OMICRON

Practical Example of Use

Testing Directional Overcurrent Protection

Author
Faris Elhaj | faris.elhaj@omicronenergy.com
Robert Wang | robert.wang@omicronenergy.com

Date
September 14, 2018

Related OMICRON Product
CMC – Test Universe

Application Area
Directional Overcurrent

Keywords
Test Universe, Overcurrent, Directional

Version
v1.0

Content

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.

OMICRON electronics GmbH including all international branch offices is henceforth referred to as OMICRON.

The product information, specifications, and technical data embodied in this application note represent the technical status at the time of writing and are subject to change without prior notice.

We have done our best to ensure that the information given in this application note is useful, accurate and entirely reliable. However, OMICRON does not assume responsibility for any inaccuracies which may be present.
OMICRON translates this application note from the source language English into a number of other languages. Any translation of this document is done for local requirements, and in the event of a dispute between the English and a non-English version, the English version of this note shall govern.

Preface

This paper describes how to test directional overcurrent protection elements. It contains an application example that will be used throughout the paper. The theoretical background of the directional overcurrent protection will be explained. This paper also covers the definition of the necessary **Test Object** settings as well as the **Hardware Configuration** for directional overcurrent tests. Finally the *Overcurrent* test module is used to perform the tests that are needed for the directional overcurrent protection function.

Supplements: Sample *Control Center* file **Example_Overcurrent_OvercurrentDirectional.occ** (referred to in this document).
Requirements: *Test Universe* 3.00 or later; *Overcurrent* and *Control Center* licenses.

1 Application Example

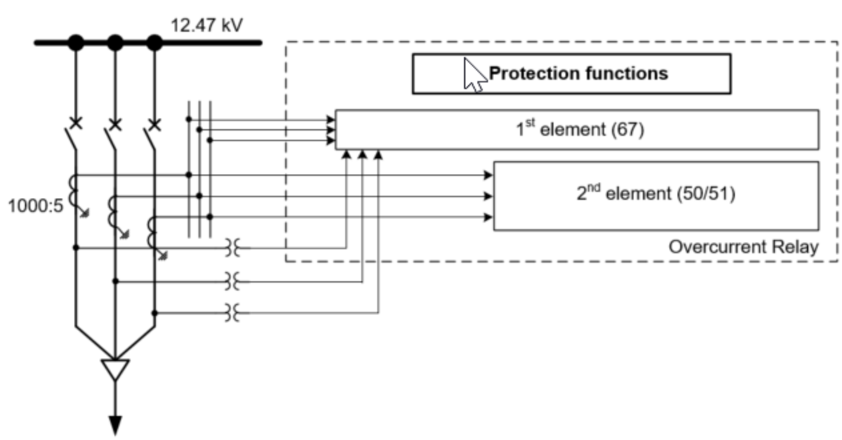


Figure 1: Feeder connection diagram for the application example

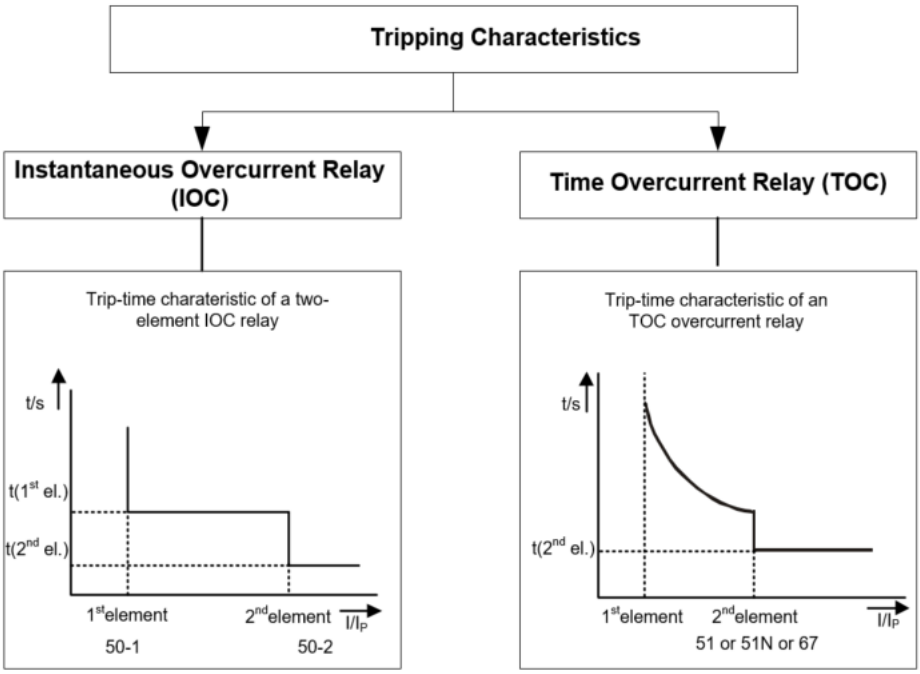
Parameter Name	Parameter Value	Notes
Frequency	60 Hz	
VT (primary/secondary)	7200 V / 69.3 V (L-N)	
CT (primary/secondary)	1000 A / 5 A	
1st element	IEEE Very Inverse	Tripping characteristic
	Directional Fwd	Directional characteristic Forward
	1.5 X CT	Pick-up 1.5 x $I_{n\ CT\ primary}$
	3	Time multiplier setting (TD; TMS; τ_P, etc.)
	30° 0.7 X VT	Relay characteristic angle (directional protection) Polarizing Voltage Threshold (directional protection)
2nd element	Definite Time	Tripping characteristic
	3 X CT	Pick-up 3 x $I_{n\ CT\ primary}$
	100 ms	Trip time delay

Table 1: Relay parameters for this example

2 Theoretical Introduction to Overcurrent Characteristics

2.1 Theory

There are two major overcurrent characteristic types: Definite-time (IOC) and Inverse-time (TOC)



The definite-time (IOC) characteristic allows for rapid fault clearance for current above a specific setting.
In North America, inverse-time (TOC) curves conforming to the IEEE C37.112-1996 standard are common.
The IEEE curves are derived from the formulae:

$$T = Time\ Multiplier * \left[\frac{A}{(\frac{I}{I_{pickup}})^P - 1} + B \right], T_{RESET} = Time\ Multiplier * \left[\frac{t_r}{1 - (\frac{I}{I_{pickup}})^2} \right]$$

IEEE Curve Shape	A	B	P	t_r
IEEE Extremely Inverse	28.2	0.1217	2.000	29.1
IEEE Very Inverse	19.61	0.491	2.000	21.6
IEEE Moderately Inverse	0.0515	0.1140	0.02000	4.85

Table 2: Inverse TOC tripping characteristics (GE850 Manual and IEEE C37.112-1996, section 4.2-4.4)

Where:

$T = operate\ time\ (in\ seconds)$
$Time\ Multiplier = Multipier\ setting$
$I = input\ current$
$I_{pickup} = Pickup\ Current\ setting$
$A, B, p = constants$
$T_{RESET} = reset\ time\ in\ seconds\ (assuming\ energy\ capacity\ is\ 100\%\ and\ RESET\ is\ \text{"Timed"})$
$t_r = characteristic\ constant$

2.2 Tripping Characteristics (50, 51, 67)

As the properties of the operational equipment differ considerably (overload, short circuit behavior, etc.) the characteristics have to be adapted to this.

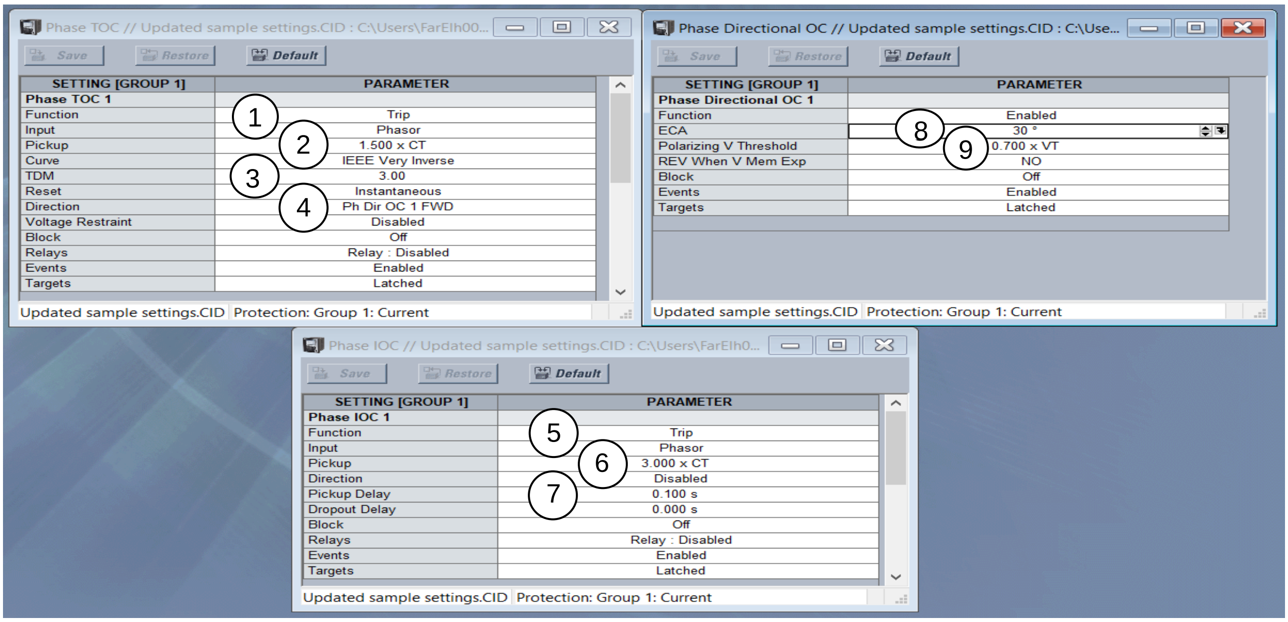


Figure 2: Parameters of an overcurrent relay (GE850)

1. Tripping characteristic for the 1st element (for this example Phase TOC1 - IEEE Very Inverse)
2. Pick-up setting of 1st element (CT=1000A)
3. Time multiplier setting (TDM) for the 1st element
4. Directional function (for this example forward)
5. Tripping characteristic for the 2nd element (Phase IOC1 for this example)
6. Pick-up setting (primary) of 2nd element
7. Trip time delay of 2nd element
8. Element characteristic angle ECA (only for the directional function)
9. Polarizing voltage threshold (VT=7200V L-N)

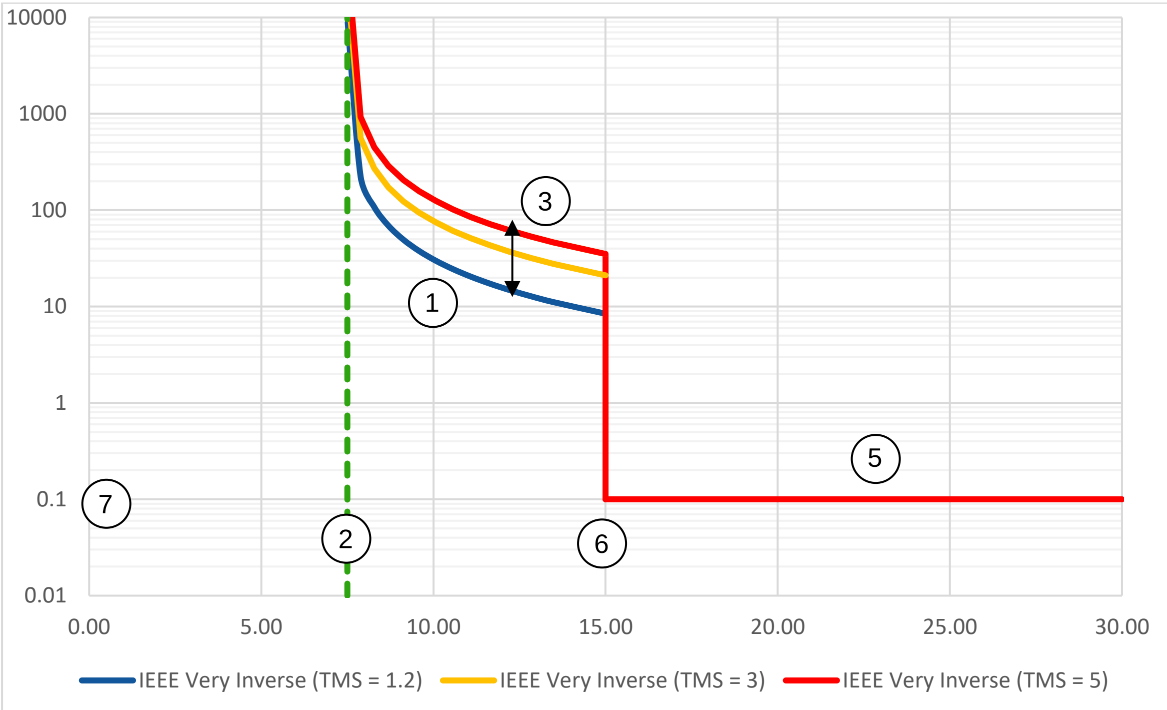


Figure 3: Comparison of IEEE Very Inverse tripping characteristics with different time multiplier settings (TDM)

2.3 Directional Overcurrent Protection (67)

Directional overcurrent protection is used in situations where fault current can flow in both directions through the relay location.

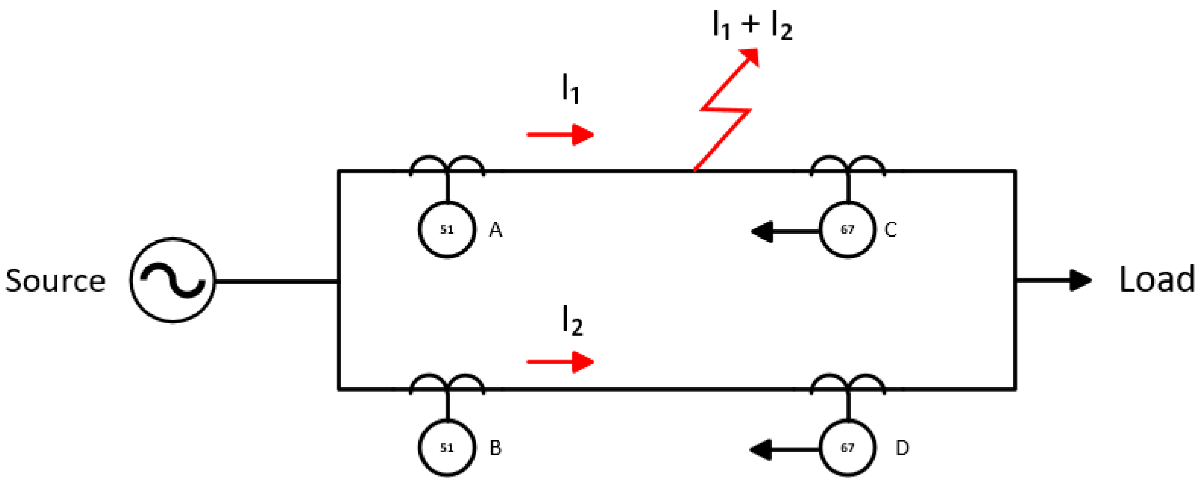


Figure 4: Fault current flow on a parallel feeder

The relays at C and D in the figure above are set to operate for faults in the forward direction (looking towards B for relay D and looking towards A for relay C). Since the flow of fault current is in the reverse direction at relay D, it does not operate. The fault on AC will be isolated by relay C.

In order to determine the current direction, forward or reverse, the relay needs a reference or polarizing voltage. The polarizing voltage is one whose phase angle will remain reasonably constant between a non-faulted and faulted system.

The following conditions should be considered when selecting the polarizing voltage:

- For a close-in fault, the fault voltage is almost zero
- The angle of the directional characteristic (ECA or MTA) depends on the fault type (Phase A-Ground, Phase B-Ground, etc.)

Note: The ECA (element characteristic angle) or MTA (maximum torque angle) is the angle by which the polarizing voltage is shifted in order to produce maximum relay sensitivity.

For this, relay connections have been developed that make use of different reference voltages with corrected phase angles.

Connections	Advantages	Disadvantages	Maximum Torque Occurs When
$0° \left(\bar{I}_{ph}, \bar{V}_{ph}\right)$	Maximum sensitivity with arc faults	Not suitable for HV-systems, no directional decision with a close-in fault	*I* lags 0°
$30° \left(\bar{I}_{ph}, \bar{V}_{ph} - \bar{V}_{ph} \cdot \bar{a}\right)$ $60° \left(\bar{I}_{ph}, -\bar{V}_{ph} \cdot \bar{a}\right)$		Reference voltage depends on the fault	*I* lags 30° *I* lags 60°
$90° \left(\bar{I}_{ph}, \bar{V}_{ph} \cdot \bar{a}^2 - \bar{V}_{ph} \cdot \bar{a}\right)$	Maximum reference voltage with phase to ground and phase to phase faults	Not suitable for arc faults	*I* lags 45° or 60°

Table 3: Relay connection for determining the reference voltage.

Phasor rotation operators:

$\bar{a} = 1\angle 120° \quad \bar{a}^2 = 1\angle -120°$

Note: The method used for the reference voltage depends on the relay manufacturer. For the following discussion we use an overcurrent relay with 90° relay connection and a relay characteristic angle (ECA or MTA) of 30° (*I* lags 60°).

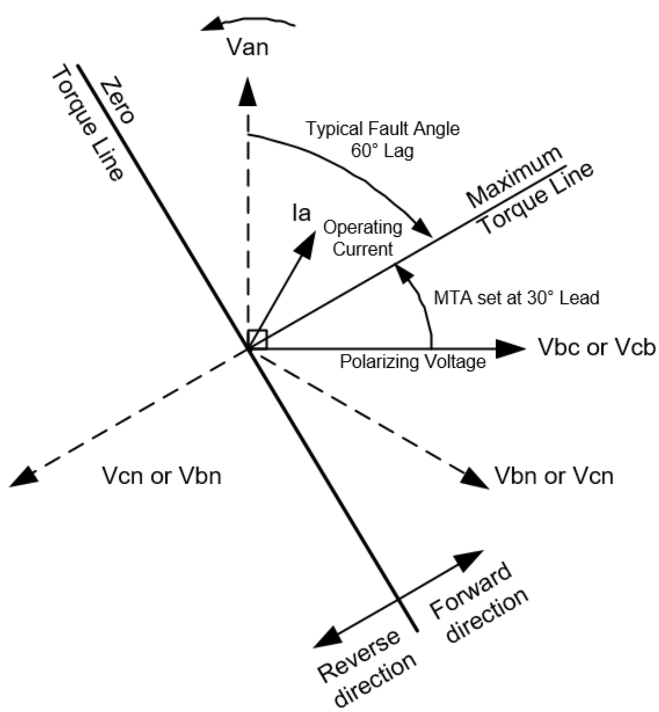
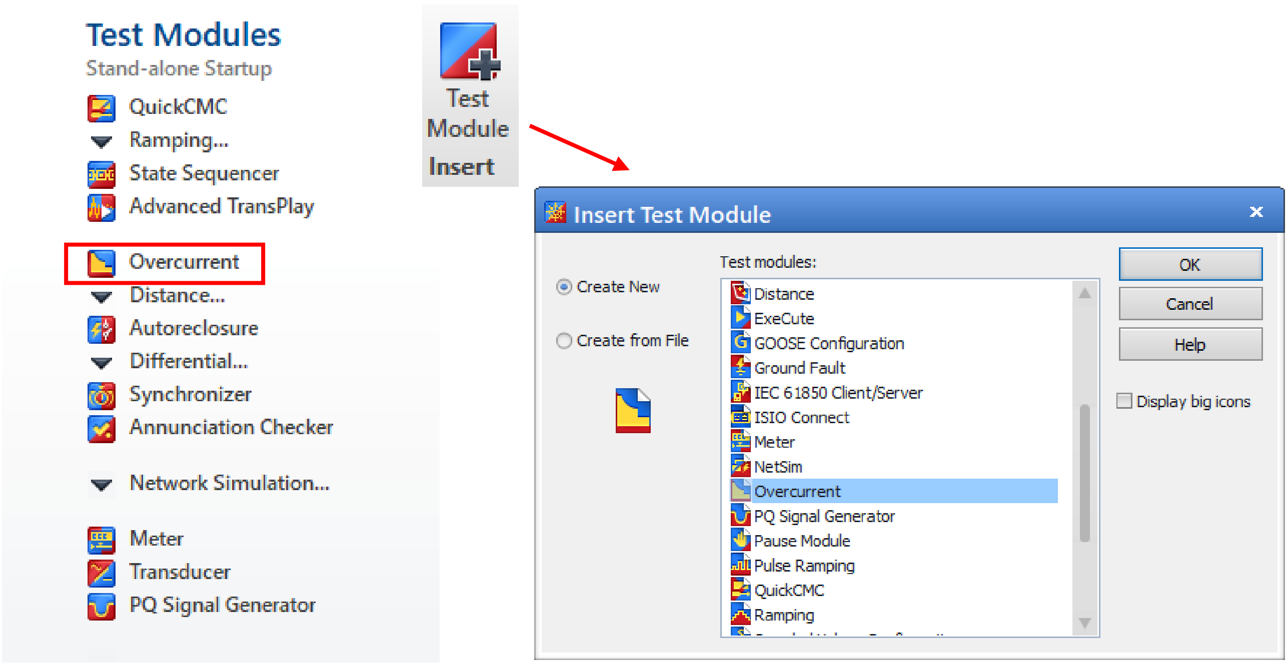


Figure 5: 90° relay connection with a relay characteristic angle of 30° (Phase A-Ground fault)

3 Practical Introduction to Overcurrent Characteristic Testing

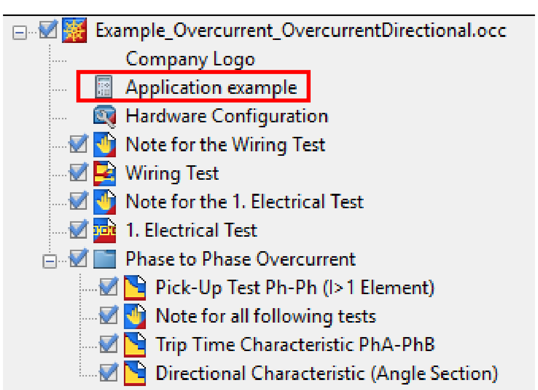
The *Overcurrent* test module is designed for testing directional and non-directional overcurrent protection functions with DTOC or IDMT tripping characteristics (short-circuit, thermal overload, zero sequence, negative sequence, and customized curve characteristics).

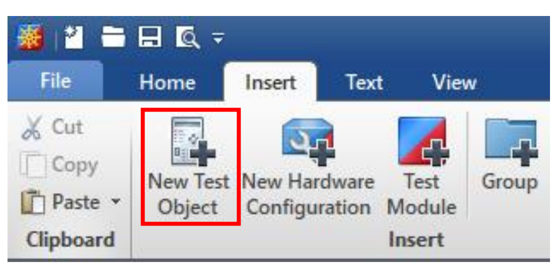
The test module can be found on the start screen of the OMICRON *Test Universe*. It can also be inserted into an OCC File (*Control Center* document).



3.1 Defining the Test Object

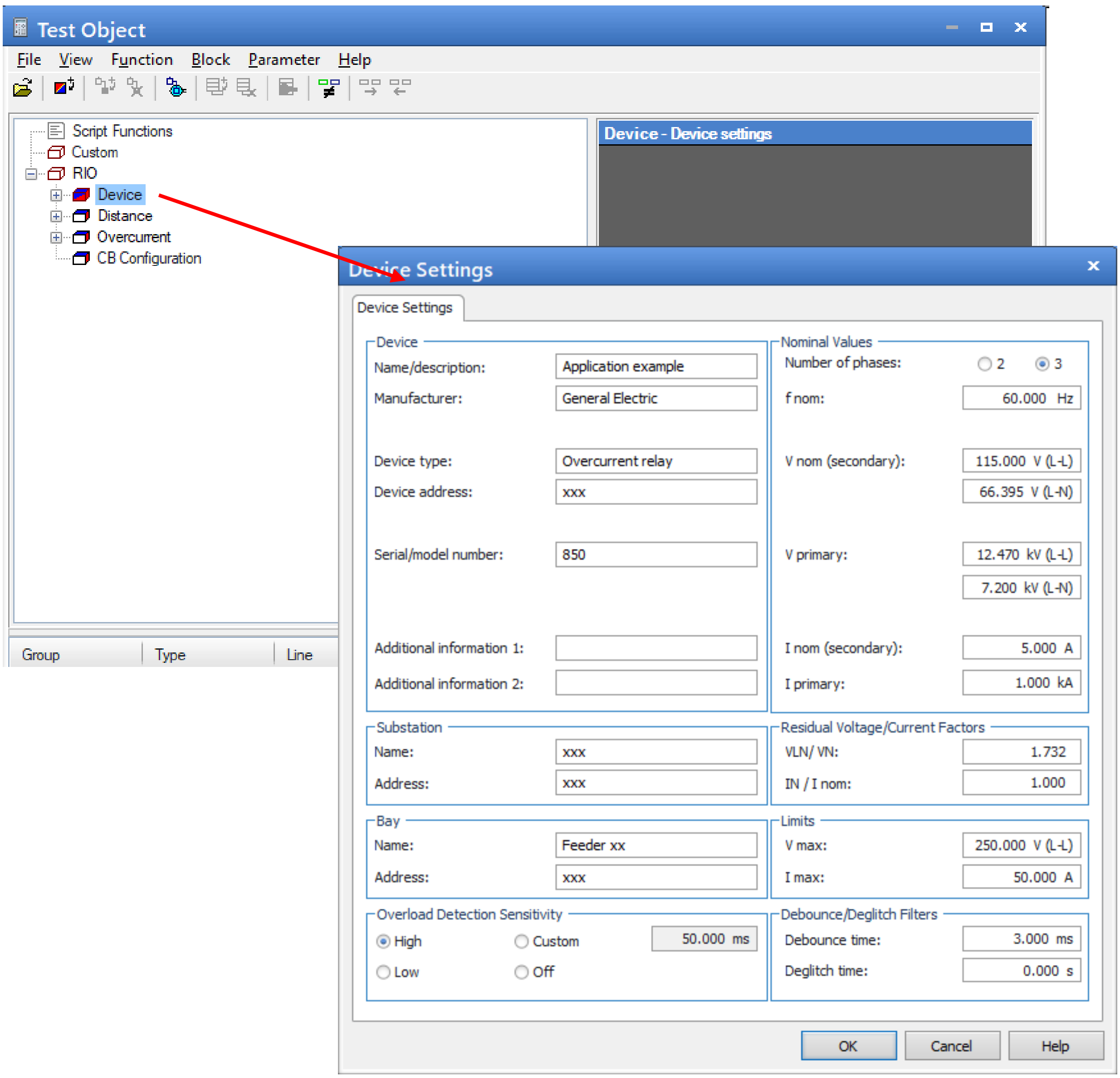
Before you start your test, define the settings of the relay (the test object) to be tested. Double-click the **Test Object** entry in the Control Center file to launch **Test Object**. Alternatively, click **Test Object** on the **Insert** tab.





3.1.1 Device Settings

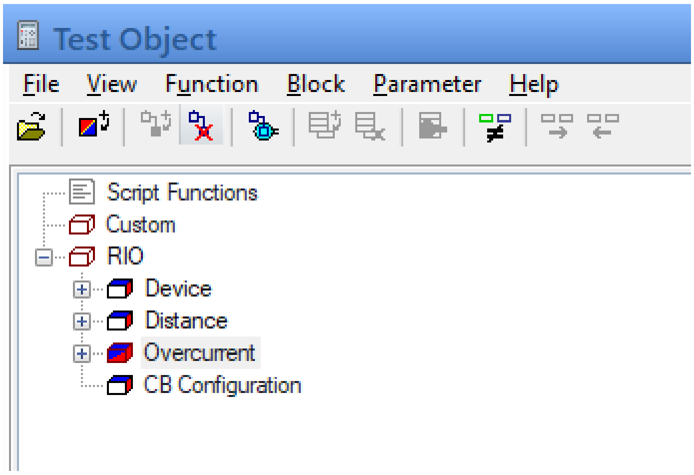
General relay settings (e.g., relay type, relay ID, substation details, CT and VT parameters) are entered in the **RIO** function **Device**.



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 Overcurrent Protection Parameters

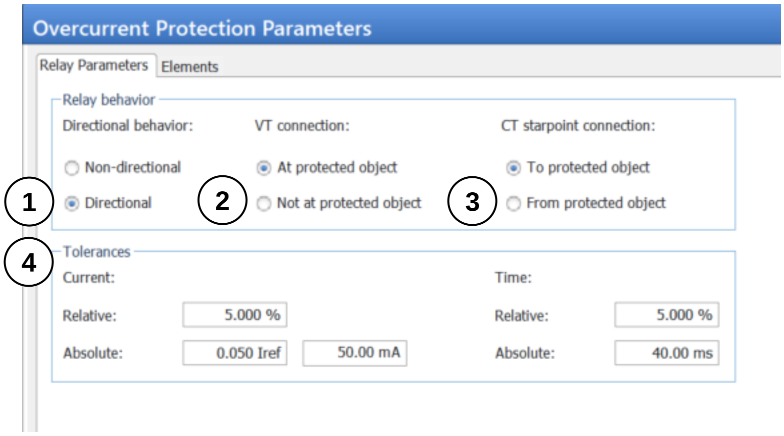
More specific data concerning the overcurrent relay can be entered in the **RIO** function **Overcurrent**. The definition of the overcurrent characteristic must also be made here.



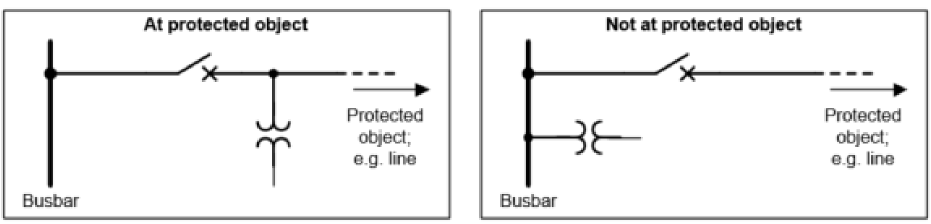
Note: Once an *Overcurrent* test module is inserted this **RIO** function is available.

Relay Parameters

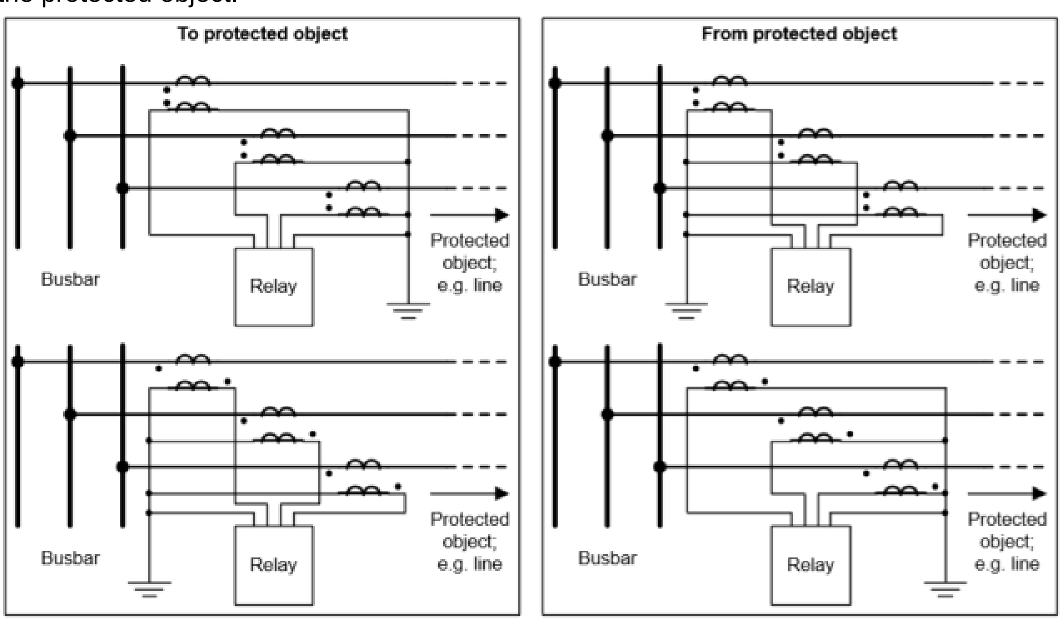
This first tab contains the definition of the directional behavior as well as the relay tolerances.



1. Since we want to test a directional overcurrent relay, this has to be activated.
2. Regarding the feeder connection diagram (Figure 1) the VT is placed **At protected object**. If **Not at protected object** is chosen, the voltage will have the nominal value after tripping.



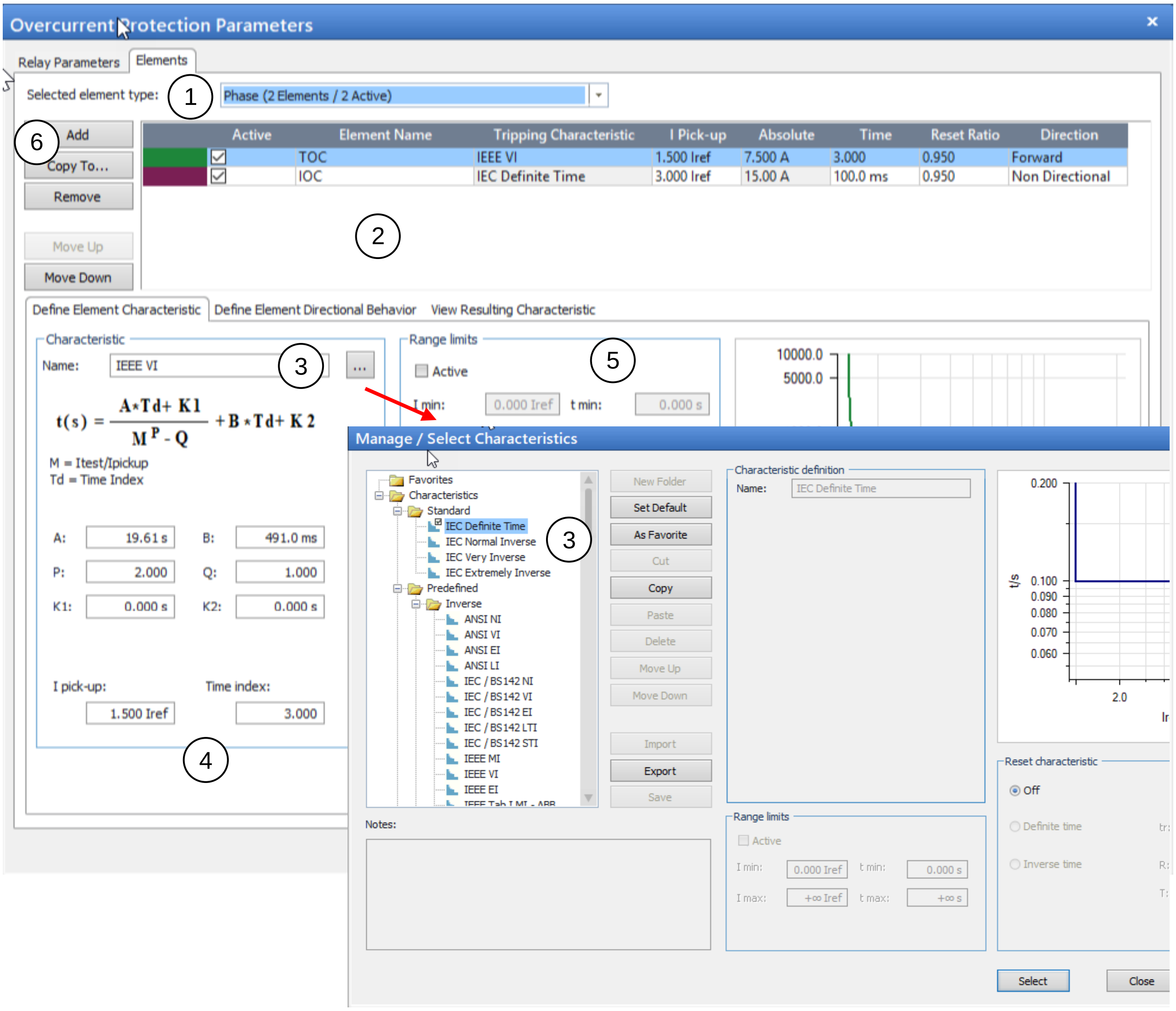
3. The **CT starpoint connection** has to be set according to the connection of the secondary windings of the CT. For this example the feeder connection diagram (Figure 1) shows that the CT grounding is towards the protected object.



4. The current and time tolerances can be obtained from the relay manual.

Elements

This tab defines the characteristic of the different overcurrent elements.

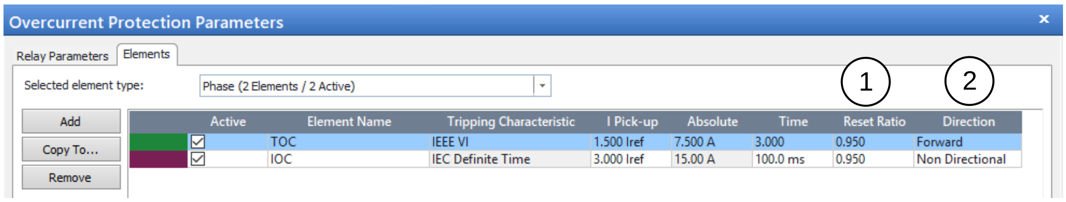


The default overcurrent characteristic is shown above. It contains an IEC Definite Time scheme with one element for a phase overcurrent protection. This characteristic should be adjusted to the parameters of the relay (Table 1):

1. In order to define the elements of the phase overcurrent protection, select **Phase** as the **Selected element type**.
   Note: If other element types are also present in the relay select the related element types consecutively in **(1)** to enter these elements. The selection field shows the number of already defined related elements and how many of these are marked as active.
2. This table shows the elements that define the tripping characteristic for the selected element type. The name of the first element may be changed according to the name used in the relay, e.g., "TOC".
3. Change the characteristic type of the first element to **IEEE Very inverse** (Table 1).
4. Afterwards set **I Pick-up** and the **Time index**.

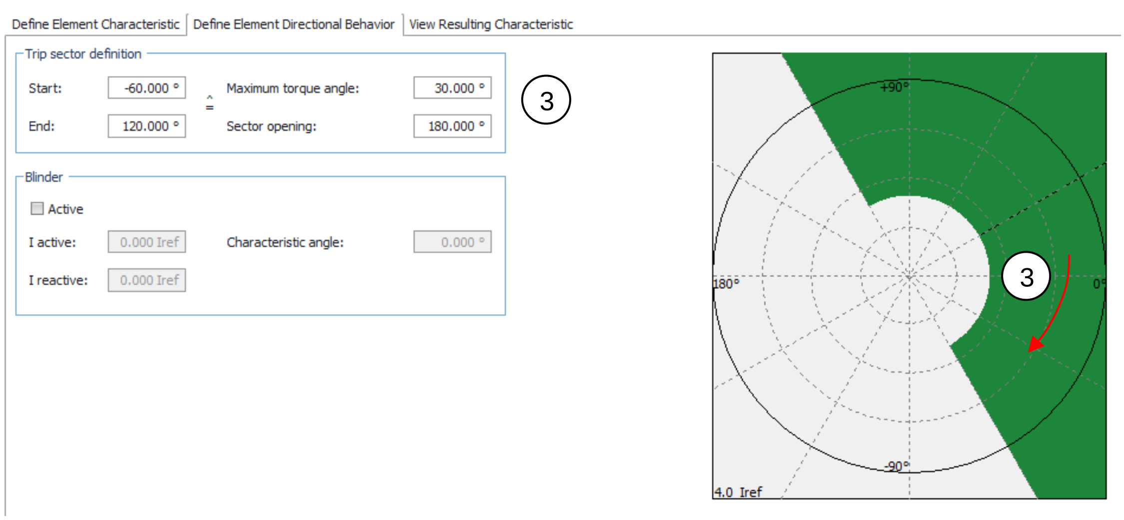
5. Now the second element can be added. It has an **IEC Definite Time** characteristic, which might be renamed to "IOC". Also set **I Pick-up** and the **Trip time**.

The list of the elements appearing after these adjustments is shown below.



1. The **Reset Ratio** must also be checked in the manual.
2. In order to define the directional behavior, the **Direction** of the 1st element has to be set to **Forward**. **Note:** This setting is an orientation help for the reader and, once it is set, it will rotate the directional limits by 180° if changed to **Backward**.

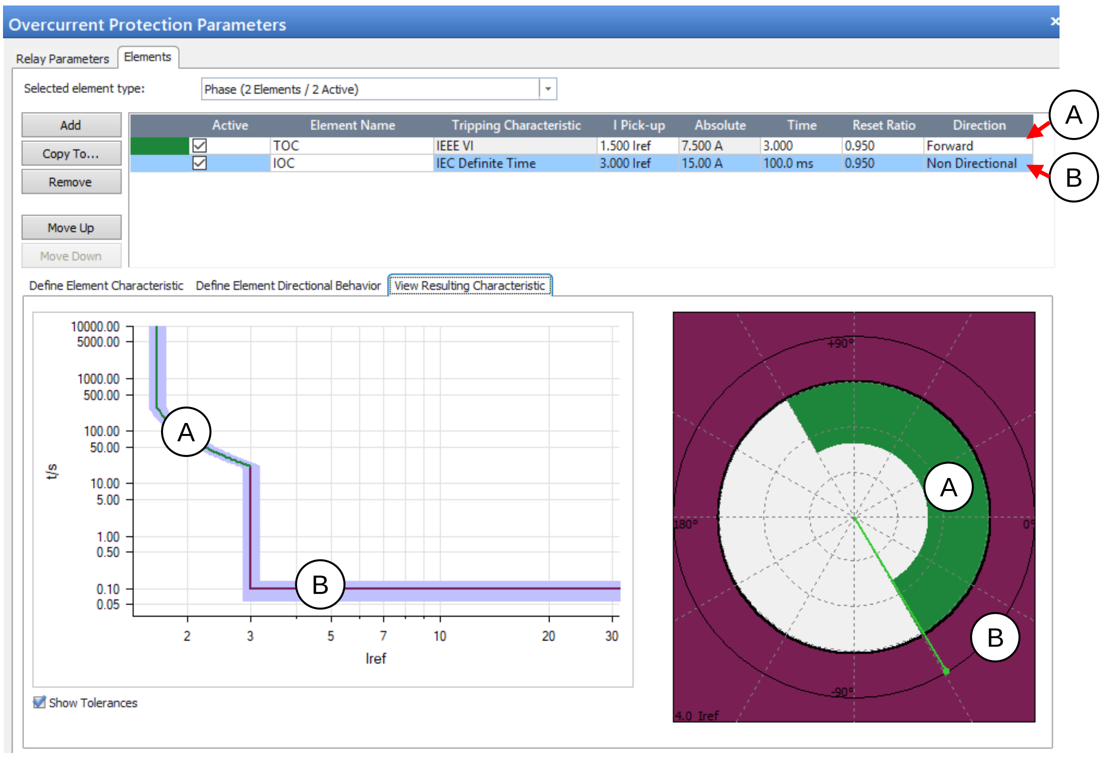
The adjustments of the directional characteristic must be made in the tab **Define Element Directional Behavior**:



As the relay characteristic angle cannot be entered in the **Test Object** directly, the **Trip sector definition** has to be calculated

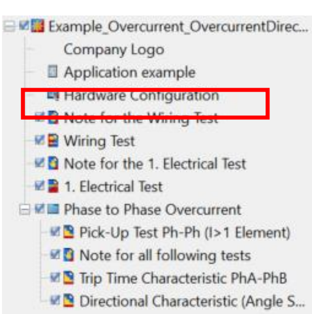
The resulting overcurrent characteristic is shown below.

A 1st element
B 2nd element

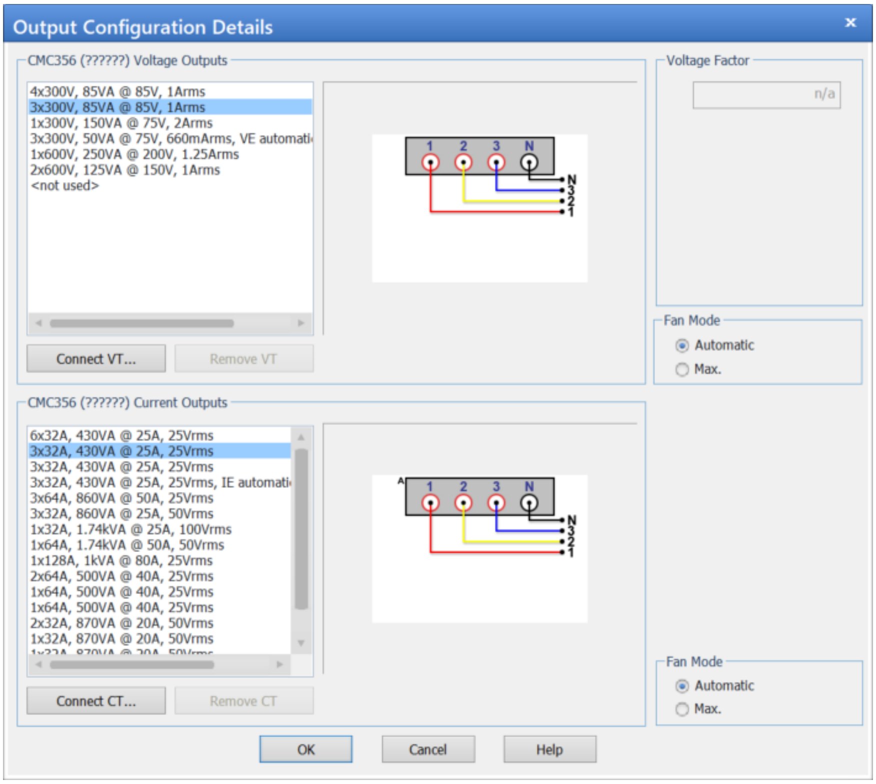


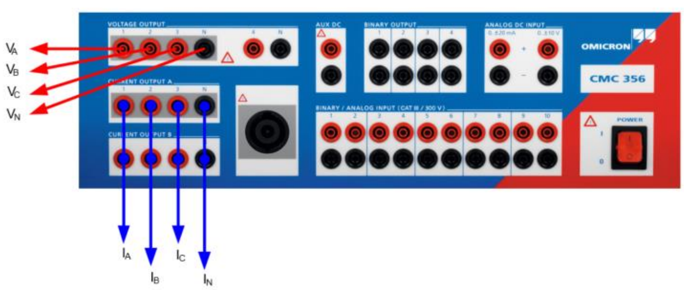
3.2 Global Hardware Configuration of the CMC Test Set

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.

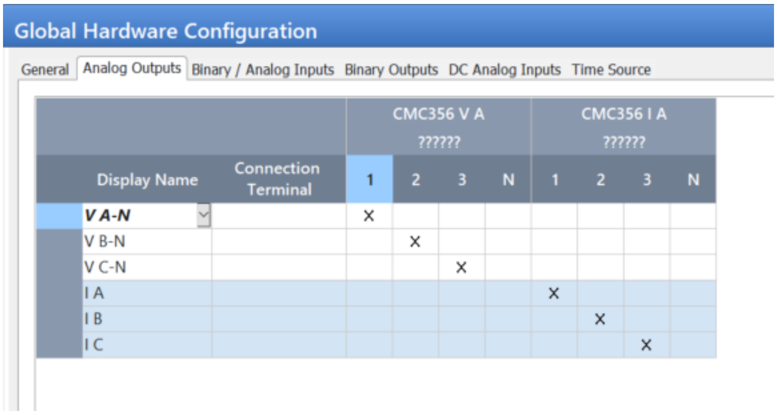


3.2.1 Example Output Configuration for Protection Relays with a Secondary Nominal Current of 5 A



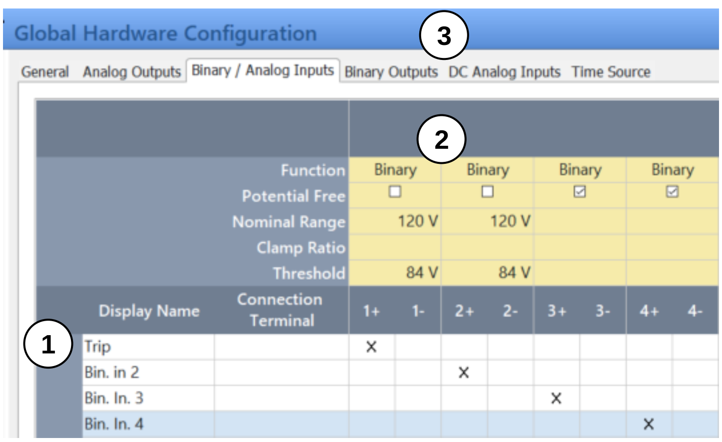


3.2.2 Analog Outputs

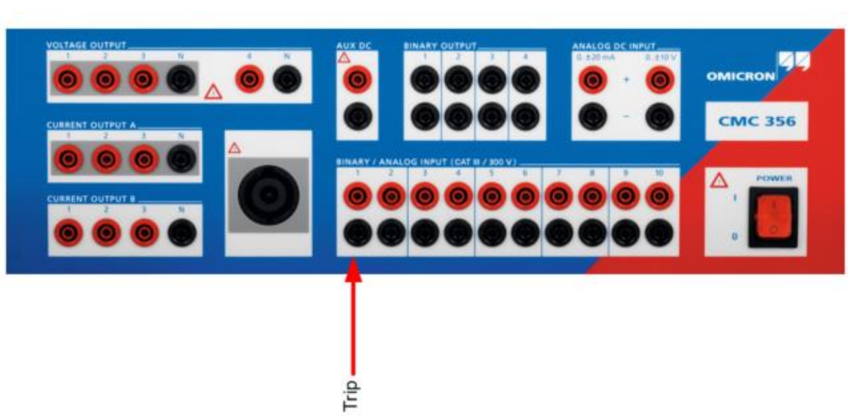


The analog outputs, binary inputs and outputs can all be activated individually in the local **Hardware Configuration** of the specific test module (see chapter 3.3 "Local Hardware Configuration for Directional Overcurrent Testing").

3.2.3 Binary Inputs

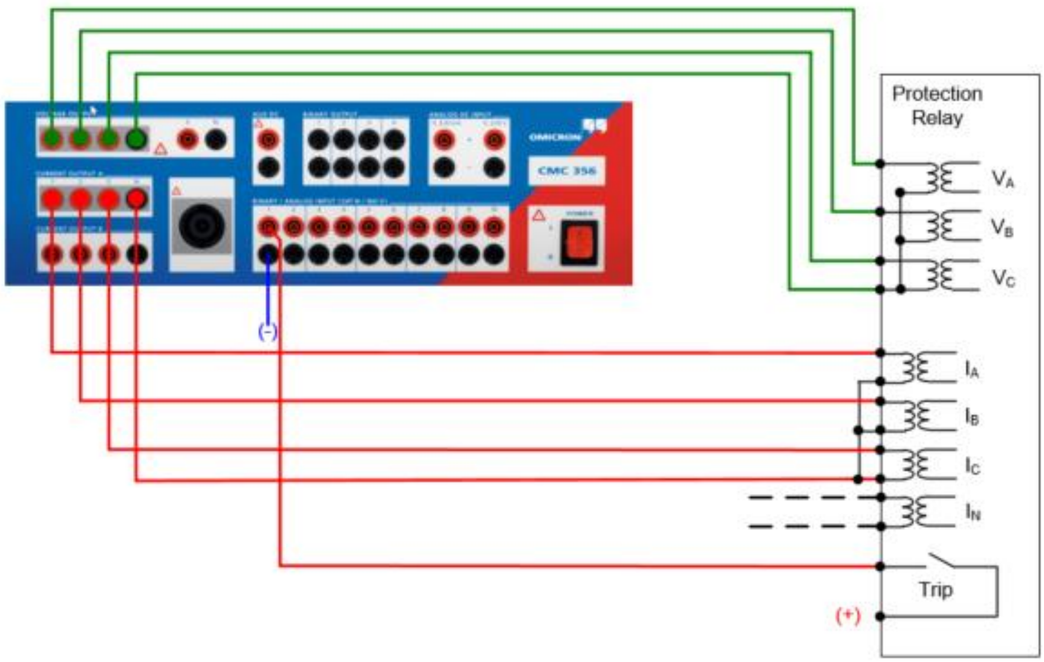


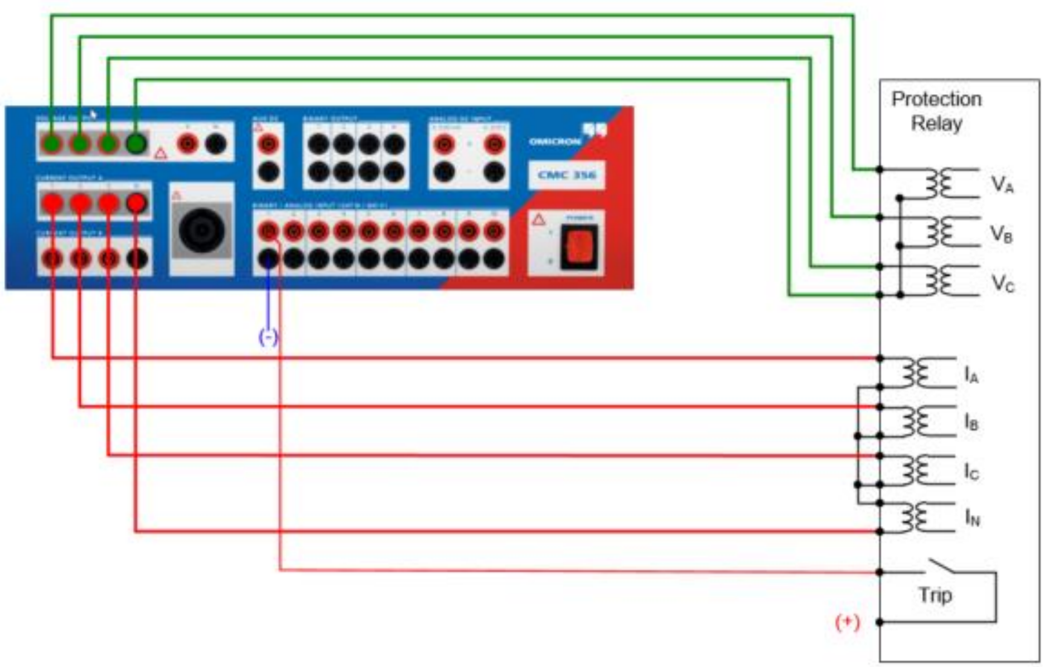
1. The trip command has to be connected to a binary input. BI1 … BI10 can be used.
2. For wet contacts adapt the nominal voltages of the binary inputs to the voltage of the circuit breaker trip command or select **Potential Free** for dry contacts.
3. The binary outputs and analog DC inputs will not be used for the following tests.



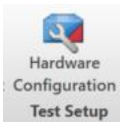
3.2.4 Wiring of the Test Set for Relays with a Secondary Nominal Current of 5A

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.



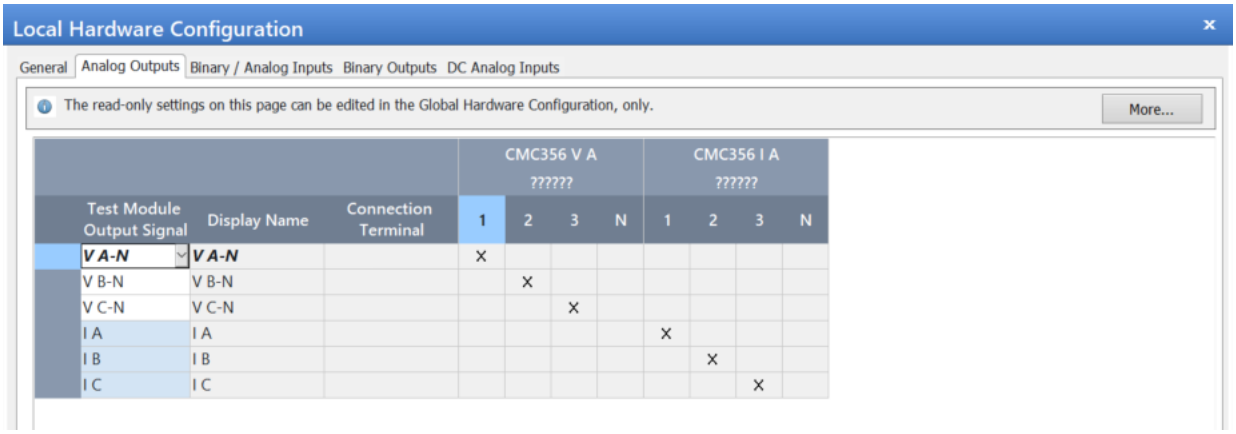


3.3 Local Hardware Configuration for Directional Overcurrent Testing

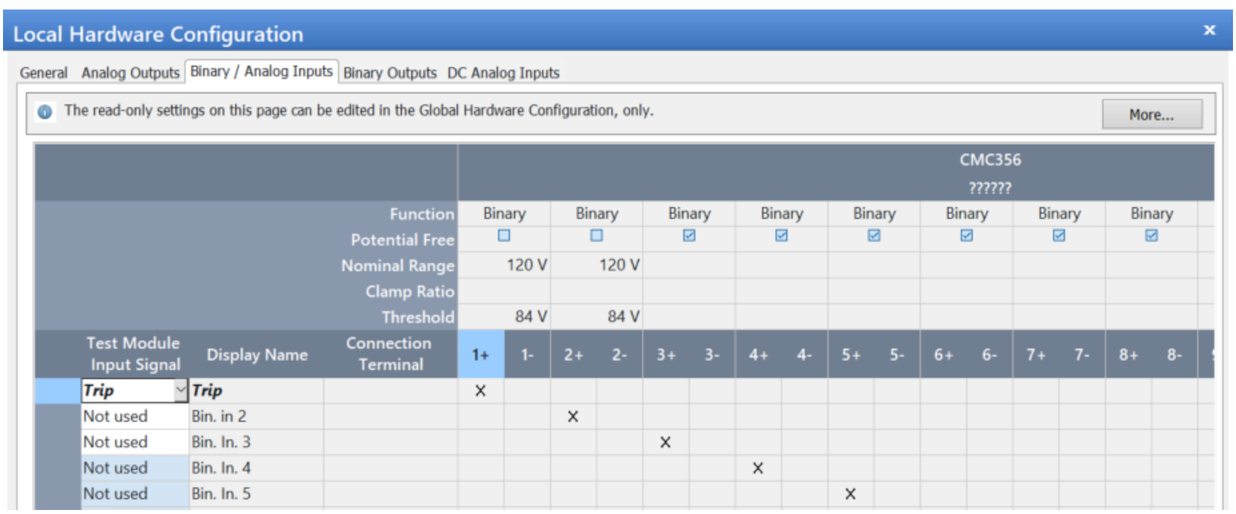


The local **Hardware Configuration** activates the outputs/inputs of the CMC test set for the selected test module. Therefore, it has to be defined for each test module separately. It can be opened by clicking the **Hardware Configuration** button in the test module.

3.3.1 Analog Outputs



3.3.2 Binary Inputs



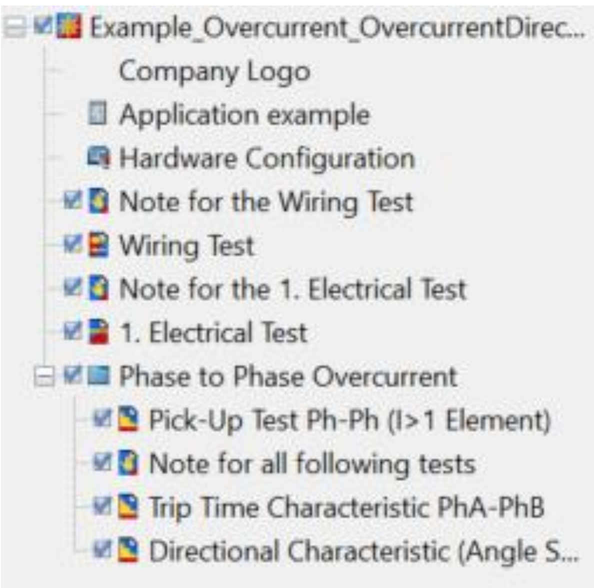
3.4 Defining the Test Configuration

3.4.1 General Approach

When testing the directional overcurrent protection, the following steps are recommended:

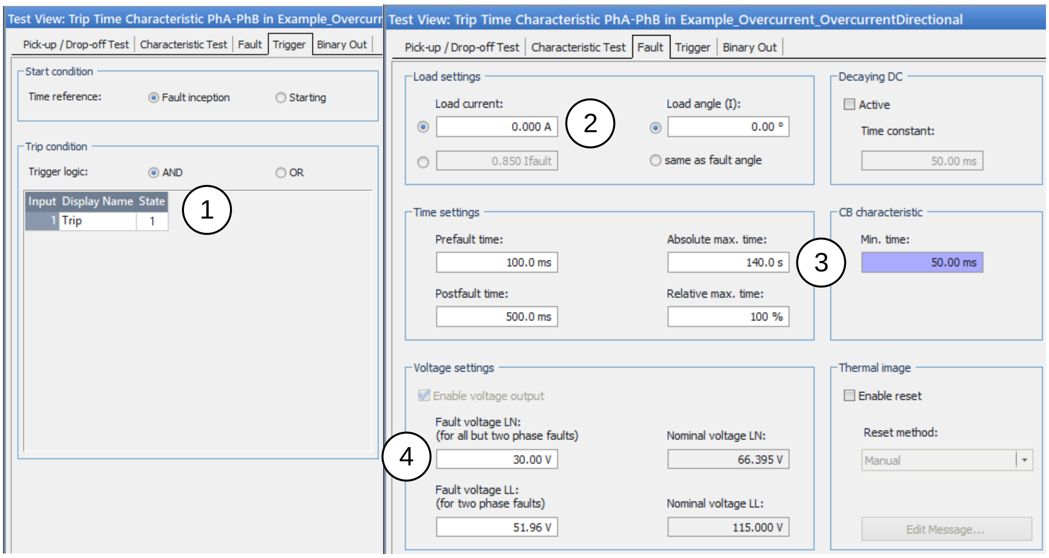
> **Trip time characteristic**: Verifying the trip times of every element of the tripping characteristic.
> **Directional characteristic**: Verifying the angle of the directional characteristic.

Each of these tests can be performed with the *Overcurrent* test module.



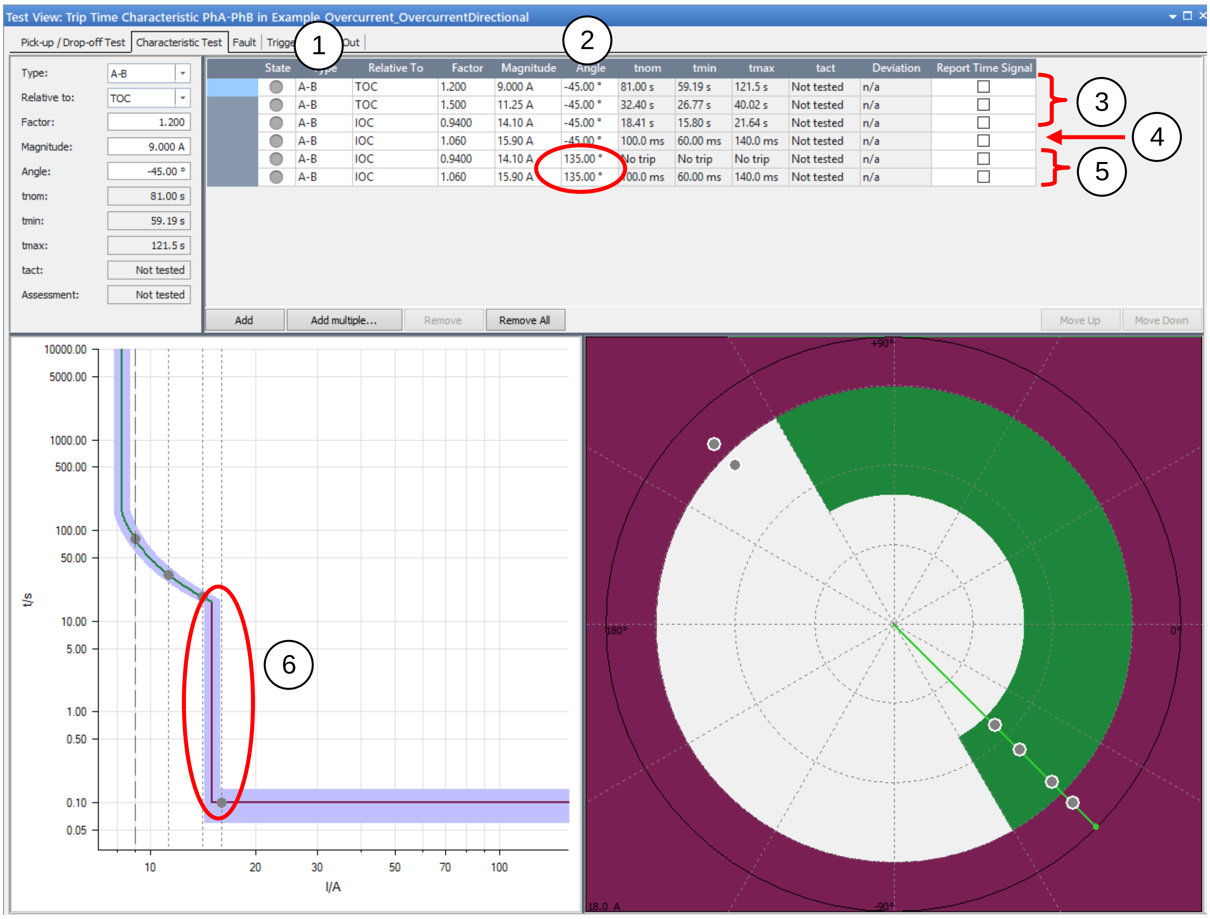
3.4.2 Trip Time Characteristic Test

Trigger and **Fault** tabs:



1. The trigger for this test will be the trip contact.
2. A **Load current** during the pre-fault state will not be used in this example.
3. The **Absolute max. time** has to be adjusted. On the one hand, it has to exceed the upper tolerance of the test point with the longest trip time otherwise an assessment will not be possible. On the other hand, it should not be set to an unnecessarily high value. For shots where **No trip** is expected this will be the waiting time until the assessment 'no trip' is made before continuing with the next shot. So if this time is set to a very high value, it would unnecessarily prolong the test duration.
4. The **Voltage settings** define the voltages for different fault types. These voltages only apply to the faulty phases. The non-faulty phases remain at nominal voltage. For most purposes it is sufficient to leave these settings at the default values.

Characteristic Test tab:



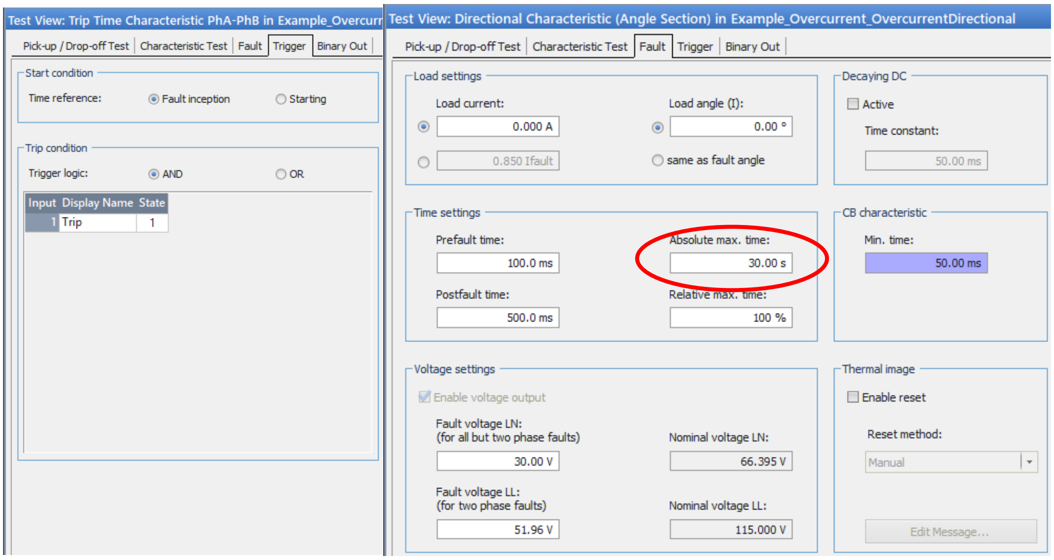
1. As the function to test is a phase overcurrent function, a phase to phase fault is used.

   Note: In this case other protection functions may interfere with the test. However, if such functions or elements (e.g., ground fault protection, negative sequence protection, etc.) are present they may be specified in the **Test Object** in the same manner as the phase elements were entered in this example. The resulting characteristic will be calculated individually and shown for each test shot depending on its fault type **(1)** and fault angle **(2)**, ensuring a proper assessment according to the expected overall relay behavior.

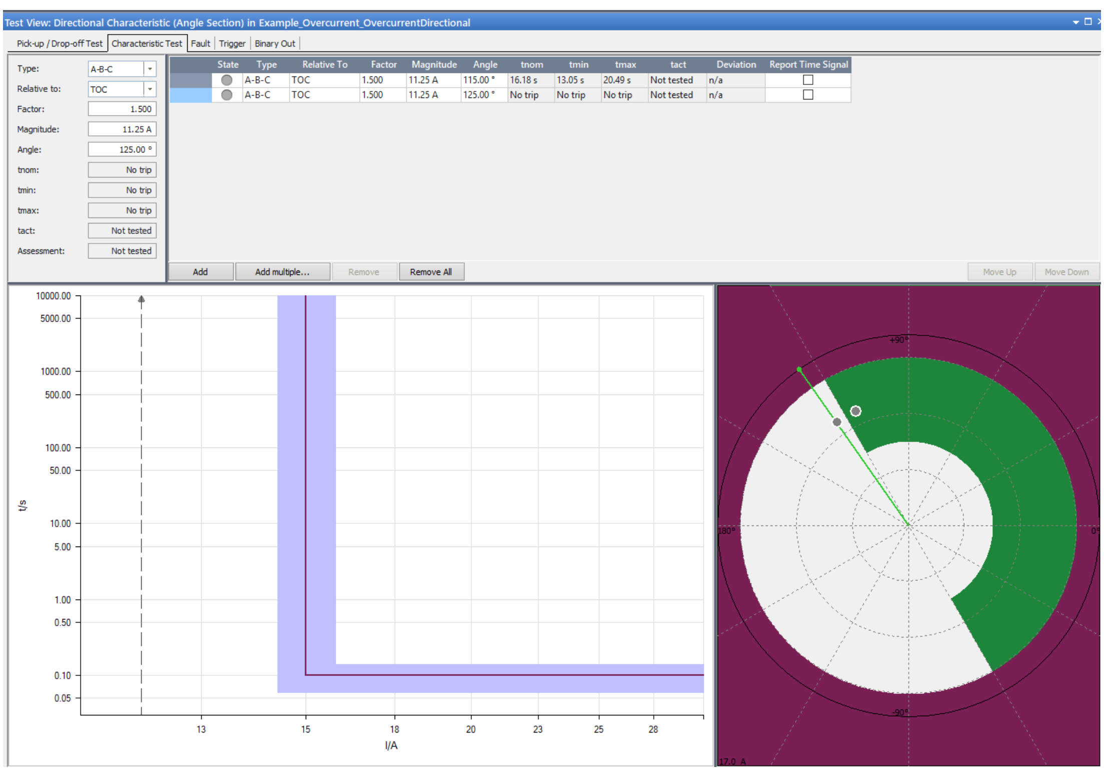
2. The **Angle** for the forward direction should be the **Maximum torque angle**. For reverse direction it has to be entered shifted by 180°.
3. As the trip time of the TOC element depends on the current, this element has to be verified with more than one test point.
4. The trip time of the 2nd element can be confirmed with only one test point.
5. The directional behavior is confirmed with one shot at each stage in reverse direction.
6. The value of the 2nd element is also confirmed by placing two test points outside of the tolerance band of this setting.
   Instead of directly entering the magnitude value it can be expressed by its relation to an element setting, e.g., set **Relative to:** to the 2nd element and set the **Factor** to 1.06 (i.e., 6% above the threshold) or 0.94 (i.e., 6% below the threshold).

Note: Regarding the ways to enter and modify test data please also consult the Help section of the module (press F1).

3.4.3 Directional Characteristic Test



The **Trigger** and **Load settings** are the same as explained for the trip time characteristic test. The **Absolute max. time** can be reduced because the test current will be set shortly below the lower tolerance of the 2nd element pick-up value.



As this test confirms the angle of the directional characteristic, the test points should be placed on both sides of the directional characteristic line. In order to get a correct assessment they should be placed just outside of the angle tolerance.

Note: A three phase fault is recommended for this test. The angle between current and voltage for each phase is the same for this fault type. This ensures a proper assessment of the test.

Support

When you are working with our products we want to provide you with the greatest possible benefits. If you need any support, we are here to assist you!

24/7 Technical Support – Get Support

www.omicronenergy.com/support

At our technical support hotline, you can reach well-educated technicians for all of your questions. Around the clock – competent and free of charge.

Make use of our 24/7 international technical support hotline:

Americas: +1 713 830-4660 or +1 800-OMICRON

Additionally, you can find our Service Center or Sales Partner closest to you at www.omicronenergy.com.

Customer Area – Stay Informed

my.omicronenergy.com

The customer area on our website is an international knowledge exchange platform. Download the latest software updates for all products and share your own experiences in our user forum.

Browse through the knowledge library and find application notes, conference papers, articles about daily working experiences, user manuals and much more.

OMICRON Academy – Learn More

www.omicronenergy.com/academy

Learn more about your product in one of the training courses offered by the OMICRON Academy.

OMICRON electronics Corp. USA, 60 Hickory Drive, Waltham, MA 02145