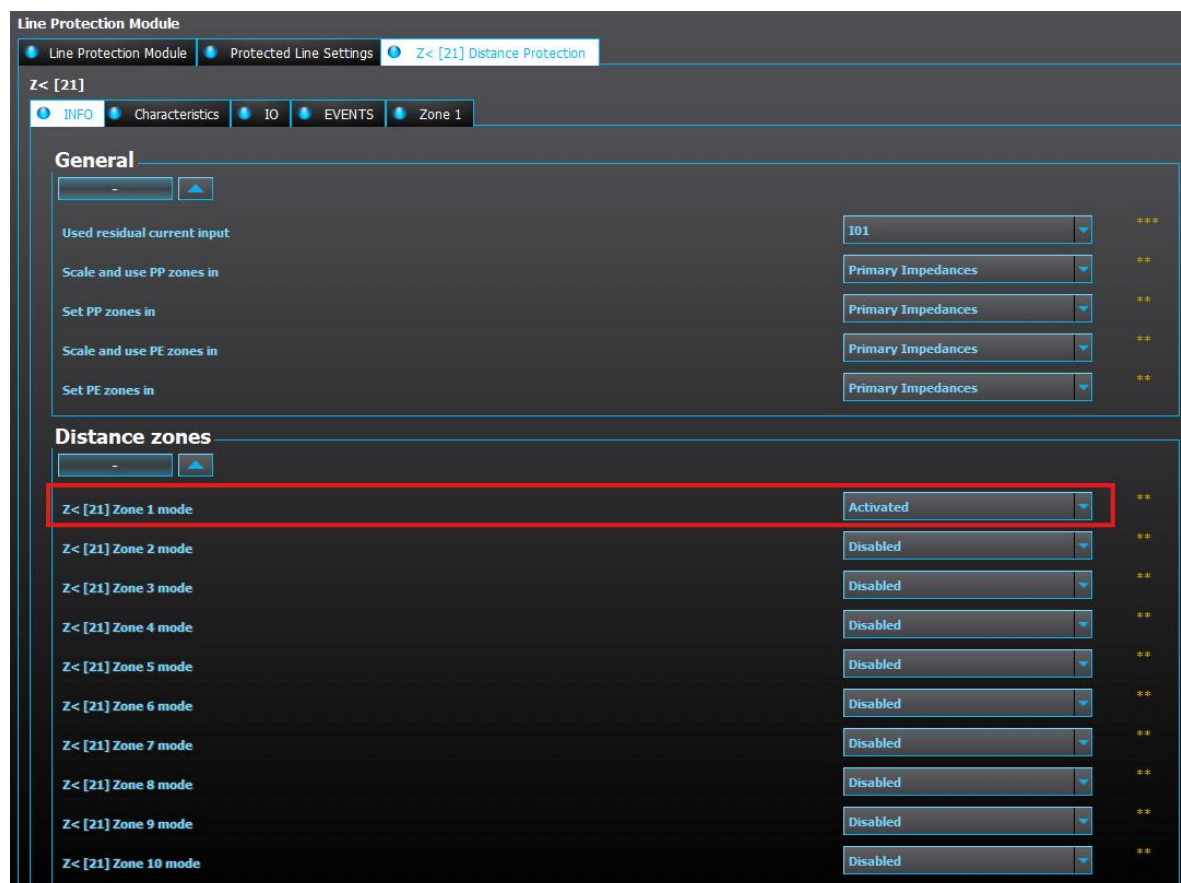
Next the user can select whether to give the settings in primary or secondary impedances using the **Set PP/PE zones in** parameter. The selection **Scale and use PP/PE zones in** defines whether the graphs and fault locator values are presented in primary or secondary impedances. Primary/secondary impedance settings are presented in Figure 9.

Figure 9. Zone primary/secondary scaling options.



Zones 1-10 can be activated in the 'Distance zones' section at the *INFO* tab. The activation is displayed in Figure 10.

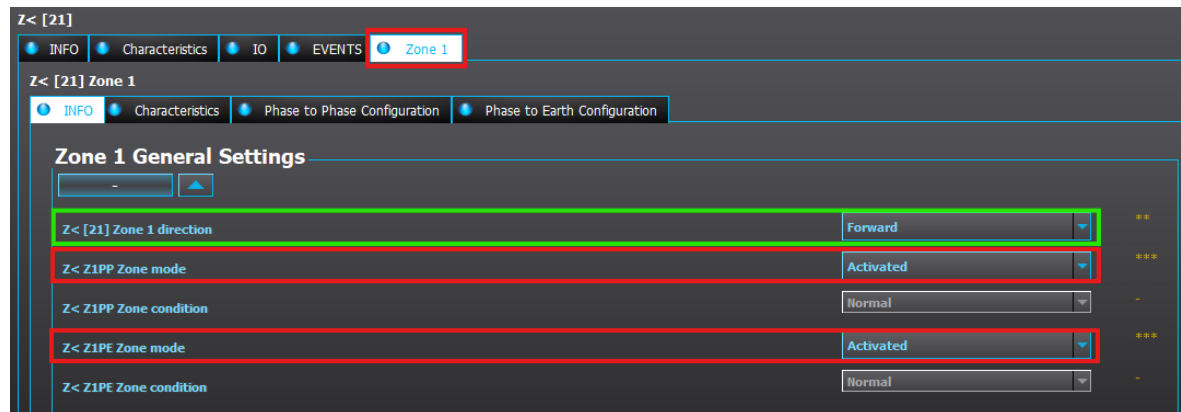
Figure 10. Zone activation section.



After activating a zone, the individual **phase-to-phase ('PP')** and **phase-to-earth ('PE')** loops can be activated separately for the respective zones in 'Zone General Settings'.

In the same section the user can define the **direction** for the zone. The available zone directions are “Forward”, “Reverse”, and “Non Directional”. **Phase-to-phase** and **phase-to-earth** activation as well as **direction** definition is displayed in Figure 11.

Figure 11. Zone direction and phase-to-phase and phase-to-earth loop activation.



Zone direction can also be set individually for PP and PE loops as a setting group controlled parameter in the *Phase to Phase / Phase to Earth Configuration* tab 'Settings' section (see Figure 12). Selecting “Stage controlled” in the parameter **Zone Operating Control** lets the user define the direction individually for each setting group. Selection “Zone common” (Figure 13) means that the direction is decided in the 'Zone General Settings' (please refer to Figure 11).

Figure 12. Zone direction definition in zone settings.

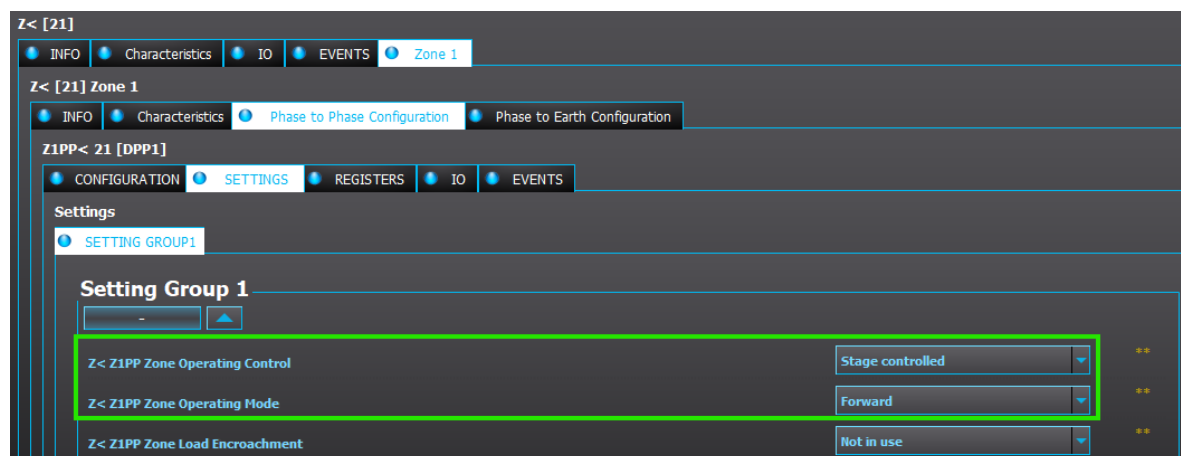
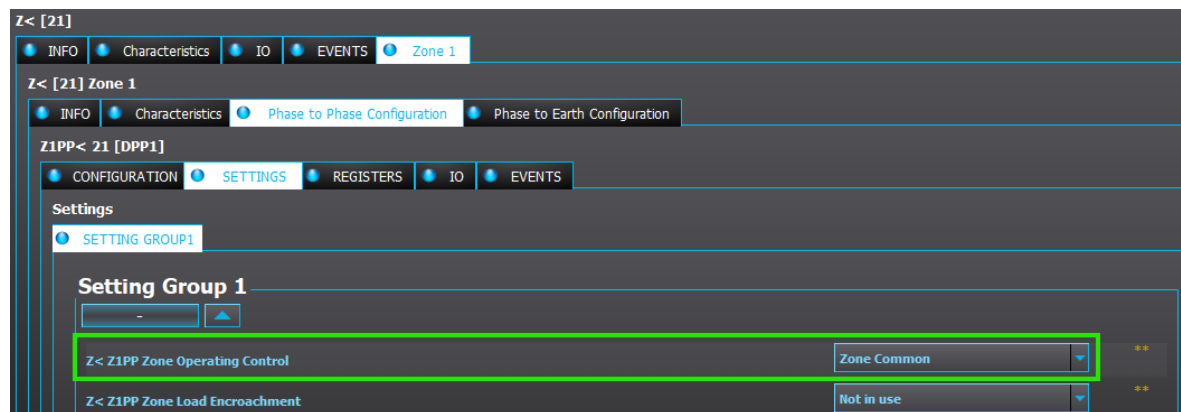


Figure 13. Zone Common setting in zone settings.



4.2 Distance Zone Starter Settings

The user should consider the zone operation starter settings when configuring the distance zones. There are two starter settings for phase-to-phase loops, the impedance starter setting and current starter setting.

The impedance starter setting is used to determine the correct fault loop. When the ratio of measured impedance and the zone maximum impedance decreases below this setting, the fault loop evaluation is started together with the current starter setting. Please note that the starter setting should be set high enough that it covers the maximum value of resistive reach. For example, if the zone reaches 50 Ω due to line angle, and the resistive reach setting is set to 20 Ω , the zone starter setting must be more than 2.5 xSet.

The current starter setting is used to both determine the correct fault loop as well as to block the operation of the distance zone if the measured phase-to-phase current doesn't exceed the set value.

The impedance and current starter settings for phase-to-phase loops are located in the *Configuration* tab of the respective loop (see Figure 14).

Figure 14. Phase-to-phase loop starter settings.

Z1PP General Settings

Z < Z1PP Zone Starter setting (Z meas < x Rmax x Xmax) xSet **
Range: 1.50..150.00 [0.01]

Z12 Impedance / Start set 11.607 ohm/se.
Range: -1800.000..1800.000 [0.001]

Z23 Impedance / Start set 11.607 ohm/se.
Range: -1800.000..1800.000 [0.001]

Z31 Impedance / Start set 11.607 ohm/se.
Range: -1800.000..1800.000 [0.001]

Z < Z1PP Zone Starter setting (I meas > Iminset) xIn **
Range: 0.01..150.00 [0.01]

I12 Current / Start set 0.000 I meas/I
Range: -1800.000..1800.000 [0.001]

I23 Current / Start set 0.000 I meas/I
Range: -1800.000..1800.000 [0.001]

I31 Current / Start set 0.000 I meas/I
Range: -1800.000..1800.000 [0.001]

Impedance Loop selected

Phase-to-earth loops have three starter settings. These include the impedance starter, residual current starter, and residual voltage starter. The working principle of the impedance starter setting is the same as the phase-to-phase loop.

Residual current starter setting determines the minimum value of measured residual current for the zone to operate. Residual voltage starter setting determines the minimum value of measured residual voltage for the zone to operate.

The phase-to-earth starter settings are displayed in Figure 15.

Figure 15. Phase-to-earth loop starter settings.

Z1PE General Settings

Z < Z1PE Zone Starter setting ($Z_{meas} < x R_{max} x X_{max}$) **xSet** **
Range: 1.50..150.00 [0.01]

Z1 Impedance / Start set **ohm/se** **
Range: -1800.000..1800.000 [0.001]

Z2 Impedance / Start set **ohm/se** **
Range: -1800.000..1800.000 [0.001]

Z3 Impedance / Start set **ohm/se** **
Range: -1800.000..1800.000 [0.001]

Z < Z1PE Zone Starter setting (xI_{0n}) **xI0n** **
Range: 0.010..150.000 [0.001]

Set Minimum I_0 current in primary A **Apri** **
Range: -1800.000..1800.000 [0.001]

Measured I_0 current in primary A **Apri** **
Range: -1800.000..1800.000 [0.001]

I_0 Current / Start set **Imeas/I** **
Range: -1800.000..1800.000 [0.001]

Z < Z1PE Zone Starter setting ($U_{0meas} > U_{0minset}$) (Set 0 to bypass condition) **%U0n** **
Range: 0.00..150.00 [0.01]

U0 Voltage / Start set **U0/U0s** **
Range: -1800.000..1800.000 [0.001]

Z0 meas (Pri) **ohm** **
Range: -1800.000..1800.000 [0.001]

Impedance Loop selected



NOTICE!

Verify the starter setting values when commissioning the distance function. Fault values should always exceed the starter setting values.

4.3 Distance Zone Characteristic Settings

Forward and reverse facing zones have similar zone characteristic settings. The settings include line segment configuration, resistive and reactive reaches, maximum resistive reach as well as zone 2nd and 4th Quadrant angles. The operation time settings are also located in the settings section (Figure 16).

Figure 16. Zone characteristic and operation time settings.

Z< [21] Zone 1

INFO Characteristics **Phase to Phase Configuration** Phase to Earth Configuration

Z1PP< 21 [DPP1]

CONFIGURATION **SETTINGS** REGISTERS IO EVENTS

Settings

SETTING GROUP1

Setting Group 1

Z< Z1PP Zone Operating Control Zone Common

Z< Z1PP Zone Load Encroachment Not in use

Z< Z1PP Zone Line segments forward 1 segs

Z< Z1PP Zone Resistive reach R< 15.00 Ohm

Z< Z1PP Zone Reactive reach X< 28.69 Ohm

Z< Z1PP Zone Maximum Q1/Q3 resistive reach RmaxQ1/Q3< (0 disabled) 27.50 Ohm

Z< Z1PP Zone Angle (FwdQ2 / RevQ4) Resistive reach (90 deg + set) 15.00 deg

Z< Z1PP Zone Angle (RwdQ4 / RevQ2) Resistive reach (0 deg - set) 15.00 deg

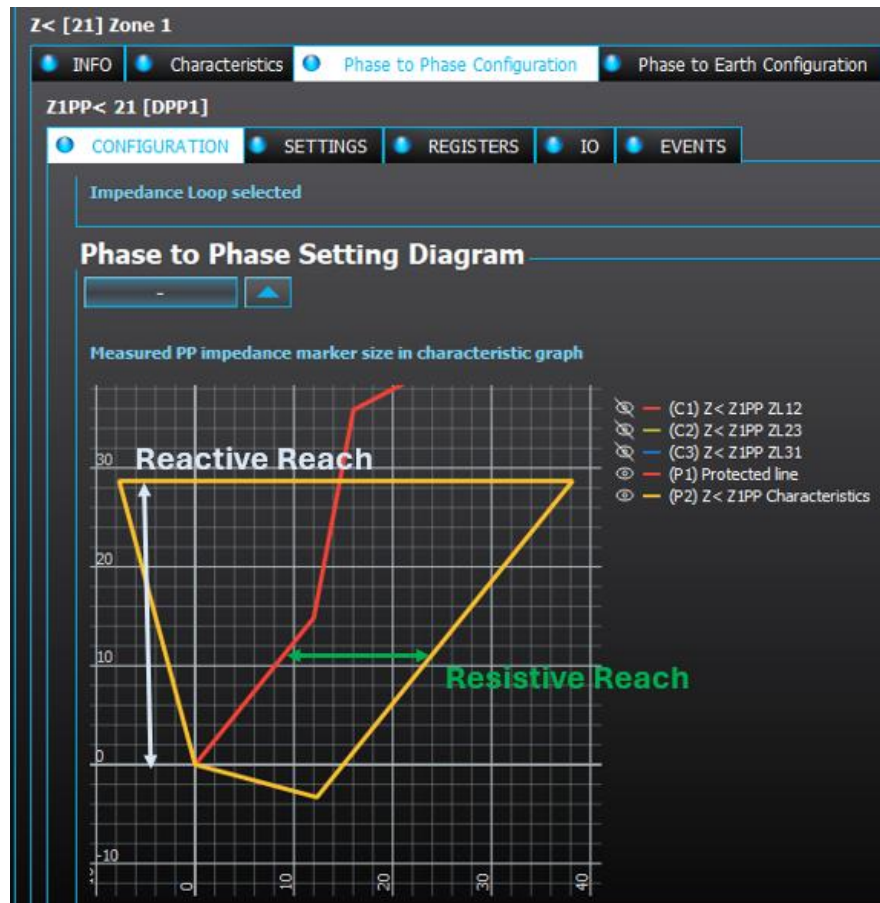
Definite (min) operating time delay 0.000 s

Delayed Pick-up release Yes

Release Time delay 0.060 s

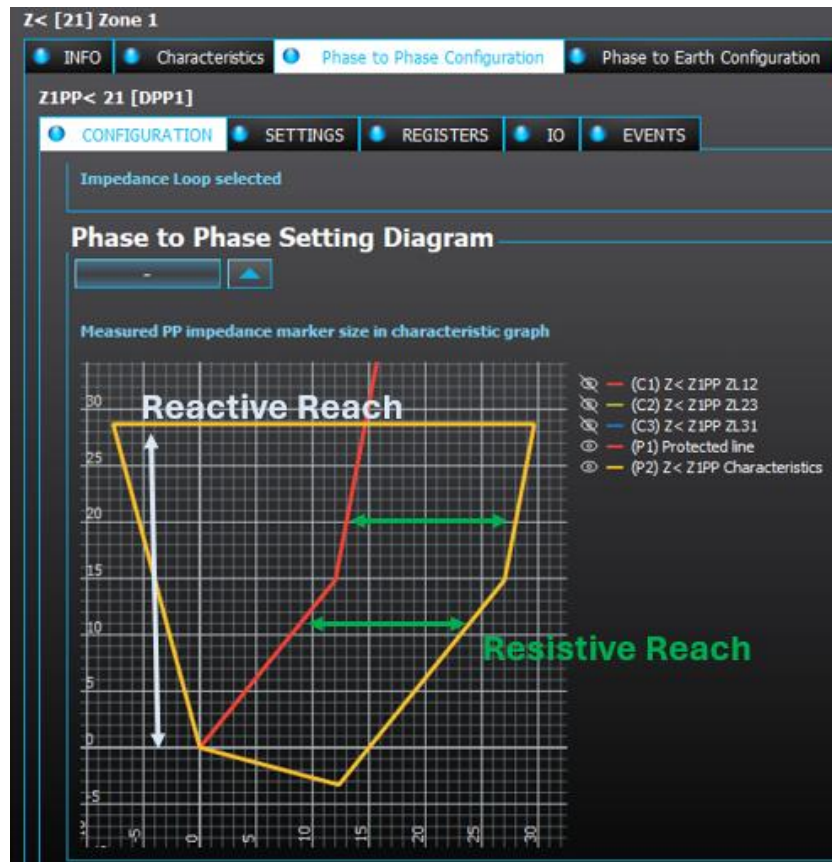
The reactive reach defines the zone length, and the zone resistive reach is added to the line resistive reach. The resulting characteristic and reach definitions can be seen in Figure 17.

Figure 17. Reactive and resistive reaches with one line segment in use.



The zone resistive reach can be made to follow the line resistive reach even if there are multiple line segments with different impedance values. In this example, the zone reactive reach covers two line segments. Configuring 2 to the **Zone Linesegments forward** setting (please refer to Figure 16 in the previous page) changes the zone resistive reach characteristic to follow the respective line segment angle. This is displayed in Figure 18.

Figure 18. Reactive and resistive reaches with two line segments in use.



The zone resistive reach can be limited using the parameter **Zone Maximum Q1/Q3 resistive reach**. Leaving this parameter to value 0 disables the limitation. Please refer to Figure 19 for the setting and Figure 20 for the resulting characteristic.

Figure 19. Zone maximum resistive reach setting.

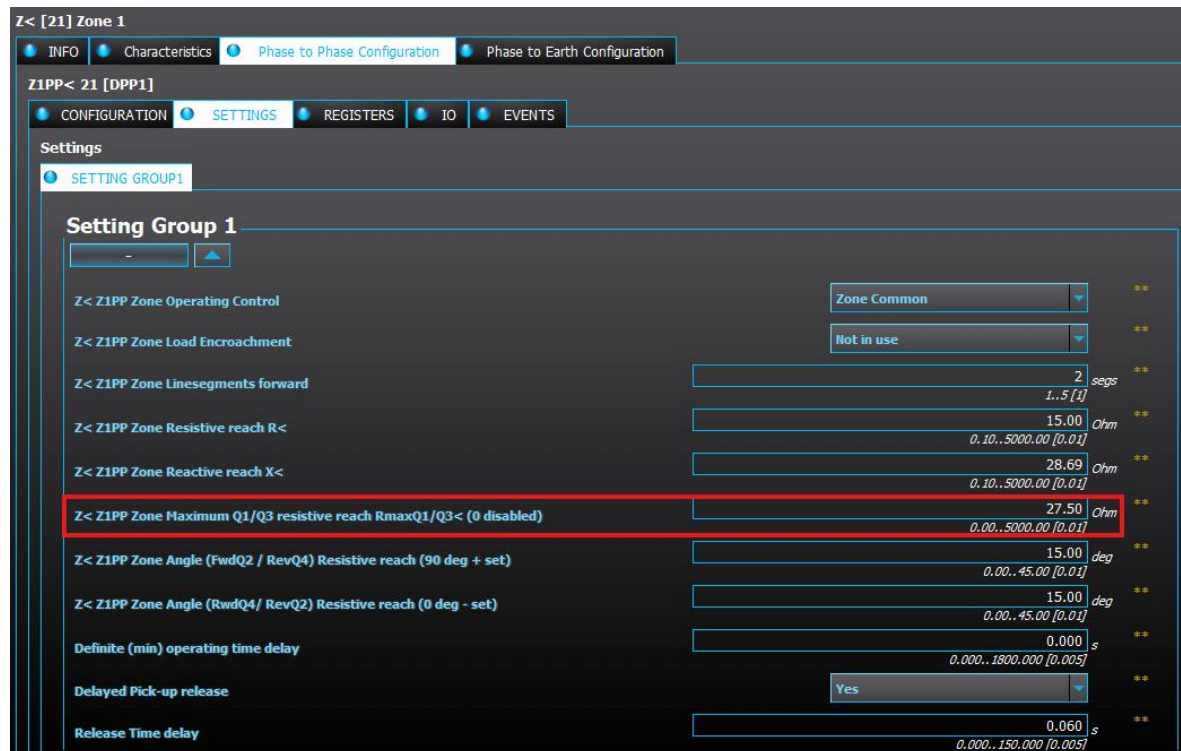


Figure 20. Resistive reach limited.



Zone angles i.e. the zone safety margins extend the zone reach to the 2nd and 4th Quadrants. These angles can be set with the parameters shown in Figure 21.

Figure 21. Zone angle settings.

Z1PP < 21 [DPP1]

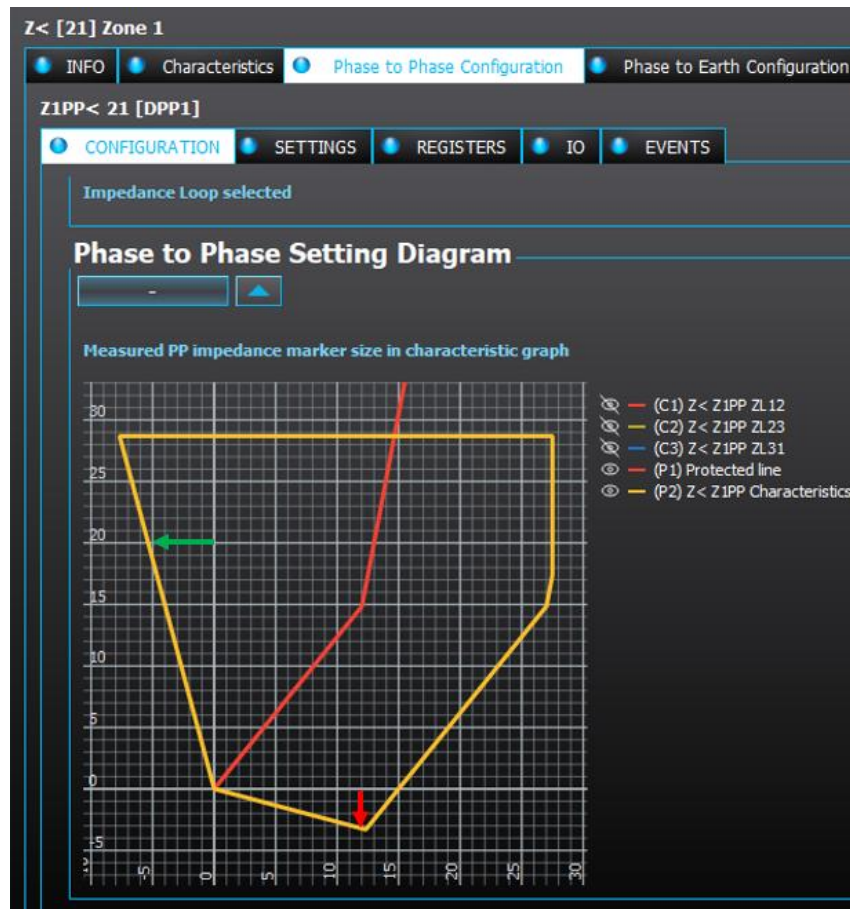
Settings

Setting Group 1

Z < Z1PP Zone Operating Control	Zone Common	**
Z < Z1PP Zone Load Encroachment	Not in use	**
Z < Z1PP Zone Line segments forward	2 segs	**
Z < Z1PP Zone Resistive reach R<	15.00 Ohm	**
Z < Z1PP Zone Reactive reach X<	28.69 Ohm	**
Z < Z1PP Zone Maximum Q1/Q3 resistive reach RmaxQ1/Q3< (0 disabled)	27.50 Ohm	**
Z < Z1PP Zone Angle (FwdQ2 / RevQ4) Resistive reach (90 deg + set)	15.00 deg	**
Z < Z1PP Zone Angle (RwdQ4 / RevQ2) Resistive reach (0 deg - set)	15.00 deg	**
Definite (min) operating time delay	0.000 s	**
Delayed Pick-up release	Yes	**
Release Time delay	0.060 s	**

The angles are explained in the characteristic of Figure 22.

Figure 22. Zone angles in the characteristic.



Non directional zone characteristic configuration follows the same principles as the forward and reverse zones. The exception for non directional zone is that the reach settings are given independently for both directions, and the zone maximum resistive reach parameter isn't available. There are two modes for a non directional zone resistive reach characteristic, the "Forward-Reverse" mode and the "Forward-Backward" mode.

In "Forward-Reverse" mode the same reverse resistive reach settings apply to both resistive directions of the reverse line. Please refer to Figure 23 for the settings and Figure 24 for the resulting characteristic.

Figure 23. Non directional zone characteristic settings, "Forward-Reverse" mode.

Z< [21] Zone 2

INFO Characteristics **Phase to Phase Configuration** Phase to Earth Configuration

Z2PP< 21 [DPP2]

CONFIGURATION **SETTINGS** REGISTERS IO EVENTS

Settings

SETTING GROUP1

Setting Group 1

Z< Z2PP Zone Operating Control Zone Common **

Z< Z2PP Zone Load Encroachment Not in use **

Z< Z2PP Zone Linesegments forward 2 segs 1..5 [1] **

Z< Z2PP Zone Linesegments reverse 2 segs 1..5 [1] **

Z< Z2PP Zone Resistive reach R< 15.00 Ohm 0.10..5000.00 [0.01] **

Z< Z2PP Zone Reactive reach X< 28.69 Ohm 0.10..5000.00 [0.01] **

Z< Z2PP Resistive reach mode Forward-Reverse **

Z< Z2PP Zone Resistive reach R< Reverse(X < 0) 7.50 Ohm 0.10..5000.00 [0.01] **

Z< Z2PP Zone Reactive reach X< Reverse (X < 0) 28.69 Ohm 0.10..5000.00 [0.01] **

Definite (min) operating time delay 0.000 s 0.000..1800.000 [0.005] **

Delayed Pick-up release Yes **

Figure 24. Non directional characteristic, "Forward-Reverse" mode.



In "Forward-Backward" mode the reverse resistive reach setting is applied to negative resistive direction of both forward and reverse line directions. Please refer to Figure 25 for the settings and Figure 26 for the resulting characteristic.

Figure 25. Non directional zone characteristic settings, "Forward-Backward" mode.

Z< [21] Zone 2

INFO Characteristics **Phase to Phase Configuration** Phase to Earth Configuration

Z2PP< 21 [DPP2]

CONFIGURATION **SETTINGS** REGISTERS IO EVENTS

Settings

SETTING GROUP1

Setting Group 1

Z< Z2PP Zone Operating Control Zone Common **
 Z< Z2PP Zone Load Encroachment Not in use **
 Z< Z2PP Zone Linesegments forward 2 segs 1..5 [1] **
 Z< Z2PP Zone Linesegments reverse 2 segs 1..5 [1] **
 Z< Z2PP Zone Resistive reach R< 15.00 Ohm 0..10..5000.00 [0.01] **
 Z< Z2PP Zone Reactive reach X< 28.69 Ohm 0..10..5000.00 [0.01] **
 Z< Z2PP Resistive reach mode Forward-Backward **
 Z< Z2PP Zone Resistive reach R< Reverse(X < 0) 7.50 Ohm 0..10..5000.00 [0.01] **
 Z< Z2PP Zone Reactive reach X< Reverse (X < 0) 28.69 Ohm 0..10..5000.00 [0.01] **
 Definite (min) operating time delay 0.000 s 0.000..1800.000 [0.005] **
 Delayed Pick-up release Yes **

Figure 26. Non directional characteristic, "Forward-Backward" mode.



5 SUPPORT FUNCTIONALITIES

5.1 Fast VT Supervision

Fast VT supervision monitors the voltage and current of each phase. If the voltage of one phase drops below the **ULow** setting value and the measured current of the respective phase is between the **ULow** and **Current high limits**, VT failure signal is activated. The VT failure signal is connected internally to block the operation of the distance zones for the respective phases so no software connections are needed. The Fast VT supervision status signal can be used for indication purposes and is found in the device Matrix and logic.

You can find the Fast VT supervision function in the *INFO* tab (*Line Protection Module* → *Line Protection module* → *INFO*). The Fast VT supervision settings are shown in Figure 27 below.

Figure 27. Fast VT supervision settings.

The screenshot displays the 'Fast VT supervision' settings within the 'Line Protection Module [LPM]' under the 'INFO' tab. The settings are organized into two main sections: 'Send' and 'Received', and a 'Fast VT supervision' section with various parameters.

Send Section:

- Process Bus Master Trip send (Edit button)

Received Section:

- Process Bus Master Trip Receive (Edit button)

Fast VT supervision Section:

- Fast VT supervision: Activated (Dropdown menu, status: ***)
- Fast VT supervision operation: 3PH (Dropdown menu, status: ***)
- Fast VT detection mode: 2nd Max (Dropdown menu, status: ***)
- Fast VT supervision status: Not blocking (Dropdown menu, status: -)
- Fast VT supervision status L1: Not blocking (Dropdown menu, status: -)
- Fast VT supervision status L2: Not blocking (Dropdown menu, status: -)
- Fast VT supervision status L3: Not blocking (Dropdown menu, status: -)
- Fast VT supervision low voltage limit (ULow) also minimum load current limit: 0.10 (Input field, status: ***)
- Fast VT supervision low sensitivity factor (xULow): 1.50 (Input field, status: ***)
- Fast VT supervision Current high limit: 1.30 (Input field, status: ***)

The operation mode of the function can be selected to block all three phases with "3PH" mode or only the failed phase/phases with the "Phase-wise" mode. The **Fast VT supervision detection** mode determines the sensitivity of the VT supervision function. The **Fast VT supervision low sensitivity factor (xULow)** is used to determine the hysteresis of the function.

CAUTION!



The following principles should be noted when setting the **Current high limit** parameter:

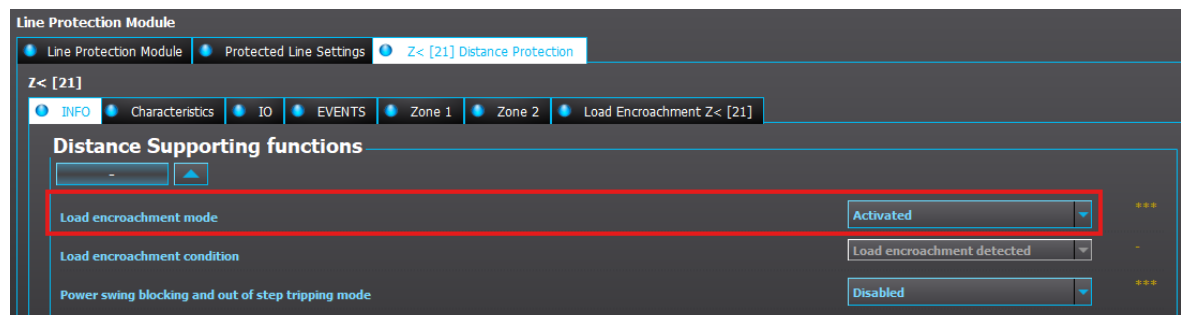
- The value should be set above the maximum expected load current to prevent normal operating conditions from incorrectly triggering a VT failure condition.
- On the other hand, the value should be set sufficiently low such that, under fault conditions causing a voltage drop below the configured **ULow** threshold, the resulting fault current will exceed this limit.

5.2 Load Encroachment

The load encroachment function sets an area in zone characteristic in which the zone operation is restrained.

You can activate the Load encroachment function in the *INFO* tab (*Line Protection Module* → *Z< [21]* Distance Protection → *INFO*) in the 'Distance Supporting functions' section (see Figure 28 below).

Figure 28. Load encroachment activation.



Load encroachment setting parameters can be found in the *Load Encroachment Z< [21]* tab. After configuring the load area, the encroachment can be applied to each zone in the respective zone settings (see Figure 29).

Figure 29. Load encroachment enabling in zone settings.

Z< [21] Zone 1

INFO Characteristics **Phase to Phase Configuration** Phase to Earth Configuration

Z1PP< 21 [DPP1]

CONFIGURATION **SETTINGS** REGISTERS IO EVENTS

Settings

SETTING GROUP1

Setting Group 1

Z< Z1PP Zone Operating Control Zone Common **

Z< Z1PP Zone Load Encroachment Is used in this Zone **

Z< Z1PP Zone Linesegments forward 2 segs **

Z< Z1PP Zone Resistive reach R< 15.00 Ohm **

Z< Z1PP Zone Reactive reach X< 28.69 Ohm **

Z< Z1PP Zone Maximum Q1/Q3 resistive reach RmaxQ1/Q3< (0 disabled) 27.50 Ohm **

Z< Z1PP Zone Angle (FwdQ2 / RevQ4) Resistive reach (90 deg + set) 15.00 deg **

Z< Z1PP Zone Angle (RwdQ4 / RevQ2) Resistive reach (0 deg - set) 15.00 deg **

Definite (min) operating time delay 0.000 s **

Delayed Pick-up release Yes **

Release Time delay 0.060 s **

Applying the encroachment to zone characteristics results in the zone characteristic to be updated (Figure 30).

Figure 30. Load encroachment in zone characteristic.



5.3 Power Swing Blocking and Out-of-Step Tripping

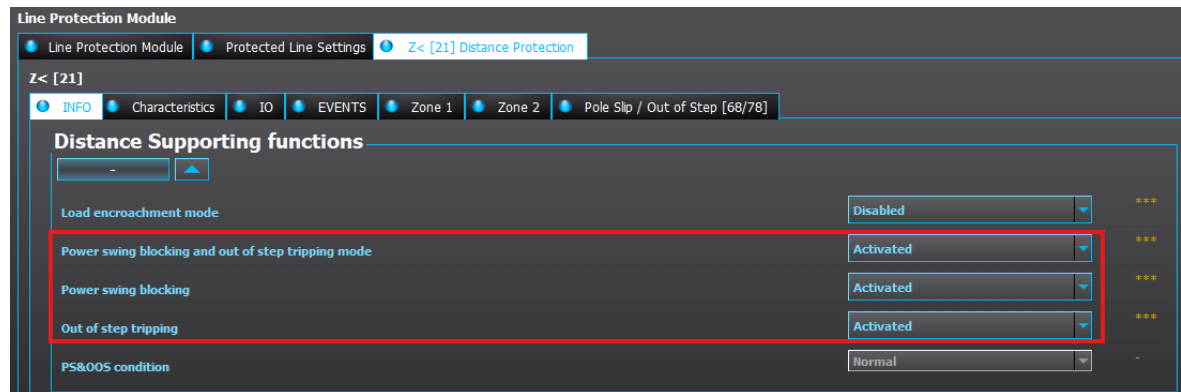
During a stable power swing, the positive sequence impedance trajectory may cross into the operating characteristic area of a distance zone. Hence, power swing blocking is essential for distance protection as it is used to prevent the unnecessary operation of the distance function.

For unstable power swings and pole slipping or out-of-step conditions, the out-of-step tripping function is applied.

For more technical information about the power swing blocking and out-of-step tripping functions, please refer to the device manuals, available on our website at <https://www.arcteq.com/documents-and-software/>.

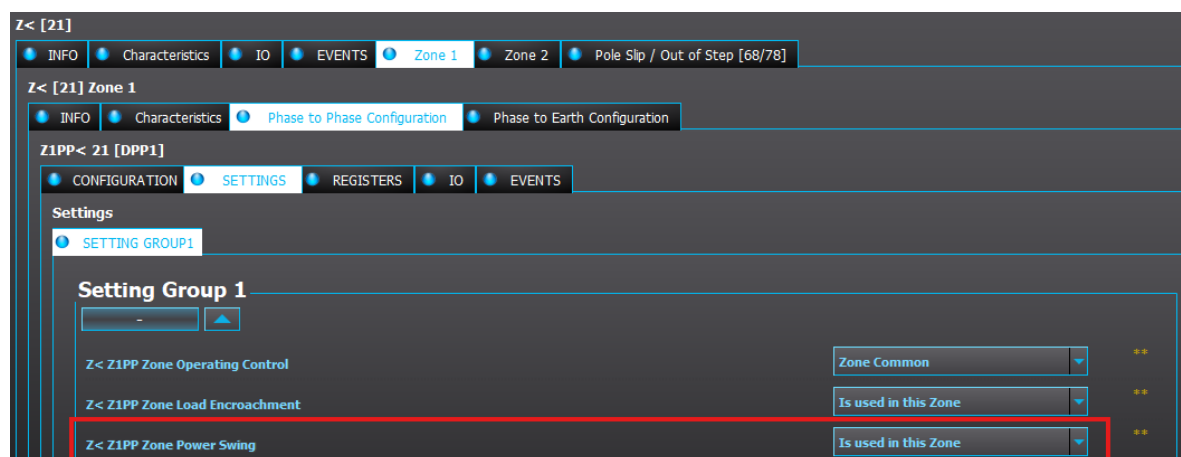
You can activate the Power swing blocking and out of step tripping functions in the *INFO* tab (*Line Protection Module* → *Z< [21] Distance Protection* → *INFO*) in the 'Distance Supporting functions' section (see Figure 31 below).

Figure 31. Power swing blocking and Out of step tripping function activation.



The power swing blocking can then be enabled for each zone separately in zone settings using the parameter **Zone Power Swing** parameter. No additional configurations are needed for the Power swing blocking. See Figure 32 for more information.

Figure 32. Power swing blocking enabling in zone settings.

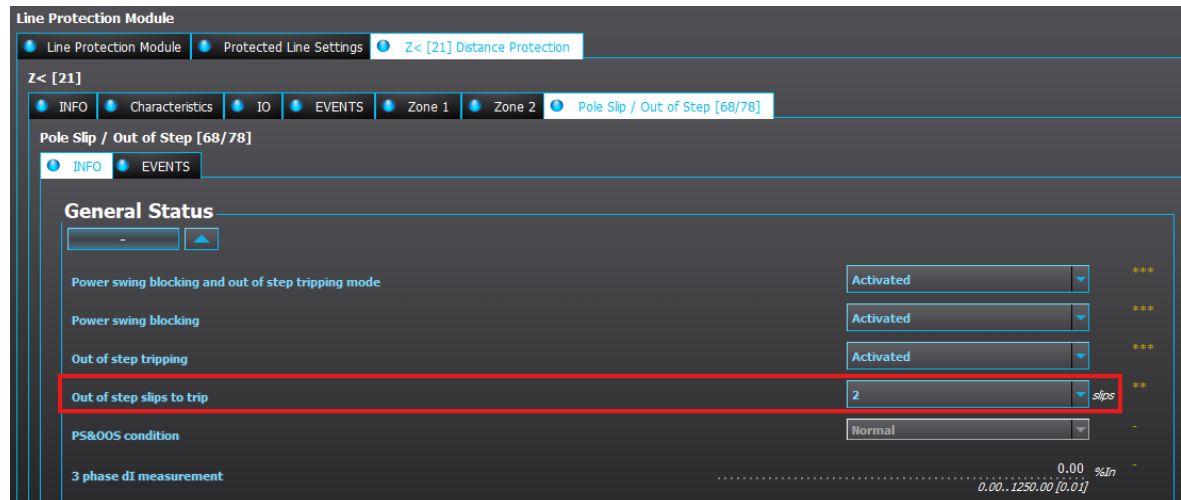


The power swing blocking has been verified to be functioning in both slow and fast power swings. For slow swings the blocking works down to 4 second, 0,1 Hz swings. Meanwhile, fast swings have been tested up to 0,2 second, 7 Hz swings.

The power swing blocking activation is prevented if a fault occurs during a swing. If there is 2nd harmonic content in any of the phase currents, the power swing blocking is restrained for a 450 ms period. The blocking is also restrained if the phase angle balance exceeds a variation of +/- 10 degrees.

For Out of step tripping, after activating the function there is only one parameter to be configured which is the **Out of step slips to trip** setting, located in *INFO* tab (*Line Protection Module* → *Z< [21] Distance Protection* → *Pole Slip / Out of Step [68/78]* → *INFO*). Please refer to Figure 33 below.

Figure 33. Out of step tripping settings. The setting range for the slips to trip setting is 1-5 slips.



The Out of step tripping function has its own output that can be found in the device Matrix and logic (see Figure 34).

Figure 34. Out of step tripping output in Matrix.

Line Protection Module

Line Protection Module Protected Line Settings Z< [21] Distance Protection

Z< [21]

INFO Characteristics IO EVENTS Zone 1 Zone 2 Pole Slip / Out of Step [68/78]

IO

Direct Output Control Blocking Input Control

Show connected only

Inputs	OUT1	OUT2	OUT3	OUT4	OUT5
Load Encroachment active					
Power swing blocking active					
Out of step trip					
Z< Z1PP Zone START					
Z< Z1PP Zone TRIP					
Z< Z1PP Zone BLOCKED					
Z< Z2PP Zone START					
Z< Z2PP Zone TRIP					
Z< Z2PP Zone BLOCKED					
Z< Z3PP Zone START					
Z< Z3PP Zone TRIP					
Z< Z3PP Zone BLOCKED					
Z< Z4PP Zone START					
Z< Z4PP Zone TRIP					
Z< Z4PP Zone BLOCKED					
Z< Z5PP Zone START					
Z< Z5PP Zone TRIP					
Z< Z5PP Zone BLOCKED					
Z< Z6PP Zone START					
Z< Z6PP Zone TRIP					
Z< Z6PP Zone BLOCKED					
Z< Z7PP Zone START					
Z< Z7PP Zone TRIP					
Z< Z7PP Zone BLOCKED					
Z< Z8PP Zone START					
Z< Z8PP Zone TRIP					
Z< Z8PP Zone BLOCKED					
Z< Z9PP Zone START					
Z< Z9PP Zone TRIP					
Z< Z9PP Zone BLOCKED					
Z< Z10PP Zone START					
Z< Z10PP Zone TRIP					

6 TRANSFER TRIP

Each Arcteq's distance protection device is equipped with high speed Process Bus functionality which can be used to transfer signals between two Arcteq line protection devices. In distance protection applications the Teleprotection functionality can be implemented with the Process Bus. The following section provides you with guidance on how to utilize the Process Bus in distance applications.

You can find all the Process Bus settings in the *Line Protection Module* tab (PROTECTION → *Line Protection Module*).

6.1 Process Bus setup

The Process Bus configuration starts with assignment of IED roles. One device must be assigned as "Master node", and the other as "Sub node". In the case of distance protection application, the role assignment of which device is "Master" and which is "Sub" is not significant.

Please refer to our Line differential protection Application note on how to commission the Process Bus. The Application note is available on our website (AQ 200 series protection devices → Resources) <https://www.arcteq.com/documents-and-software/>.

6.2 Master trip

Master trip is a support functionality located in the 'Master trip' section in the *INFO* tab. The master trip signals allow the transmission of trip commands to remote end.

An example of master trip signal transfer is shown in Figure 35. In the example the local distance device sends its zone 1 trip signals to the remote device and activates its output 1 when it receives the remote device master trip signal.

Figure 35. Master trip functionality.

Master Trip

Send

- ▲

Process Bus Master Trip send

Z< Z1PP Zone TRIP

Z< Z1PE Zone TRIP

Edit

Received

- ▲

Process Bus Master Trip Receive

OUT1

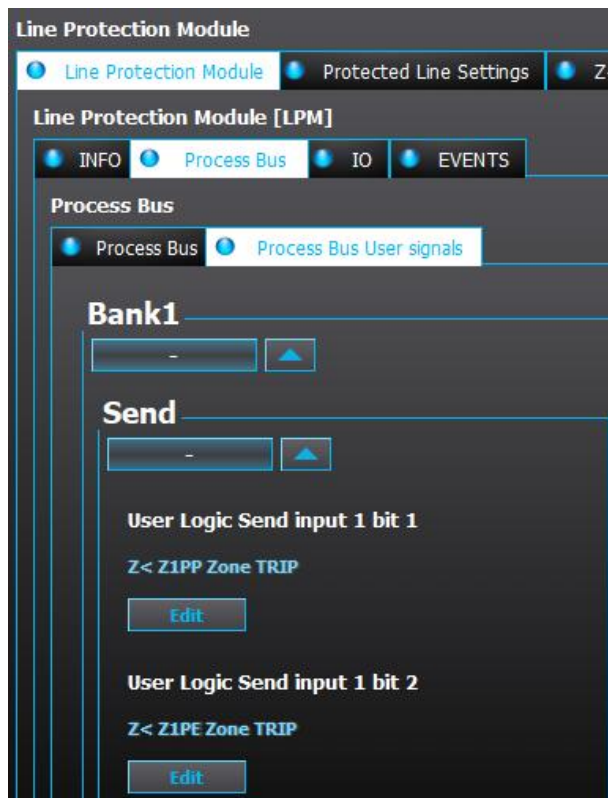
Edit

6.3 Permissive Underreach Transfer Trip (PUTT)

The Permissive Underreach Transfer Trip (PUTT) can be implemented with the use of Process Bus and device logic. In an underreaching distance scheme, two distance devices have instantaneous underreaching zones in both ends of the protected line segment. As a consequence, a fault at the end of the line would be cleared with a significant delay by the remote device, as the next overreaching zone has typically a few hundred millisecond delay. In a PUTT scheme, both distance devices send their underreaching zone (Z1) **trip** signals which, combined with the overreaching zone (Z2) **start** signal in the remote device, accelerate the remote device trip.

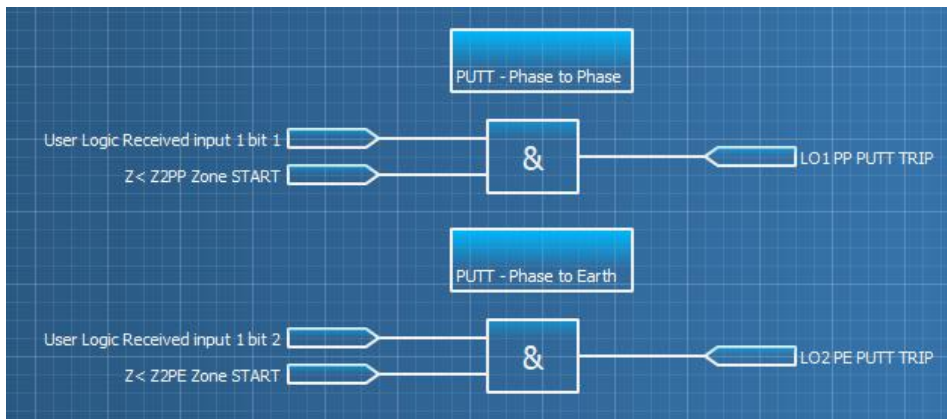
The local zone 1 trip signals are sent to remote device in both devices using the Process Bus. The Process Bus signal configuration is done in the *Process Bus User signals* tab located in the Process Bus menu. The user can assign the sent signals in the 32-bit banks (see Figure 36).

Figure 36. Process Bus sent signals, PUTT scheme.



These signals can be configured in the logic editor using the *User Logic Received input* signals. The received underreaching zone 1 **trip** is then combined with the local zone 2 **start** signal to create an accelerated trip. See Figure 37 for reference.

Figure 37. PUTT logic.



6.4 Permissive Overreach Transfer Trip (POTT)

The operating principle of Permissive Overreach Transfer Trip (POTT) scheme is the same as with the underreaching one. The main difference is that in POTT scheme the overreaching zone 2 **start** signal is sent to the remote device. Combining this received signal together with the local zone 2 **start** signal accelerates the remote device trip. Figure 38 shows the sent zone 2 start signals. Figure 39 shows the logic of the POTT scheme.

Figure 38. Process Bus sent signals, POTT scheme.

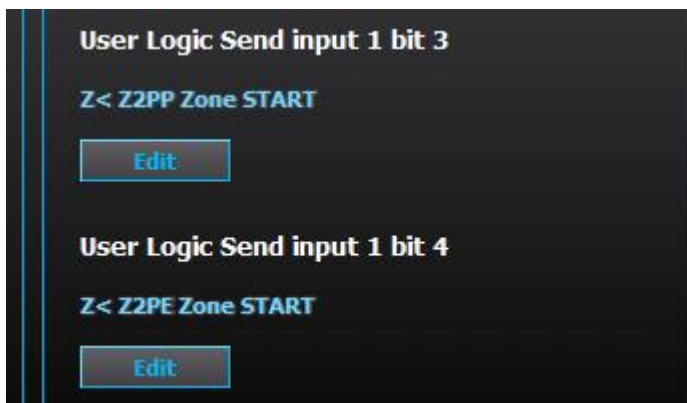
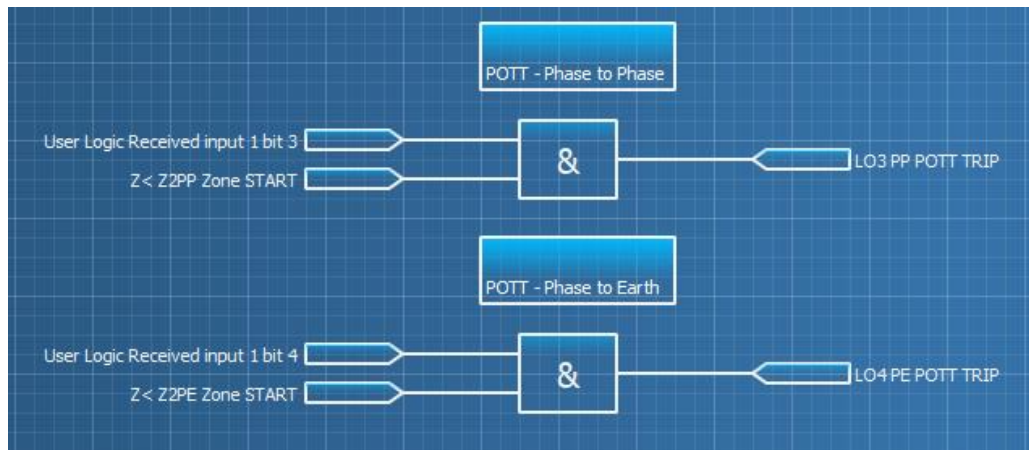


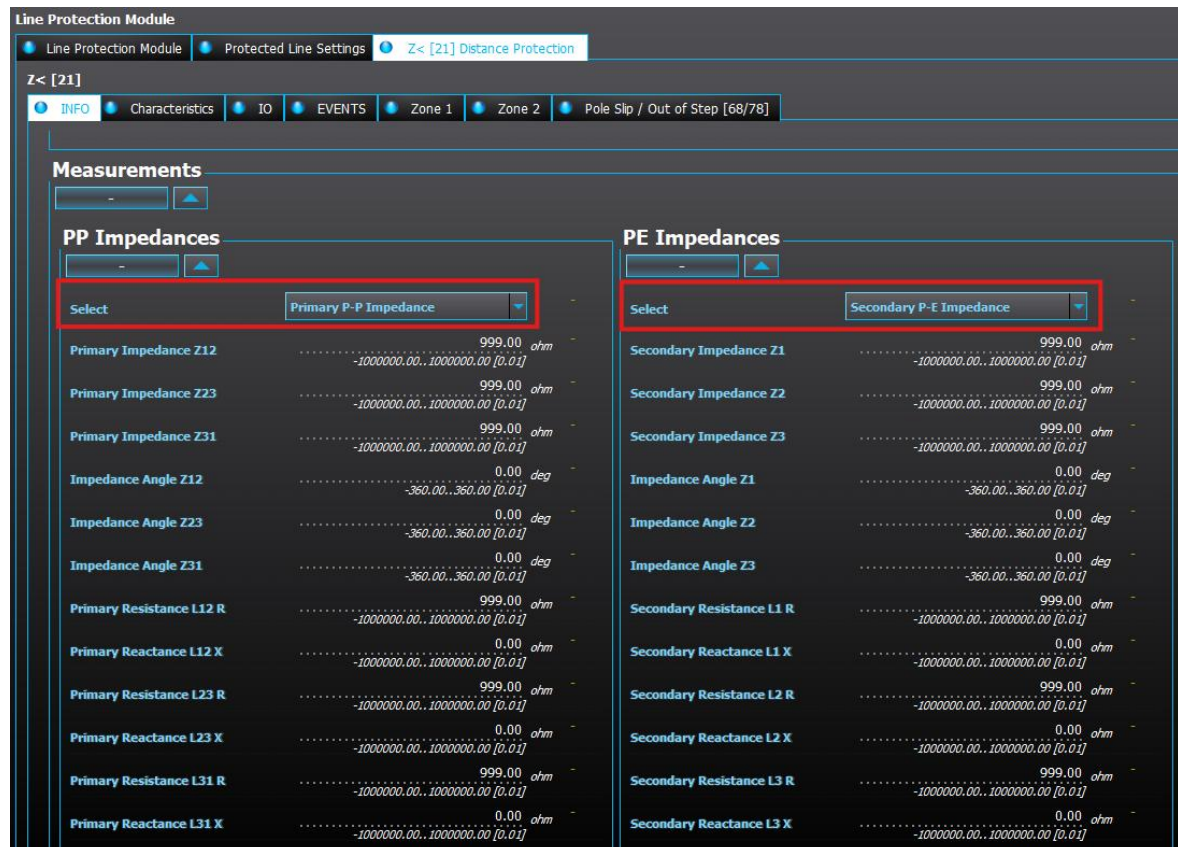
Figure 39. POTT logic.



7 COMMISSIONING

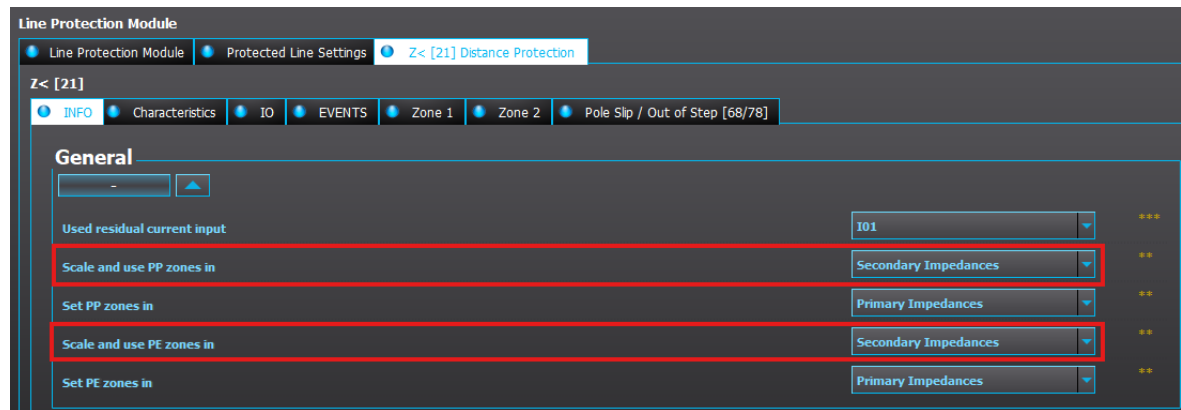
To ease the commission of an Arcteq distance device, the user can switch between primary and secondary impedance measurements and graphs. On the *INFO* tab of the Distance protection page, the 'Measurements' section contains all the phase-to-phase (PP) and phase-to-earth (PE) impedance measurements. These measurements can be viewed in both primary and secondary impedances (see Figure 40 below).

Figure 40. Impedance measurement primary and secondary scaling.



As mentioned previously, the zone graphs can be viewed in both primary and secondary, using the selections in Distance protection *INFO* tab (see Figure 41).

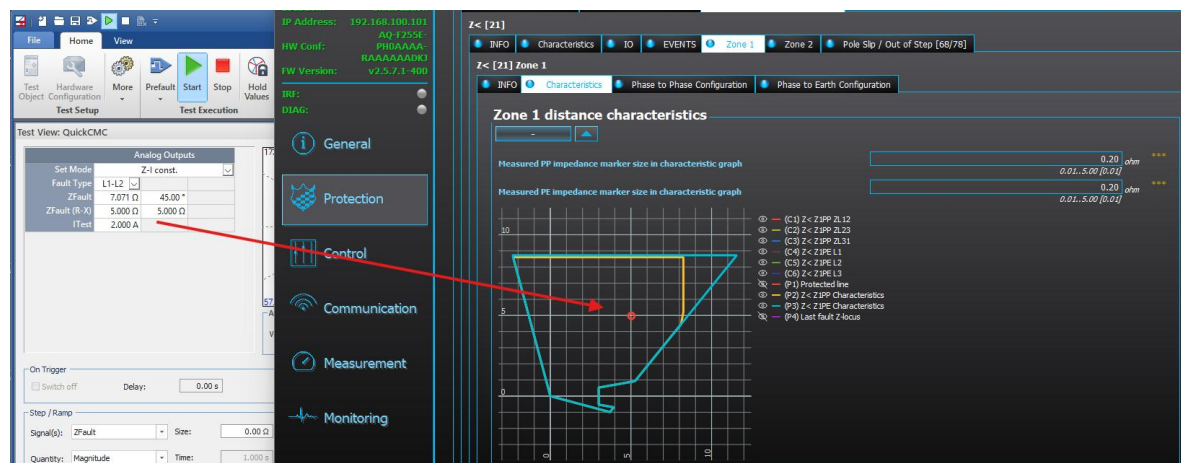
Figure 41. Primary and secondary scaling option for graphs and measurements.



The zone characteristic graphs are now in secondary ohms, as Figure 41 shows. The secondary ohm graphs can be viewed in individual zone *Characteristics* tab. The characteristic graphs contain the measured impedance markers that display the impedance value in the R-X plane.

When injecting fault values with a testing device, the user can check that the impedance values are corresponding. See Figure 42 for more information. Please note that the **Live edit** mode should be enabled to see live measurements.

Figure 42. Characteristics and measurements in secondary impedances. The ZL12 impedance marker displays the measured L1-L2 impedance value in the R-X plane.



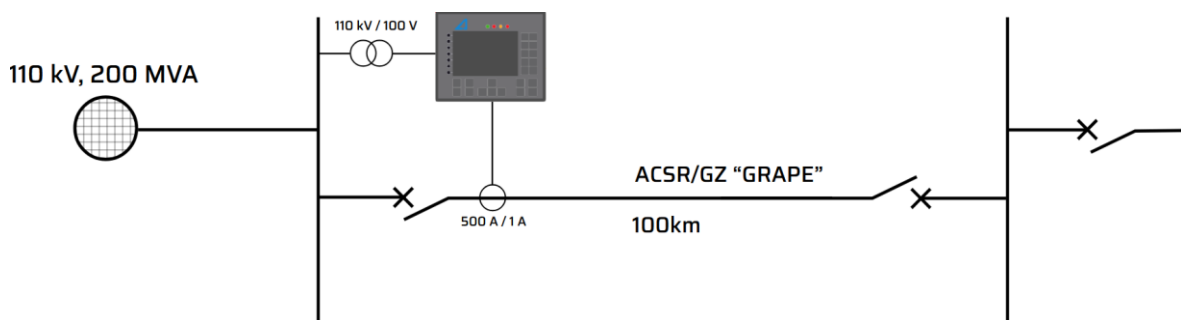
8 SETTING EXAMPLE

This section gives a simple setting example for a three-zone distance function. The settings are done for a 100 km ACSR/GZ “GRAPE” 110 kV overhead line. Line positive sequence impedances per kilometer are

- $r1 = 0.196 \, \Omega/\text{km} \rightarrow R1 = 100 \, \text{km} * 0.196 \, \Omega/\text{km} = 19.6 \, \Omega$
- $x1 = 0.235 \, \Omega/\text{km} \rightarrow X1 = 100 \, \text{km} * 0.235 \, \Omega/\text{km} = 23.5 \, \Omega$

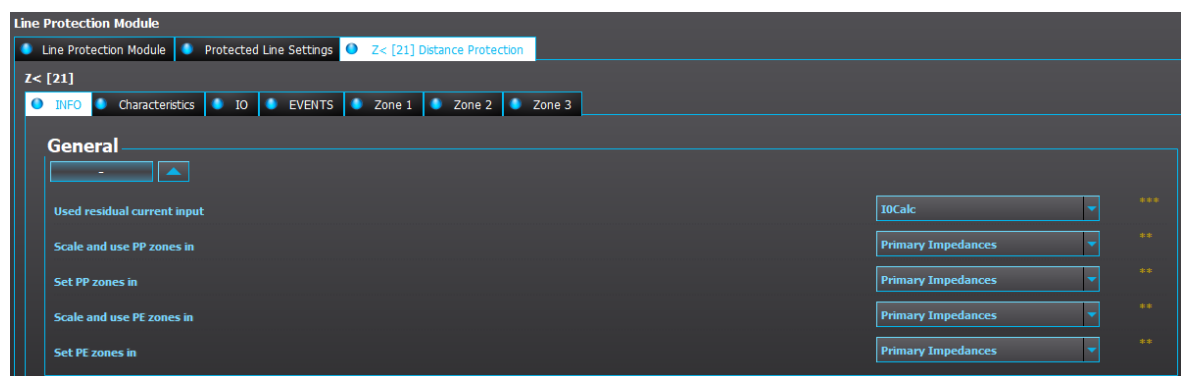
Line zero sequence values are three times (3x) the positive sequence impedances. The source short circuit power at the relay location is 200 MVA. Application drawing of the protected line is presented below in Figure 43.

Figure 43. Application drawing of the protected line.



The goal is to have two forward zones and one backup non-directional zone. All the settings are given in primary impedances. This can be defined in Distance Protection *INFO* tab in the ‘General’ section (see Figure 44). Please note that the VT and CT scalings must be correct when using primary impedance settings.

Figure 44. Primary/secondary impedance selection.



The positive sequence impedances can be set in AQtivate in *Protected Line Settings* tab for both forward (Figure 45). For simplicity, the reverse direction impedances are set equal.

Figure 45. Positive sequence impedance settings.

Protection

Stage activation | **Line Protection Module** | ArcProtection | Current | Voltage | Frequency | Sequence | Support

Line Protection Module

Line Protection Module | Protected Line Settings | Z< [21] Distance Protection

Forward Line Settings

Positive Sequence Line Settings

Forward Line segmenting settings: Equal Segments (Line and Ground)

Forward Line Segments: 1 Segment

Forward Segment 1 values in: (R/X) / km

Fwd. Line seg. 1 Length: 100.000 km

Fwd. Line seg. 1 Pos.Seq. Resistance (RL+) / km: 0.196 ohm/km

Fwd. Line seg. 1 Pos.Seq. Reactance (XL+) / km: 0.235 ohm/km

8.1 Zero sequence compensation

The zero sequence compensation needs to be determined for distance protection to compensate for the neutral impedance in earth faults. The compensation factor is calculated using the formula presented on page 7. As stated above, the zero sequence impedances are three times the positive sequence impedance. The compensation factor k_0 is then

$$k_0 = \frac{Z_0 - Z_1}{3 \cdot Z_1} = \frac{3 \cdot (19.6 + 23.5i) \Omega - (19.6 + 23.5i) \Omega}{3 \cdot (19.6 + 23.5i) \Omega} = 0.67 \angle 0^\circ.$$

Figure 46 shows the zero sequence compensation factor k_0 set in *Protected Line Settings* tab in AQTivate.

Figure 46. Zero sequence line settings in AQtivate.

The screenshot displays the 'Zero Sequence Line Settings' window in the AQtivate software. The window is divided into two main sections: 'Positive Sequence Line Settings' and 'Zero Sequence Line Settings'. The 'Zero Sequence Line Settings' section is currently active and shows the following parameters:

- Forward Zero Seq. k0:** Set to 'k0'.
- Forward k0 given in:** Set to 'Z/Angle'.
- Fwd. Line Zero Seq. k0 Z:** Set to 0.670 ohm, with a range of -10000.000...10000.000 [0.001].
- Fwd. Line Zero Seq. k0 angle:** Set to 0.000 deg, with a range of -360.000...360.000 [0.001].
- Fwd. Line k0 factor R set:** Set to 0.670, with a range of -10000.000...10000.000 [0.001].
- Fwd. Line k0 factor X set:** Set to 0.000, with a range of -10000.000...10000.000 [0.001].
- Fwd. Line k0 factor Z set:** Set to 0.670 ohm, with a range of -10000.000...10000.000 [0.001].
- Fwd. Line k0 factor Angle set:** Set to 0.000 deg, with a range of -360.000...360.000 [0.001].

8.2 Reactive reach setting

In typical distance protection schemes the first zone is set to operate instantly. It is then recommended that zone 1 covers only around 80 % of the protected line distance. In this example the zone 1 reactive reach is set as follows.

$$X_{Reach\ Z1} = 80 \% * X1 = 80 \% * 23.5 \Omega = 18.8 \Omega$$

Zone 2 is typically backup for the opposite end substation which means that it has some operating time delay. The second zone is set to reach 120 % of the protected line length. The zone 2 reactive reach setting is then

$$X_{Reach\ Z2} = 120 \% * X1 = 120 \% * 23.5 \Omega = 28.2 \Omega$$

For non-directional backup zone 3 the reactive reach is set to cover the next line after the opposite end substation. In this example, reactive reach of 200 % of protected line length is used.

$$X_{Reach\ Z3} = 200 \% * X1 = 200 \% * 23.5 \Omega = 47.0 \Omega$$

The same reactive reaches apply for both phase-to-phase and phase-to-earth loops.

Figure 47 shows the reactive reach setting for phase-to-phase zone 1 in zone *Settings* tab.

Figure 47. PP zone 1 reactive reach setting.

The screenshot shows the 'Z1PP Zone 1' settings page. The 'Z1PP Zone Reactive reach X<' parameter is highlighted with a red box. The value is set to 18.80 Ohm, with a range of 0.10...5000.00 [0.01]. Other visible settings include 'Z1PP Zone Operating Control' set to 'Zone Common', 'Z1PP Zone Load Encroachment' set to 'Not in use', 'Z1PP Zone Line segments forward' set to 1 segs, 'Z1PP Zone Resistive reach R<' set to 22.80 Ohm, 'Z1PP Zone Maximum Q1/Q3 resistive reach RmaxQ1/Q3<' set to 0.00 Ohm, 'Z1PP Zone Angle (FwdQ2 / RevQ4) Resistive reach (90 deg + set)' set to 15.00 deg, 'Z1PP Zone Angle (RwdQ4 / RevQ2) Resistive reach (0 deg - set)' set to 15.00 deg, 'Definite (min) operating time delay' set to 0.000 s, 'Delayed Pick-up release' set to 'Yes', and 'Release Time delay' set to 0.060 s.

8.3 Resistive reach setting

Typically, at least two factors must be considered for resistive reach setting. These include calculating the maximum value of arc resistance and load current.

To determine the arc resistance, the minimum 2-phase short circuit current is calculated. First, as the source impedance is calculated using the following formula.

$$Z_s = \frac{U^2}{S_k} = \frac{110 \text{ kV}^2}{200 \text{ MVA}} = 60.5 \Omega$$

The minimum 2-phase short circuit current is calculated using the source impedance value as well as the line impedance.

$$I_{k2ph} = \frac{U}{2 * (Z_s + Z_1)} = \frac{110 \text{ kV}}{2 * (60.5 + \sqrt{19.6^2 + 23.5^2}) \Omega} = 603.7 \text{ A}$$

Arc resistance can be calculated using the Warrington equation. It uses the calculated short circuit current as well as the maximum spacing between two conductors. In this example a value of 1.8 m is used.

$$R_{arc} = \frac{28710 * L}{I_{k2ph}^{1.4}} = \frac{28710 * 1.8 \text{ m}}{603.7^{1.4} \text{ A}} = 6.6 \Omega$$

This resistance value should always be covered by the resistive reach setting.

The minimum load impedance at maximum load condition must also be considered when setting the resistive reach. In this example the maximum load current is the line

type maximum load capacity (605 A). Safety margins of 85 % and 150 % are used for voltage and current respectively. The minimum load impedance is calculated as follows.

$$Z_{Lmin} = \frac{U * 85 \%}{\sqrt{3} * I_L * 150 \%} = \frac{110 \text{ kV} * 85 \%}{\sqrt{3} * 605 \text{ A} * 150 \%} = 59.5 \Omega$$

As the minimum load impedance is high compared to the arc resistance, load encroachment does not need to be considered.

Following the general guidelines for phase-to-phase zone resistive reach settings, the farthest reaching zone 3 is set to reach 60 % of the calculated minimum load impedance which gives some room for errors and power swings. The next zone 2 is set to reach 80 % of zone 3 and zone 1 reach setting is again 80 % of zone 2. The zone resistive reaches are the following.

$$R_{ReachPP\ Z3} = 60 \% * Z_{Lmin} = 60 \% * 59.5 \Omega = 35.7 \Omega$$

$$R_{ReachPP\ Z2} = 80 \% * R_{Reach\ Z3} = 80 \% * 35.7 \Omega = 28.6 \Omega$$

$$R_{ReachPP\ Z1} = 80 \% * R_{Reach\ Z2} = 80 \% * 28.6 \Omega = 22.8 \Omega$$

All of the zone reaches cover the calculated arc resistance.

The resistive reach setting for earth faults should cover also the earth resistance at fault location, for example the tower resistance. Generally, a setting value of 80 % of minimum load impedance can be used for phase-to-earth loops.

$$R_{ReachPE\ Z1-3} = 80 \% * Z_{Lmin} = 80 \% * 59.5 \Omega = 47.6 \Omega$$

This setting is applied equally for all three phase-to-earth loops. Figure 48 shows the phase-to-phase zone 1 resistive reach setting in Zone 1 *Settings* tab. Figure 49 shows the corresponding setting for zone 1 phase-to-earth loop.

Figure 48. PP zone 1 resistive reach.

Z< [21] Zone 1

Z1PP< 21 [DPP1]

Settings

Setting Group 1

Z< Z1PP Zone Operating Control	Zone Common	**
Z< Z1PP Zone Load Encroachment	Not in use	**
Z< Z1PP Zone Linesegments forward	1 segs	**
Z< Z1PP Zone Resistive reach R<	22.80 Ohm	**
Z< Z1PP Zone Reactive reach X<	18.80 Ohm	**
Z< Z1PP Zone Maximum Q1/Q3 resistive reach RmaxQ1/Q3< (0 disabled)	0.00 Ohm	**
Z< Z1PP Zone Angle (FwdQ2 / RevQ4) Resistive reach (90 deg + set)	15.00 deg	**
Z< Z1PP Zone Angle (RwdQ4/ RevQ2) Resistive reach (0 deg - set)	15.00 deg	**
Definite (min) operating time delay	0.000 s	**
Delayed Pick-up release	Yes	**
Release Time delay	0.060 s	**

Figure 49. PE zone 1 resistive reach.

Z< [21] Zone 1

Z1PE< 21 [DPE1]

Settings

Setting Group 1

Z< Z1PE Zone Operating Control	Zone Common	**
Z< Z1PE Zone Load Encroachment	Not in use	**
Z< Z1PE Zone Linesegments forward	1 segs	**
Z< Z1PE Zone Resistive reach R<	47.60 Ohm	**
Z< Z1PE Zone Reactive reach X<	18.80 Ohm	**
Z< Z1PE Zone Maximum Q1/Q3 resistive reach RmaxQ1/Q3< (0 disabled)	0.00 Ohm	**
Z< Z1PE Zone Angle (FwdQ2 / RevQ4) Resistive reach (90 deg + set)	15.00 deg	**
Z< Z1PE Zone Angle (RwdQ4/ RevQ2) Resistive reach (0 deg - set)	15.00 deg	**
Definite (min) operating time delay	0.000 s	**
Delayed Pick-up release	Yes	**
Release Time delay	0.060 s	**

8.4 Time delay settings

Co-ordinated time delay settings are essential for selective distance protection. Typically, a time grading of 200-500 ms is used between zones. As the zone 1 is set to operate instantaneously, the zone 2 delay is set to 300 ms. The non-directional zone 3 is then delayed another 500 ms from zone 2, adding up to 800 ms delay. The time grading is equal for both phase-to-phase and phase-to-earth zones.

- $T_{Z1} = 0 \text{ ms}$
- $T_{Z2} = 300 \text{ ms}$
- $T_{Z3} = 800 \text{ ms}$

Figure 50 displays the operating time delay for zone 1 in zone *Settings* tab.

Figure 50. PP zone 1 operating time delay setting.

The screenshot shows the 'Z1PP Zone 1' settings interface. The 'Zone 1' tab is selected, and the 'Settings' sub-tab is active. The 'Setting Group 1' section contains the following parameters:

Parameter	Value	Unit
Z< Z1PP Zone Operating Control	Zone Common	
Z< Z1PP Zone Load Encroachment	Not in use	
Z< Z1PP Zone Line segments forward	1	segs
Z< Z1PP Zone Resistive reach R<	22.80	Ohm
Z< Z1PP Zone Reactive reach X<	18.80	Ohm
Z< Z1PP Zone Maximum Q1/Q3 resistive reach RmaxQ1/Q3< (0 disabled)	0.00	Ohm
Z< Z1PP Zone Angle (FwdQ2 / RevQ4) Resistive reach (90 deg + set)	15.00	deg
Z< Z1PP Zone Angle (RwdQ4/ RevQ2) Resistive reach (0 deg - set)	15.00	deg
Definite (min) operating time delay	0.000	s
Delayed Pick-up release	Yes	
Release Time delay	0.060	s

8.5 Characteristics

Applying the settings to relay, the resulting phase-to-phase and phase-to-earth characteristics are presented in figures 51 and 52 below.

Figure 51. Resulting three-zone PP characteristics.

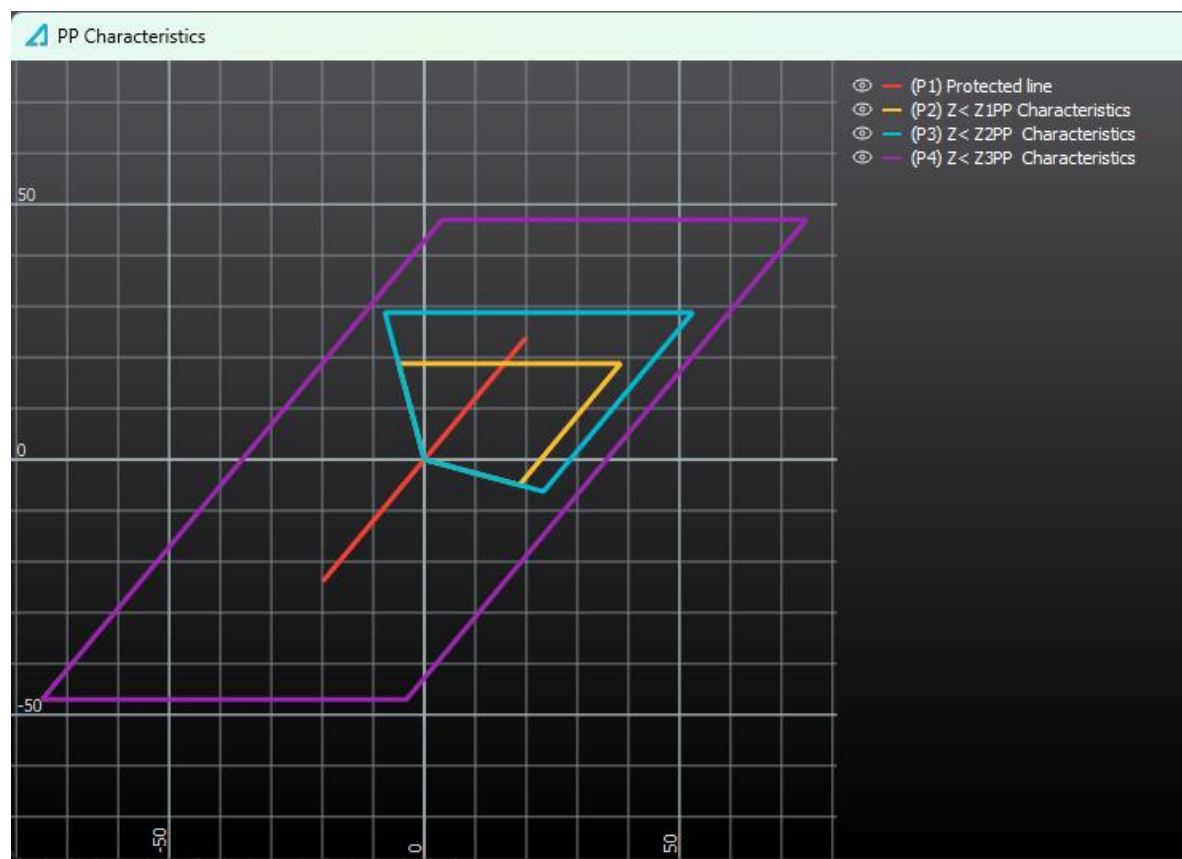
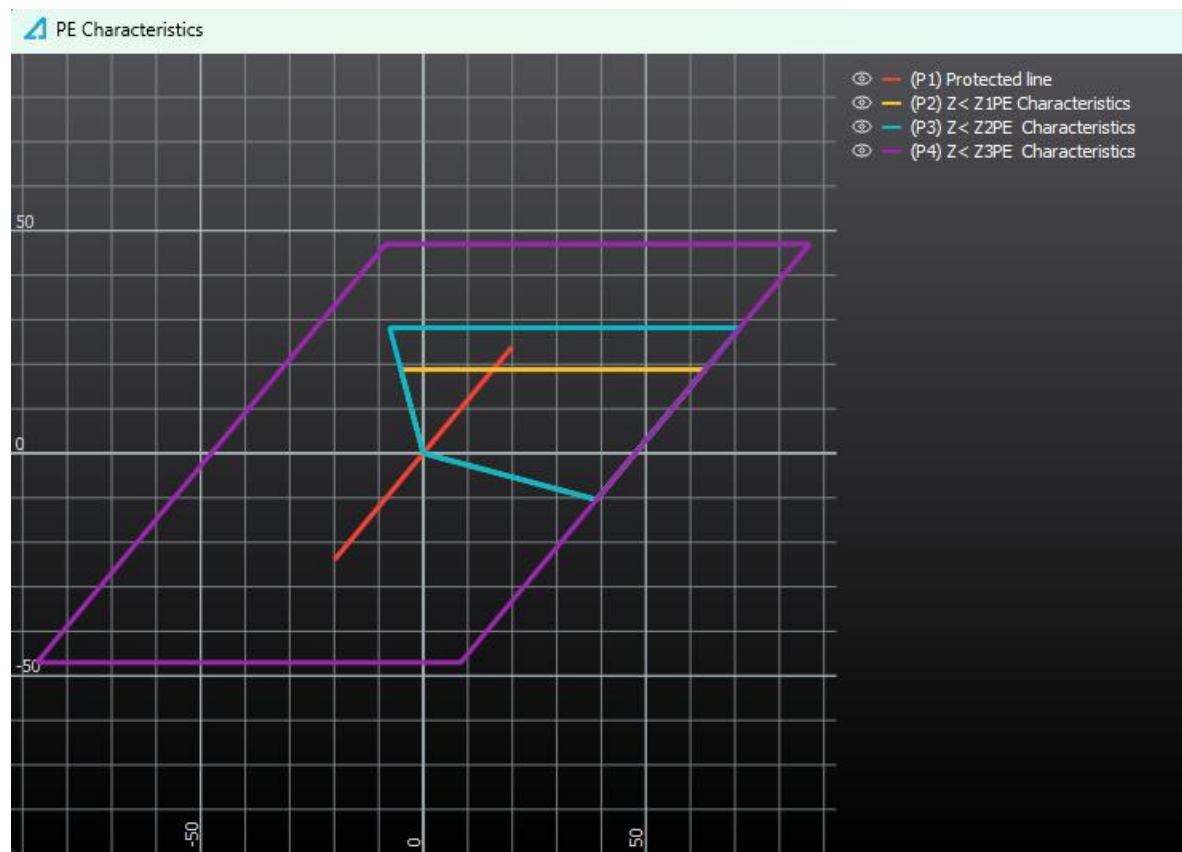


Figure 52. Resulting three-zone PE characteristics.



9 CONTACT INFORMATION

Support portal: arcteq.com/support
Support line: +358 10 3221 388 (EET 9:00–17:00)