

Protection Testing Bulletin

Testing Distance Protection

Date

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Related OMICRON Product

CMC Product Line, Test Universe Software

This document is an adapted version of the “Examples of Use – Testing Distance Protection” document which is available from the Test Universe Start Page.

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Please use this note only in combination with the related product manual which contains several important safety instructions. The user is responsible for every application that makes use of an OMICRON product.

Preface

This paper describes how to test distance protection zones. It contains an application example that will be used throughout the paper. The theoretical background of the distance protection function will be explained. This paper also covers the definition of the necessary **Test Object** settings as well as the **Hardware Configuration** for distance protection tests. Finally, the *Distance* or *Advanced Distance* test modules are used to perform the tests that are needed for the distance protection zones.

Supplements: Sample *Control Center* file **DistanceTest.occ**
(referred to in this document).

Requirements: *Test Universe* 4.20 or later; *Distance* or *Advanced Distance* and *Control Center* licenses.

1 Application Example

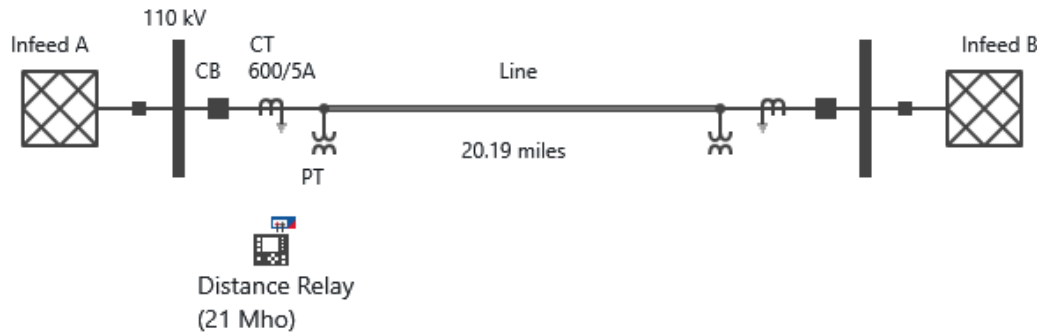


Figure 1: Grid diagram of the application example

Note: Testing of associated functions (e.g. Switch-Into-Fault, backup overcurrent, auto-recloser, communication-assisted scheme) are not part of this document.

Parameter Name	Parameter Value	Notes
Frequency	60 Hz	
VT (primary/secondary)	110000 V / 110 V	PTR = 1000
CT (primary/secondary)	600 A / 5 A	CTR = 120
Power System Data	64°	Line impedance angle Z1ANG (φ_{sc})
	7.87 Ω	Pos.-Seq. Line impedance magnitude Z1MAG (Ω)
	32.5 km (20.19 miles)	Line length in km (miles)
	0.6	Zero-sequence compensation factor mag. K0 ¹⁾
	0°	Angle for the Zero-sequence compensation factor
Distance protection zone settings for Mho shapes (secondary values)	Forward	Operating mode Z1
	6.66 Ω	Reach for phase to phase faults of zone 1
	6.66 Ω	Reach for phase to ground faults of zone 1
	0 s	Trip time zone 1 (ground/phase common delay)
	Forward	Operating mode Z2
	10.2 Ω	Reach for phase to phase faults of zone 2
	10.2 Ω	Reach for phase to ground faults of zone 2
	30 cy (0.5 s)	Trip time zone 2 (ground/phase common delay)
	Reverse	Operating mode Z3
	6.22 Ω	Reach for phase to phase faults of zone 3
	6.22 Ω	Reach for phase to ground faults of zone 3
	60 cy (1.0 s)	Trip time zone 3 (ground/phase common delay)

1) The structure of this parameter depends on the relay manufacturer and model (see chapter 2.3 "Zero-Sequence Compensation"). In this example this factor is valid for all zones.

Table 1: Relay parameters for this example

2 Introduction to Distance Characteristics

Distance relays are applied as short-circuit protection in almost all transmission systems where overcurrent relays cannot be used for reasons of selectivity, fault detection requirements or where there is a need for improved fault clearing times. They are mainly applied in ring networks with multiple feeds and meshed HV grids.

2.1 Impedance Diagrams

A distance protection function measures voltage and current at the relay location and calculates impedance to detect and locate faults in the system. Based on the primary line data, system data and coordination with other relays, the reach and behavior during arc faults are defined in the impedance diagram. There are different shapes of impedance characteristics. For this example, only the Mho type will be used.

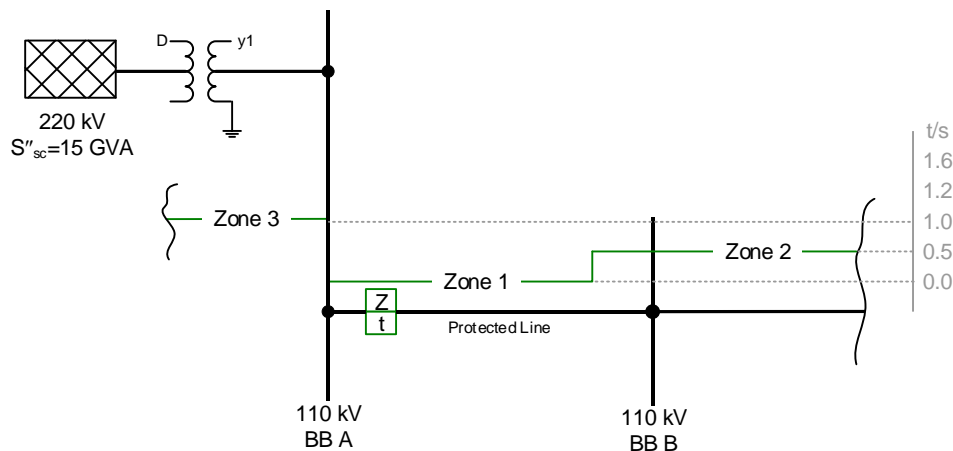


Figure 2: Time grading diagram for step distance protection of protected line

Three zones of protection are used. Zone 1 reach is about 85% of the line length and provides an instantaneous trip. Zone 2 has a 130% reach providing a 30-cycle delayed trip for the remainder of the line plus backup coverage for the adjacent line. Zone 3 looks backward and provides a 60-cycle backup protection for the predecessor lines. Zone 2 and Zone 3 are usually used for permissive and blocking communication-assisted schemes, respectively.

Phase Distance Elements	Ground Distance Elements
E21P Mho Phase Distance Zones 3 Select: N, 1-5	E21MG Mho Ground Distance Zones 3 Select: N, 1-5
Mho Phase Distance Element Reach	Mho Ground Distance Element Reach
Z1P Zone 1 Reach (ohms, sec) 6,66 Range = 0,05 to 64,00, OFF ①	Z1MG Zone 1 (ohms, sec) 6,66 Range = 0,05 to 64,00, OFF ④
Z2P Zone 2 Reach (ohms, sec) 10,20 Range = 0,05 to 64,00, OFF ②	Z2MG Zone 2 (ohms, sec) 10,20 Range = 0,05 to 64,00, OFF ⑤
Z3P Zone 3 Reach (ohms, sec) 6,22 Range = 0,05 to 64,00, OFF ③	Z3MG Zone 3 (ohms, sec) 6,22 Range = 0,05 to 64,00, OFF ⑥

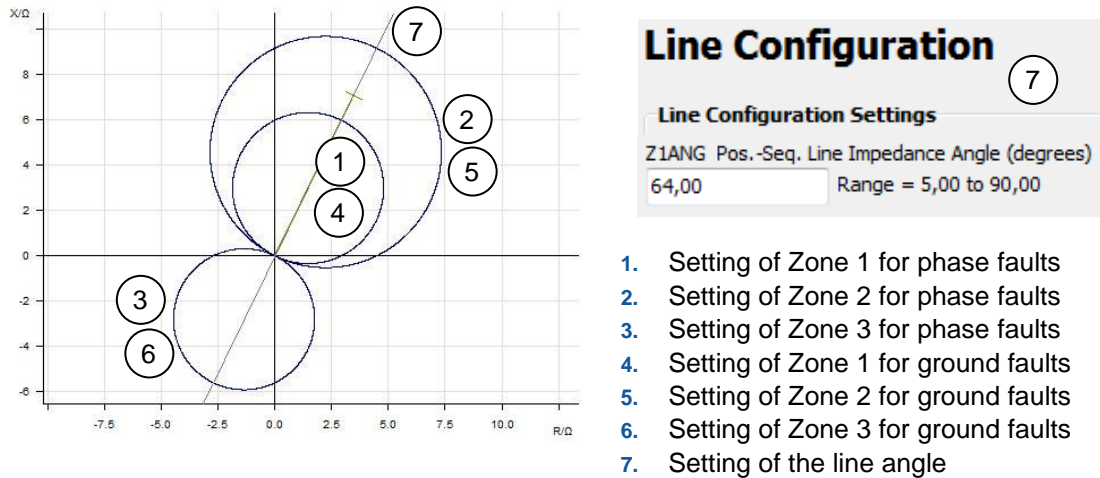


Figure 3: Setting of zones in impedance diagram (mho) for a SEL-421

Note: For the logic of the Ground Distance Elements see chapter 2.3 “Zero-Sequence Compensation”.

2.2 Line Impedance Angle

The line impedance angle is a characteristic of the line, which depends on many factors such as tower geometry and conductor material. For a short-circuit with no arc-resistance, the fault will be located along the line impedance angle in the impedance diagram.

	380 kV	220 kV	110 kV	10 ... 30 kV	Electric arc
Line impedance angle φ_{sc}	Approx. 85°	Approx. 80°	Approx. 72°	30 ... 50°	Approx. 0°

Table 2: Typical line impedance angle for different voltage levels

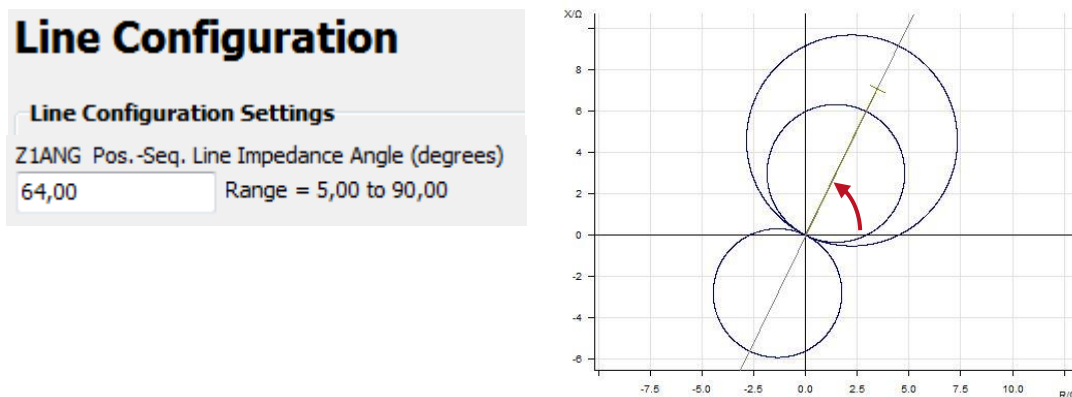
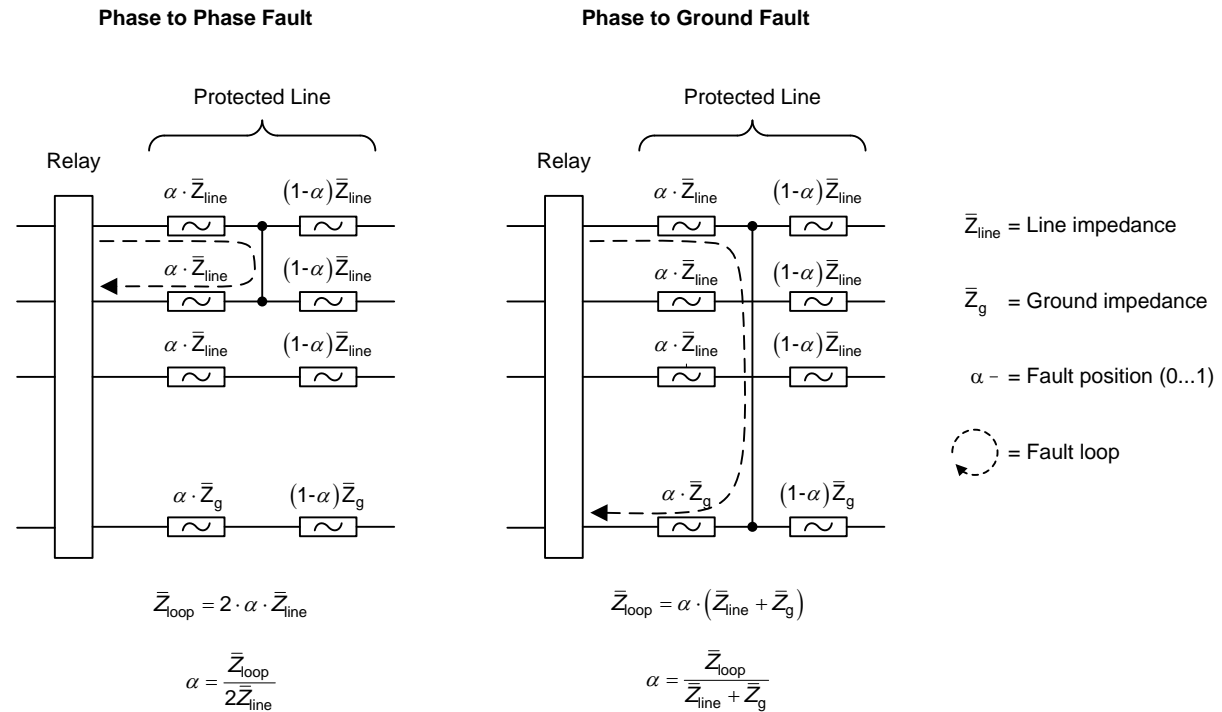


Figure 4: Line impedance angle for SEL-421

2.3 Zero-Sequence Compensation



For phase to phase faults the distance between the relay and the fault can be calculated from the loop impedance by just using the line impedance. However, for phase to ground faults the ground impedance is also needed. To take the ground impedance into account, a zero-sequence compensation factor (grounding factor) is used. Depending on the relay manufacturer, this factor is defined in different ways:

Factor	Definition	Manufacturer
\bar{k}_L	$= \frac{\bar{Z}_g}{\bar{Z}_{line}}$ $= \frac{\bar{Z}_0 - \bar{Z}_L}{3\bar{Z}_L}$	Examples include AEG, Alstom, Areva, SEL, Siemens
$\frac{R_E}{R_L}$ and $\frac{X_E}{X_L}$	$\frac{R_E}{R_L} = \frac{R_g}{R_{line}} = \frac{1}{3} \cdot \left(\frac{R_0}{R_1} - 1 \right)$ $\frac{X_E}{X_L} = \frac{X_g}{X_{line}} = \frac{1}{3} \cdot \left(\frac{X_0}{X_1} - 1 \right)$	Examples include Siemens
$\frac{\bar{Z}_0}{\bar{Z}_L}$	$= \frac{\bar{Z}_0}{\bar{Z}_{line}} = 3 \cdot \frac{\bar{Z}_g}{\bar{Z}_{line}} - 1$	Examples include ABB

Ground Distance Elements

Zero-Sequence Compensation Factor

k0M1 Zone 1 ZSC Factor Magnitude

0,600 Range = 0,000 to 10,000, AUTO

k0A1 Zone 1 ZSC Factor Angle (degrees)

0,00 Range = -180,00 to 180,00

Figure 5: Zero sequence compensation factor for SEL-421

Setting this factor will influence the resulting zone (fault loop impedance) for phase to ground faults as shown below.

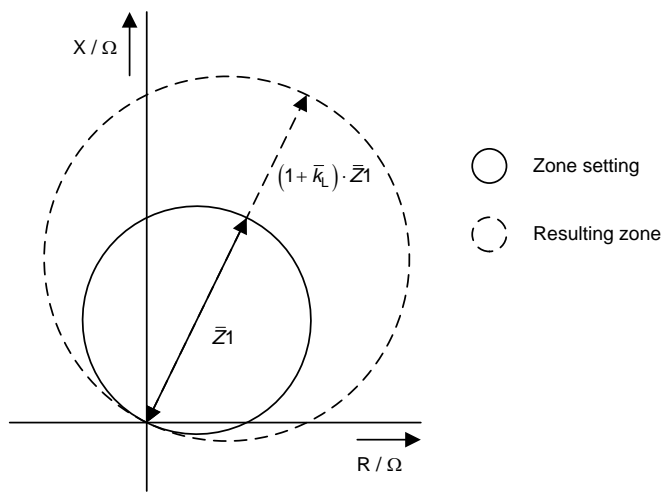


Figure 6: Influence of the zero-sequence compensation factor on the zone

When configuring the distance ground zones in Test Universe, there are 2 options:

- Configure zone as per zone setting (see Figure 3) and set the zero-sequence compensation factor embedded in the software. The software will automatically do the compensation
- Configure zone as resulting zone (see Figure 6 and Figure 7) and set zero-sequence compensation factor in the software to zero. Note that magnitude and angle of ground zones will differ from settings.

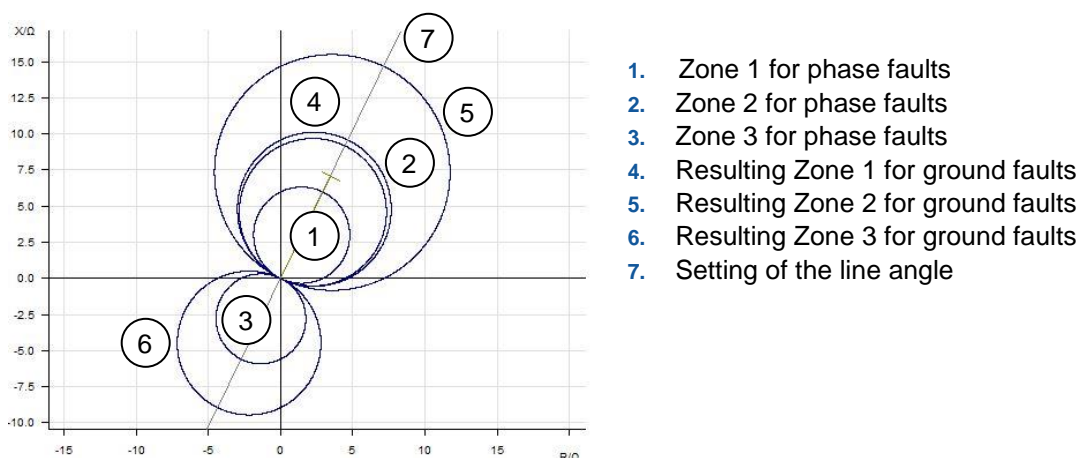


Figure 7: Setting of ground zones as fault loop impedance

3 Practical Introduction

The *Advanced Distance* test module and the *Distance* test module are designed for testing distance protection functions (e.g., impedance diagram, trip times, etc.).

Note: The functionality of the *Advanced Distance* test module and the *Distance* test module is different!

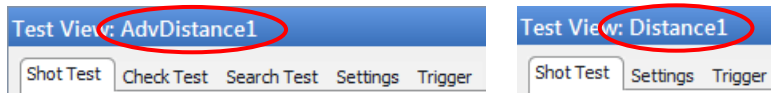
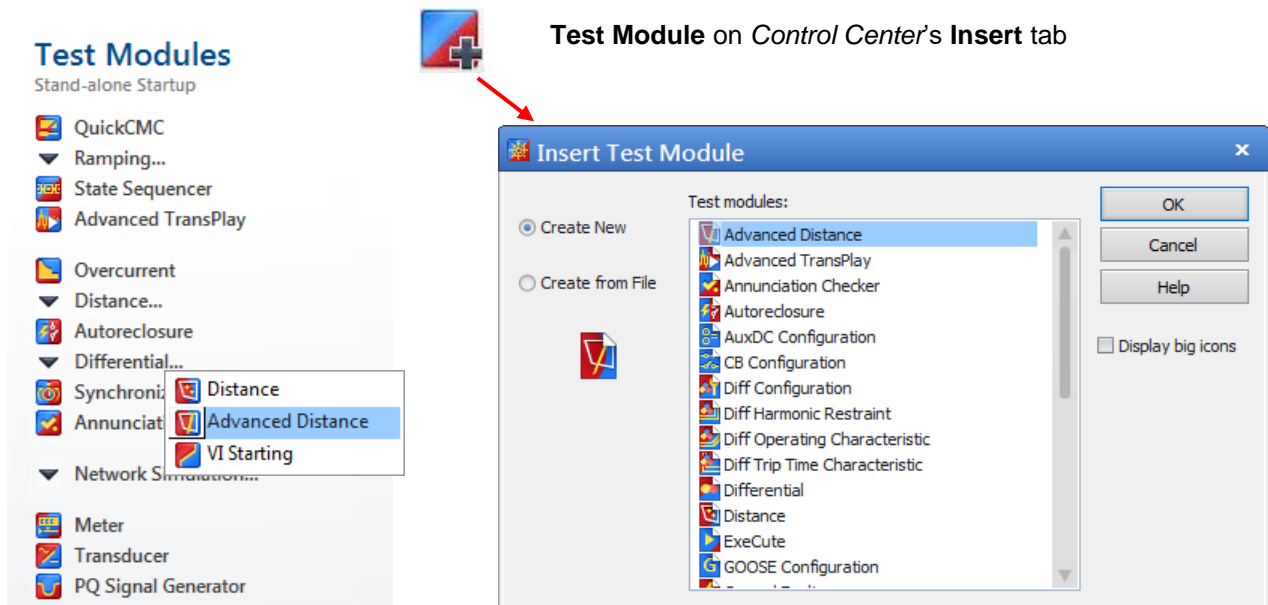


Figure 8: Test View of the Advanced Distance test module and Distance test module

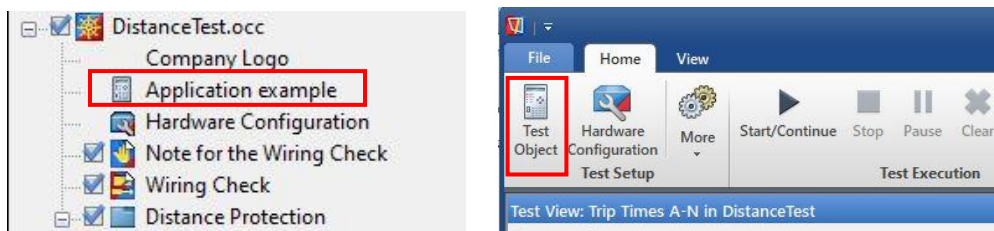
For all following discussions, the *Advanced Distance* test module is used. This test module incorporates the functionality of the *Distance* test module.

You find the *Advanced Distance* test module on the start screen of the OMICRON *Test Universe* software. *Advanced Distance* can also be inserted into an OCC File (a *Control Center* document).



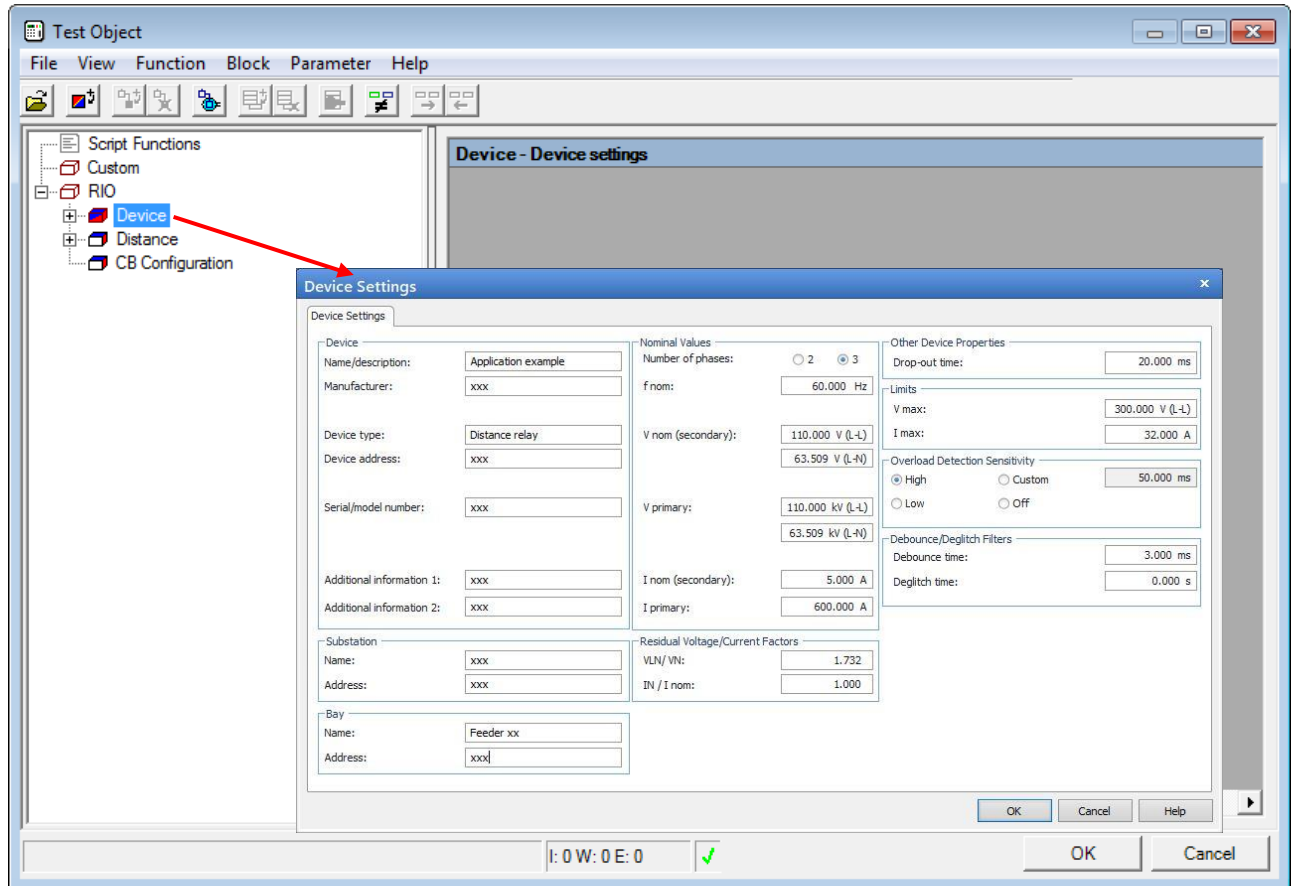
3.1 Defining the Test Object

Before testing can begin the settings of the relay to be tested must be defined. In order to do that, the **Test Object** must be opened by double clicking the **Test Object** in the OCC file or by clicking the **Test Object** button in any test module.



3.1.1 Device Settings

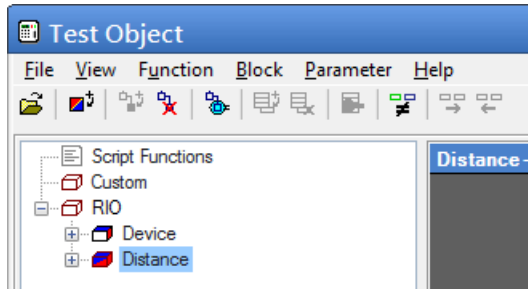
General relay settings (e.g., relay type, relay ID, substation details, CT and VT parameters) are entered in the **RIO** function **Device**.



Note: The parameters **V max** and **I max** limit the output of the currents and voltages to prevent damage to the device under test. These values must be adapted to the respective **Hardware Configuration** when connecting the outputs in parallel or when using an amplifier. The user should consult the manual of the device under test to make sure that its input rating will not be exceeded.

3.1.2 Defining the Distance Protection Parameters

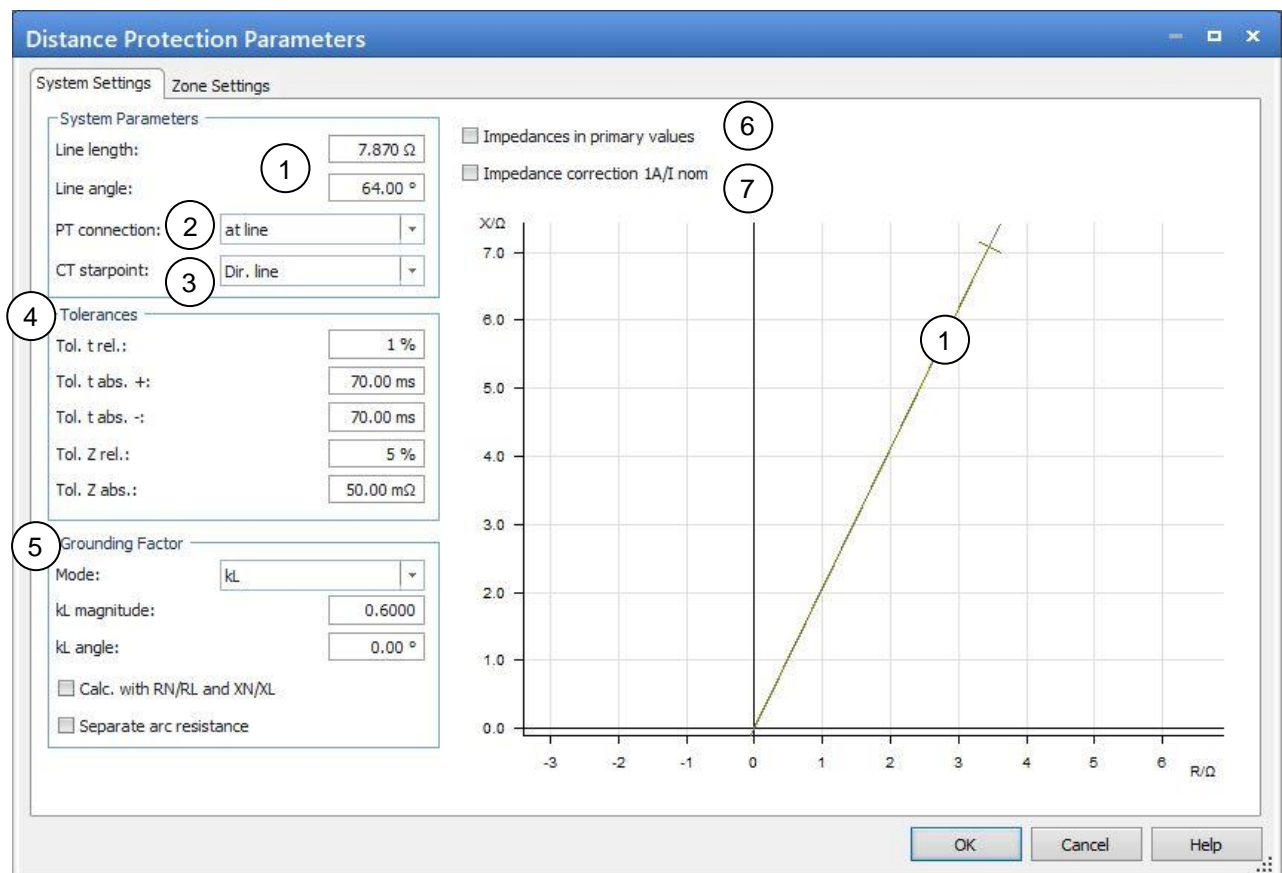
More specific data concerning the distance protection relay can be entered in the **RIO** function **Distance**. The definition of the distance impedance diagram must be made here as well.



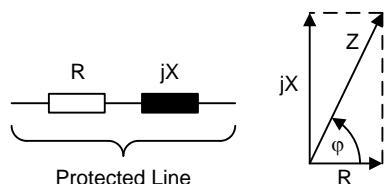
Note: Once an *Advanced Distance* / *Distance* test module is inserted, this **RIO** function is available.

System Settings

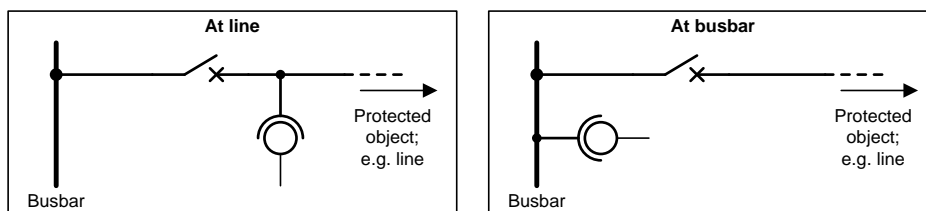
The first tab contains the definition of the system data, the relay behavior as well as the relay tolerances.



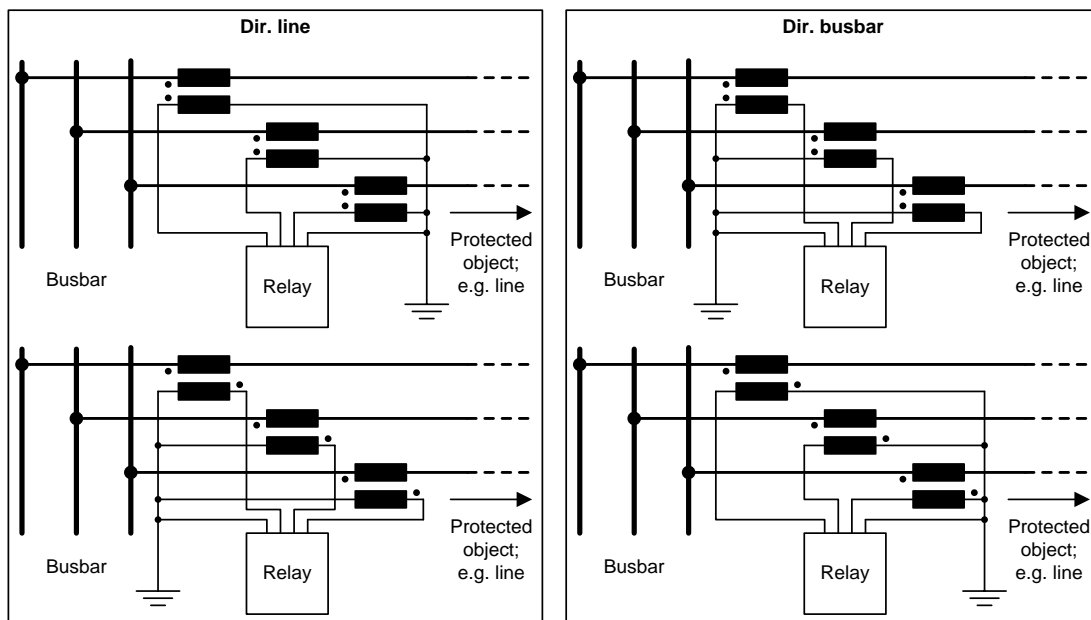
1. The line length and line angle are the positive-sequence line impedance magnitude ($Z1MAG$) and angle ($Z1ANG$) of the protected line (see Table 1). They are needed to calculate faults correctly with respect to the power system.



2. Regarding the feeder connection diagram (**Error! Reference source not found.**) the PT is placed at **I ine**. If **at busbar** is chosen, the voltage will have the nominal value after tripping.



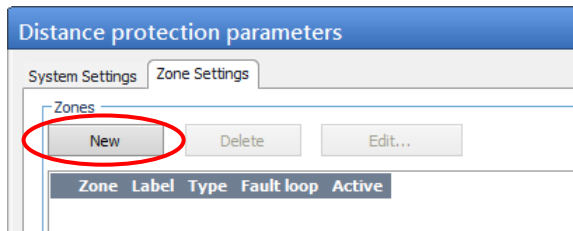
3. The **CT starpoint** must be set according to the connection of the secondary windings of the CT. For this example, the feeder connection diagram (**Error! Reference source not found.**) shows that the CT g rounding is towards the line.



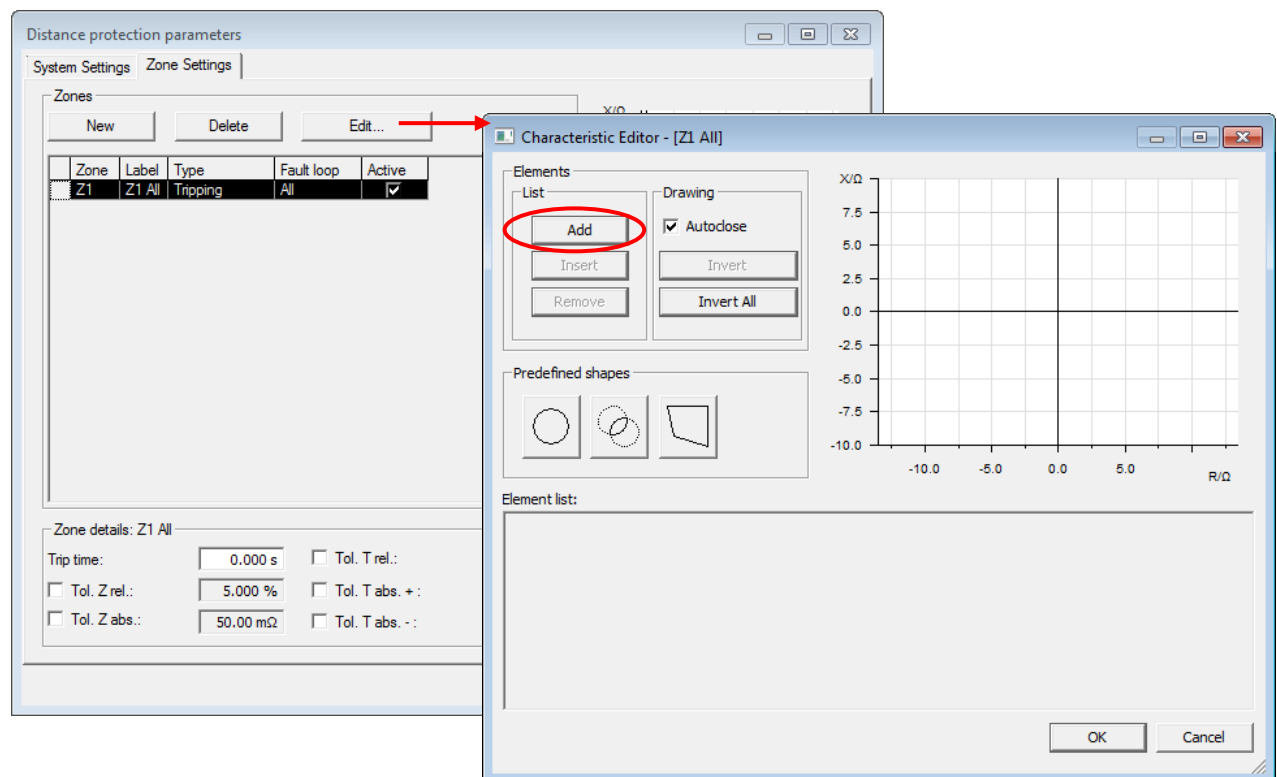
4. The impedance and time tolerances are found in the relay manual.
5. The grounding factor compensates the effect of the ground impedance on the distance zones (see chapter 2.3 "Zero-Sequence Compensation"). For further information about the settings of the grounding factor, refer to the Help.
6. Select this checkbox only when entering all impedances in primary values.
7. Not used for most relays, including SEL-421. This checkbox must be activated if a 5 A relay is tested that uses 1 A as reference for the impedance calculation.

Zone Settings

On the **Zone Settings** tab, enter the distance zones.

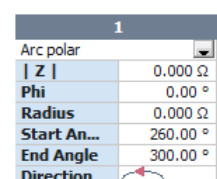
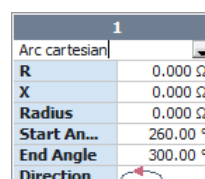
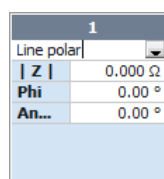
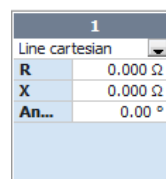
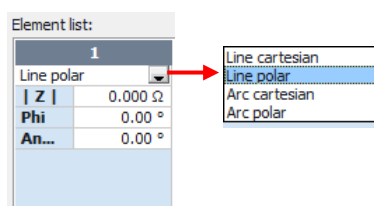


As shown above, no zone is set by default. Click **New** to insert a zone. Afterwards the characteristic editor can be opened by clicking **edit**. Here the distance zone can be entered.

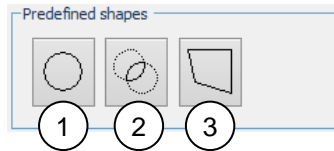


Click **Add** to add a new element to the Element list. The element can be either a line or an arc.

- > A line must be set with an angle and a point on the line. This point can be set either in Cartesian or in polar coordinates. Therefore, the options **Line cartesian** and **Line polar** exist.
- > A circle must be set with a center point, a radius, a start angle, an end angle as well as a direction. As the center can be set in Cartesian as well as in polar coordinates, the options **Arc cartesian** and **Arc polar** can be used.



It is also possible to use **Predefined shapes**.



1. Mho shape
2. Lens/Tomato shape
3. Quadrilateral

1

1	
Mho	
Forward Rea...	6.600 Ω
Offset	0.000 Ω
Angle	64.00 °

2

1	
Lens/Tomato	
Forward Rea...	1.000 Ω
Offset	0.000 Ω
Angle	64.00 °
Width	800.0 m Ω
A/B	0.800

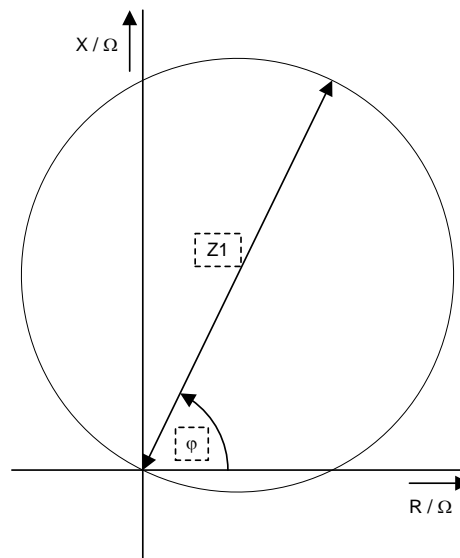
3

1	2	3	4
Line cartesian	Line cartesian	Line cartesian	Line cartesian
R	R	R	R
X	X	X	X
An...	An...	An...	An...
0.000 Ω	1.000 Ω	0.000 Ω	0.000 Ω
0.000 Ω	0.000 Ω	1.000 Ω	0.000 Ω
-15.00 °	90.00 °	180.00 °	135.00 °

Now the zones can be defined by combining several elements.

Note: The shape of a distance zone depends on the type of relay as well as on the settings in the relay. The shape can be found in the relay manual. The elements for one mho shape are shown below.

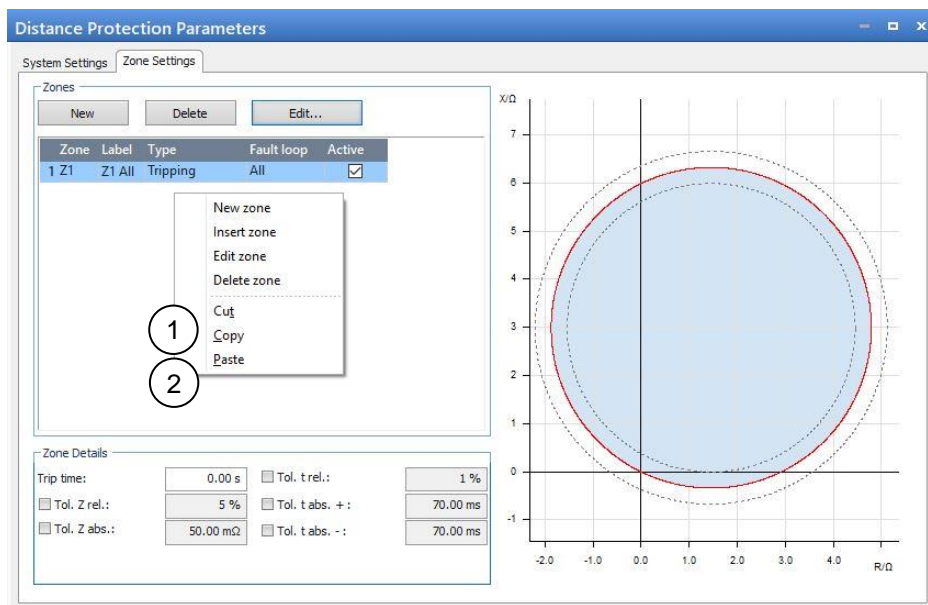
Mho shape (SEL-421)



 Relay Parameters

1	
Mho	
Forward Reach	6.660 Ω
Backward Reach	0.00 Ω
Angle	64.00 °

After the first zone has been defined, the Zone settings tab will look like this:

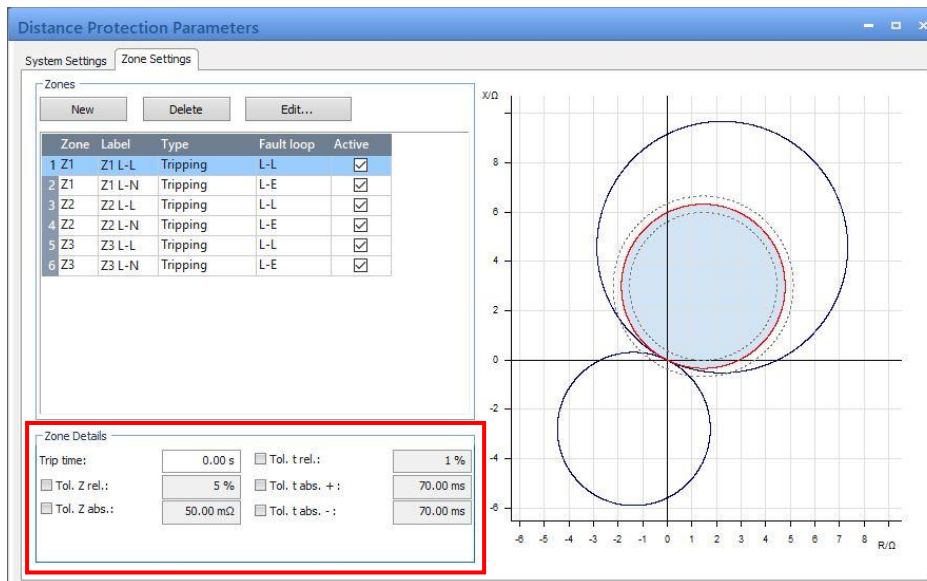


If additional zones are required, the first zone can be copied (1) and pasted to the list (2). Afterwards the settings of the other zones can be adapted. After all the zones have been entered the list could look like this:

3	4	5	6	7	3	5	6
Zone	Label	Type	Fault loop	Active	Z1	Tripping	All
1	Z1	Z1 L-L	Tripping	L-L	<input checked="" type="checkbox"/>	Starting	L-E
2	Z1	Z1 L-N	Tripping	L-E	<input checked="" type="checkbox"/>	Extended	L-L
3	Z2	Z2 L-L	Tripping	L-L	<input checked="" type="checkbox"/>	Non tripping	L1-E
4	Z2	Z2 L-N	Tripping	L-E	<input checked="" type="checkbox"/>		L2-E
5	Z3	Z3 L-L	Tripping	L-L	<input checked="" type="checkbox"/>		L3-E
6	Z3	Z3 L-N	Tripping	L-E	<input checked="" type="checkbox"/>		L1-L2

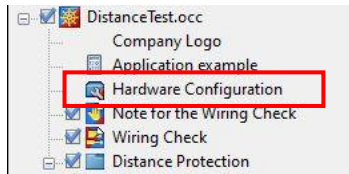
3. The number of each zone can be defined here.
4. The label of the zones is set automatically but a name can also be entered manually.
5. Four different types of zones can be defined:
 - > **Tripping:** These zones resemble the tripping zones of the relay
 - > **Starting:** This is a zone that normally causes pickup only. It is also possible to define a range on the impedance plane where starting will be followed by tripping after the maximum operating time
 - > **Extended:** This is a tripping zone that is only activated occasionally, e.g., by means of "manual close" detection, auto-reclosure, etc.
 - > **Non tripping:** There can be no tripping in this zone, even if it is overlapped by a tripping zone. One example of its use is to model load encroachment.
6. With this option the fault loop for each zone can be defined. Therefore, it is possible to set different zones for phase to phase or phase to ground faults.
7. Each zone can also be deactivated.

After all zones are defined, the tripping time for each zone can be set. It is also possible to define separate tolerances for each of the zones.

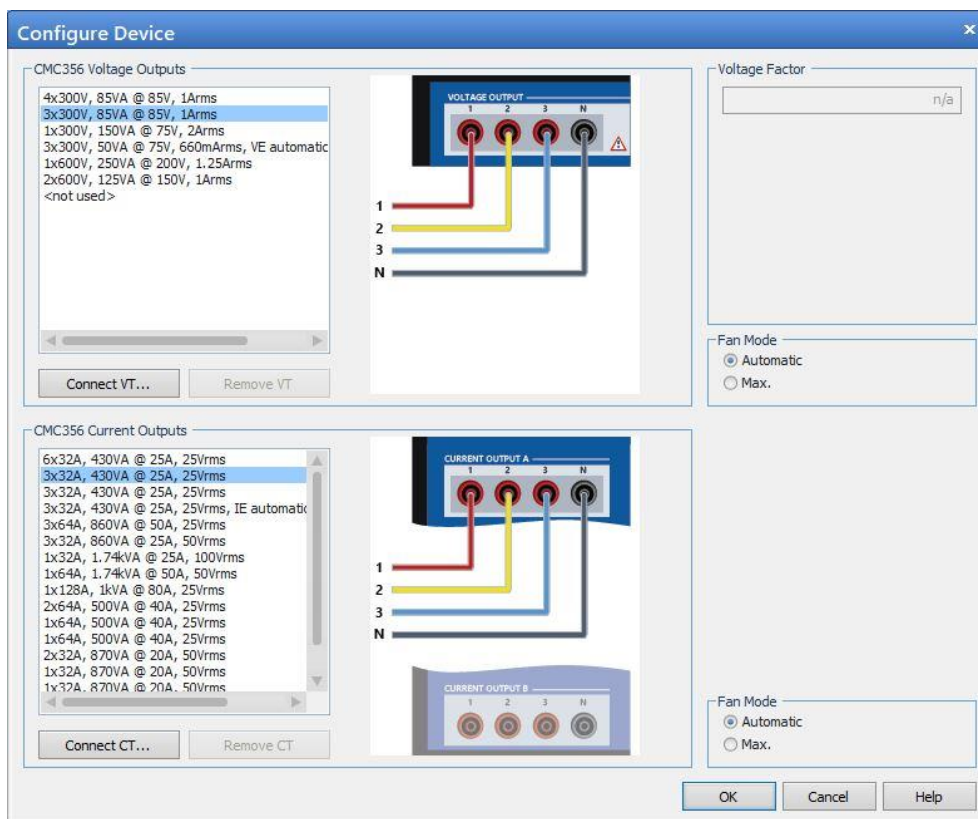


3.2 Global Hardware Configuration of the CMC Test Set

The global Hardware Configuration specifies the general input/output configuration of the CMC test set. It is valid for all subsequent test modules and, therefore, it has to be defined according to the relay's connections. It can be opened by double clicking the **Hardware Configuration** entry in the OCC file.



3.2.1 Example Output Configuration



3.2.2 Analog Outputs

Global Hardware Configuration

General

Analog Outputs

Binary / Analog Inputs

Binary Outputs

DC Analog Inputs

Time Source

		CMC356 V A				CMC356 I A			
Display Name	Connection Terminal	1	2	3	N	1	2	3	N
VA-N		X							
VB-N			X						
VC-N				X					
IA						X			
IB							X		
IC								X	

The analog outputs, binary inputs and outputs can all be activated individually in the local **Hardware Configuration** of the specific test module (see chapter 3.3 “Local Hardware Configuration for Distance Protection Testing”).

3.2.3 Binary Inputs

Global Hardware Configuration

4

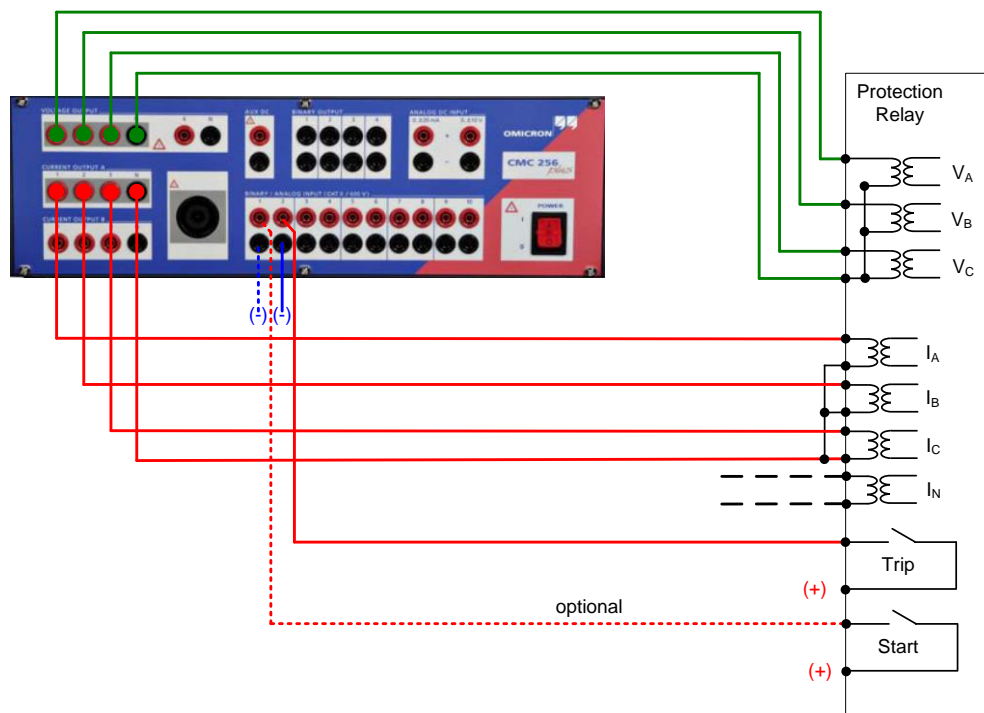
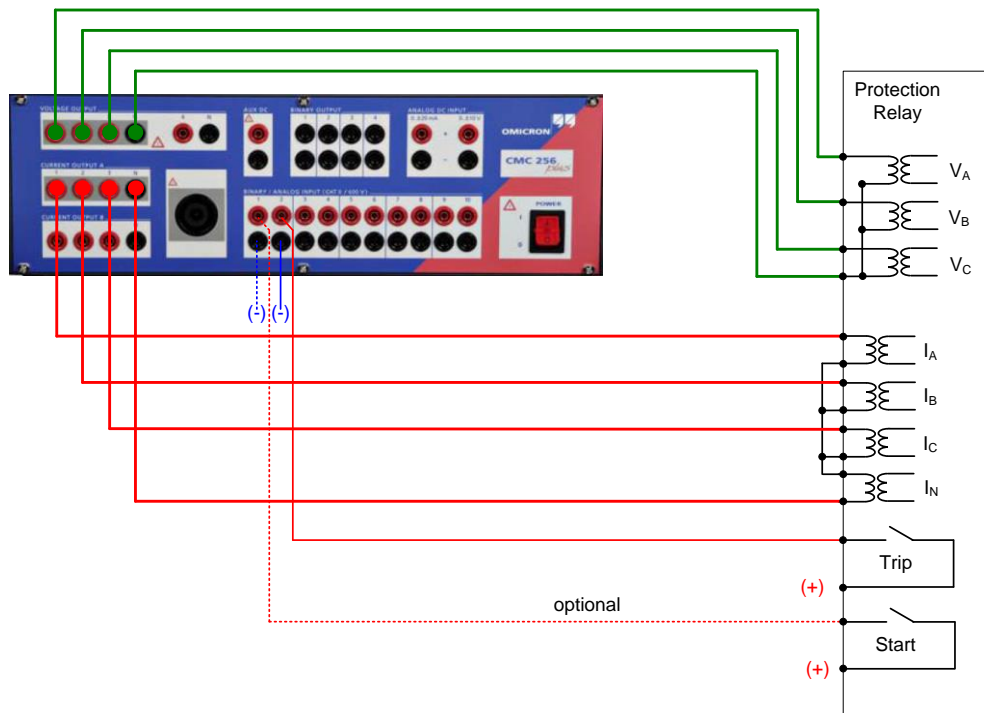
GeneralAnalog OutputsBinary / Analog InputsBinary OutputsDC Analog InputsTime Source

		3							
Function		Binary		Binary		Binary		Binary	
Potential Free		<input type="checkbox"/>		<input type="checkbox"/>		<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>	
Nominal Range		110 V		110 V					
Clamp Ratio									
Threshold		77 V		77 V					
Display Name	Connection Terminal	1+	1-	2+	2-	3+	3-	4+	4-
1 Start		X							
Trip	2			X					
Bin. In. 3						X			
Bin. In. 4								X	

1. The start command is optional (it is needed if **Starting** is selected as a time reference in the test).
2. The trip command has to be connected to a binary input. BI1 ... BI10 can be used.
3. For wet contacts (if connected to trip circuit) adapt the nominal voltages of the binary inputs to the substation DC voltage or select **Potential Free** for dry contacts (e.g. connected to spare relay output).
4. The binary outputs and the analog inputs etc. will not be used for the following tests.

3.2.4 Wiring of the Test Set to the Relay

Note: The following wiring diagrams are examples only. The wiring of the analog current inputs may be different if additional protective functions such as sensitive ground fault protection are provided. In this case I_N may be wired separately.



3.3 Local Hardware Configuration for Distance Protection Testing



The **local Hardware Configuration** activates the output/input signals of the CMC test set for the selected test module. Therefore, define it separately for each individual test module once you have opened it. Click **Hardware Configuration** on the **Home** tab and check/adjust the test module signal selection.

3.3.1 Analog Outputs


Local Hardware Configuration

General

Analog Outputs

Binary / Analog Inputs

Binary Outputs


 The read-only settings on this page can be edited in the Global Hardware Configuration, only.

Test Module Output Signal	Display Name	Connection Terminal	CMC356 V A				CMC356 I A			
			1	2	3	N	1	2	3	N
V A-N	V A-N		X							
V B-N	V B-N			X						
V C-N	V C-N				X					
I A	I A						X			
I B	I B							X		
I C	I C								X	

3.3.2 Binary Inputs

Local Hardware Configuration

GeneralAnalog OutputsBinary / Analog InputsBinary Outputs

 The read-only settings on this page can be edited in the Global Hardware Configuration, only.

			Function					
			Binary		Binary		Binary	
			<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>	
Test Module Input Signal	Display Name	Connection Terminal	1+	1-	2+	2-	3+	3-
Start	Start		X					
Trip	Trip				X			
Not used	Bin. In. 3						X	

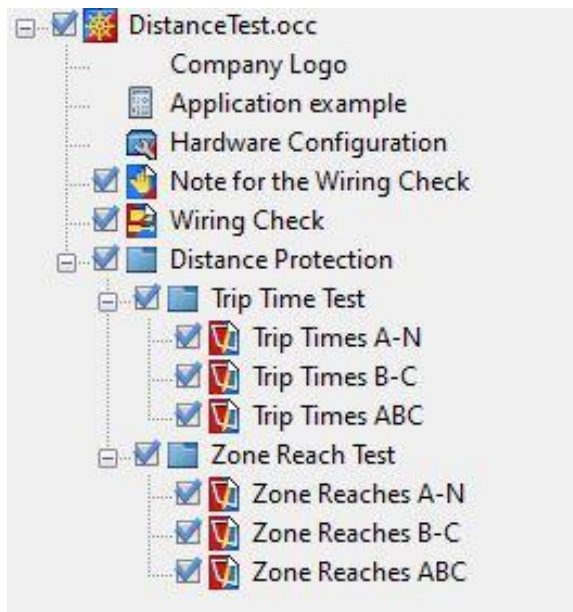
3.4 Defining the Test Configuration

3.4.1 General Approach

When testing the distance protection elements, the following steps are recommended:

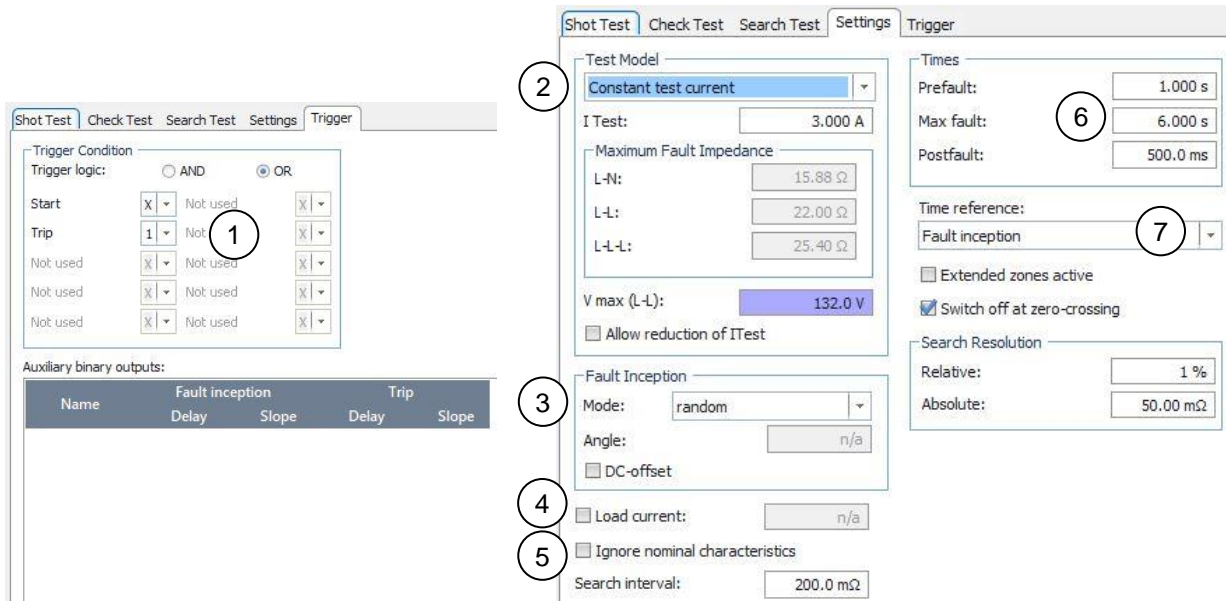
- > **Trip time test:** The trip times of the distance protection function are verified.
- > **Zone reach test:** The zone reaches of the distance protection are verified.

The trip time test, as well as the zone reach test, is performed with the *Advanced Distance* test module.



3.4.2 Trip Time Test

Trigger and Settings tabs:

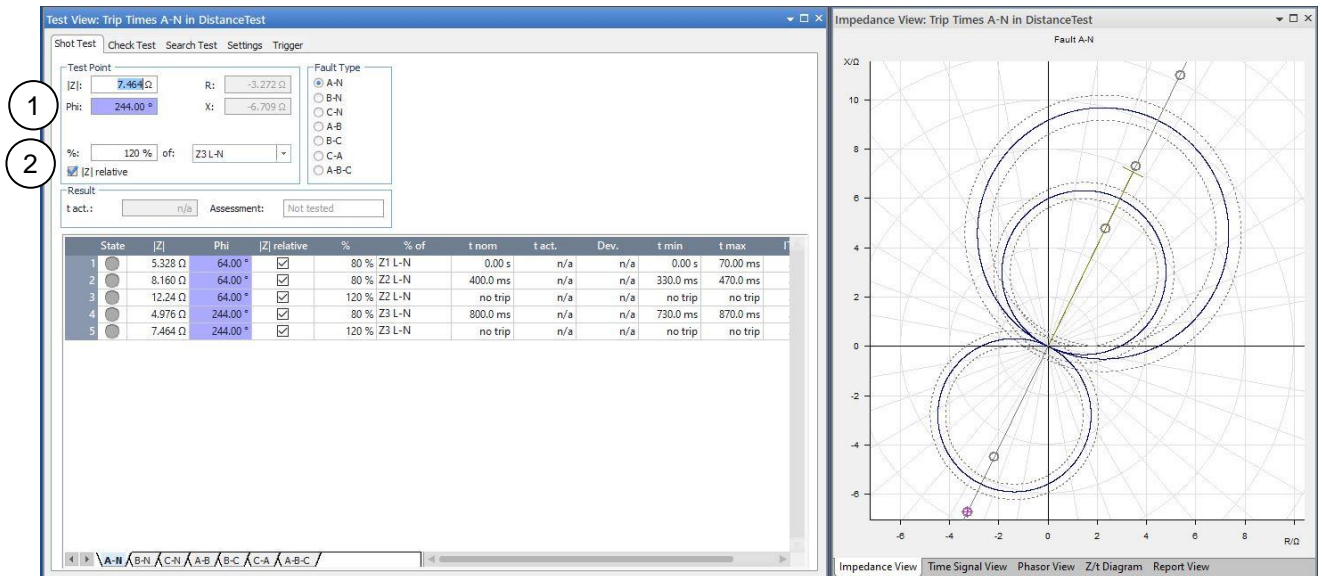


The screenshot displays the 'Settings' tab of the Trip Time Test configuration. The interface includes several sections with various input fields and checkboxes. Numbered callouts highlight specific settings:

- 1:** Trigger Condition: Trip (1) Not used (X) Not used (X) Not used (X) Not used (X) Not used (X)
- 2:** Test Model: Constant test current
- 3:** Fault Inception Mode: random
- 4:** Load current: n/a
- 5:** Ignore nominal characteristics: n/a
- 6:** Max fault: 6.000 s
- 7:** Time reference: Fault inception

1. The trip contact is the trigger for this test.
2. The test model will be **Constant test current**. The test current is automatically set to $2 \times I_{nom}$ but can be changed if needed. This current has to be above the pick-up of the overcurrent supervision element.
3. Here you set the angle of the fault occurrence (voltage of faulty reference phase). In this example, the mode of the fault inception is set to **random**.
4. A **Load current** during the pre-fault state can be set if desired.
5. **Ignore nominal characteristic** ignores the zone settings of the test object for the search test. In this example it is not selected.
6. These times define the pre-fault, fault and post-fault states. It should be ensured that the **Max. fault** time is longer than the highest zone time delay setting.
7. The time reference defines whether the fault inception or the start contact is used as a reference for the trip time measurement. In this example it is set to **Fault inception**.

Shot Test tab:



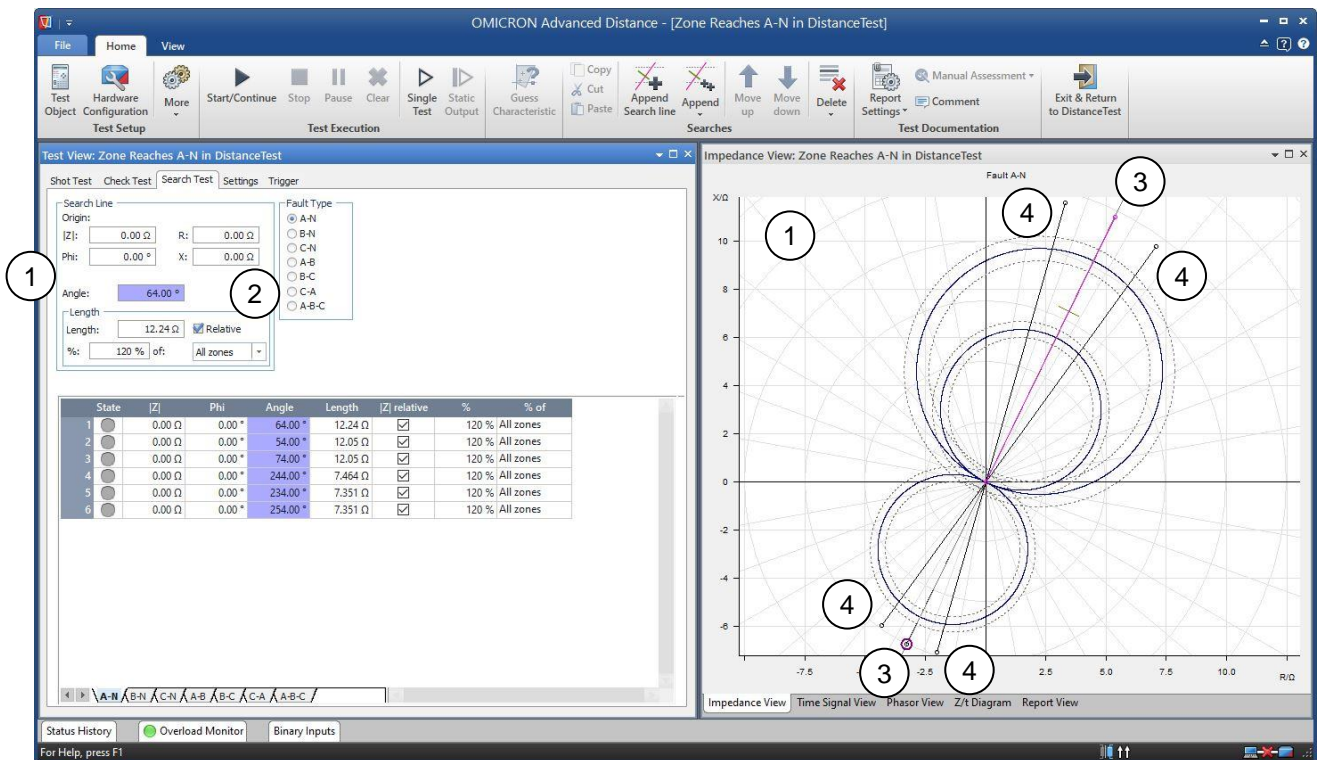
The trip times are tested with the shot test. With this test method test shots can be placed in the impedance plane. These test shots can either be set manually by entering **R** and **X** or **|Z|** and **Phi** values or an angle can be entered **(1)** and the values can be set relative to the respective zone **(2)**. To do so, the option **|Z| relative** has to be selected. If this option is used, the test shots will be adapted whenever the zone settings change. Select the **Follow line angle change** option to adapt the angle of the test shots to a changing line angle.

For this test, test shots are placed both inside and outside of the tripping zones. Hence, it is possible to test the trip times of all the tripping zones, as well as no trip outside the distance zones.

3.4.3 Zone Reach Test

In the **Trigger** and the **Settings** tab, the same adjustments as for the trip time test apply.

For the zone reach test the **Search Test** is used. With this tab the user can define search lines. The test module applies test shots along these lines to search for the reach of each zone. It is also possible to use the **Check Test**. With this test lines are again defined. However, this time test shots will be placed along these lines outside the tolerance bands. This confirms if the zone reach is within the defined tolerances.



1. Search lines can be defined either by dragging a line in the impedance plane or by setting a start point, an angle and the length. After defining a line, click **Add** to add it to the list of test lines.
2. By using LinkToXRIO for the **Angle** and activating **Relative**, test lines can be defined in a way that they adapt to changes of the zone settings or the line angle.
3. In the forward and reverse direction, one search line is defined to test the zone reach settings of the zones.
4. Additional test lines along the line angle can also be set. This confirms that the relay works correctly in the area where faults normally occur. In this example, reaches are verified at ± 10 degrees off the line angle.

Feedback regarding this application is welcome by email at OMICRON Protection Bulletin
PTB@omicronenergy.com.

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