Protection Testing Bulletin

Testing Transformer Differential Protection

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Related OMICRON Product
CMC Product Line

This document is an adapted version of the "Examples of Use – Transformer Differential 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

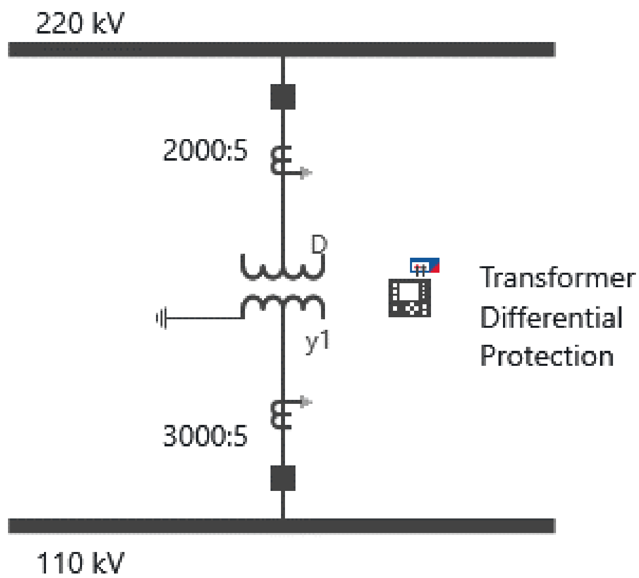
This paper describes how to test the transformer differential protection function. It contains an application example which will be used throughout the paper. The theoretical background of transformer differential protection will be explained. This paper also covers the definition of the necessary **Test Object** settings as well as the **Hardware Configuration** for these tests. Finally the *Advanced Differential* test modules are used to perform the tests which are needed for this protection function.

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

Requirements: *Test Universe* 3.00 or later; *Advanced Differential* and *Control Center* licenses.

Note: The *description* of the *Differential* test module is not a part of this document.

1 Application Example



Parameter Name	Parameter Value	Notes
Frequency	60 Hz	
Transformer data	160 MVA	Rated power
	231 kV	Rated voltage, Side 1 (used for the calculation of the transformation ratio of the transformer)
	115.5 kV	Rated voltage, Side 2 (used for the calculation of the transformation ratio of the transformer)
	Dyn1	Vector group
CT data	2000 A / 5 A	CT ratio, Side 1
	3000 A / 5 A	CT ratio, Side 2
Differential characteristic settings	0.25 I_{ref}	O87P, Pick-up value of the differential protection (I_{ref} is a reference current which can be obtained from the relay manual. In this case it is the rated current of the transformer)
	6.0 I_{ref}	U87P, Second element of the differential protection (there is no stabilization above this value)
	0.3	Slope 1 of the differential characteristic
	0.7	Slope 2 of the differential characteristic
	4.0 I_{ref}	Bias current where the first slope ends and the second slope begins.
Harmonic restraint settings	20% I_{diff}	2^{nd} harmonic restraint value (relative to the fundamental frequency differential current)

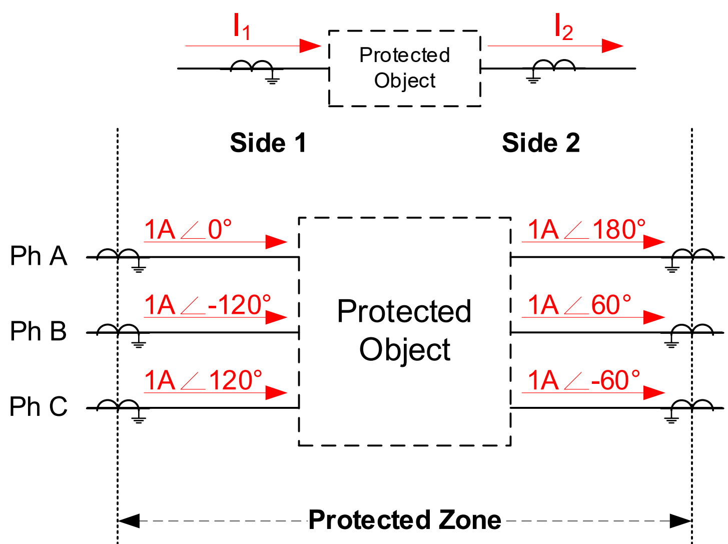
Note: Testing of the Restricted Earth Fault protection function, Thermal Overload protection function, etc. is not part of this document.

2 Theoretical Introduction to Transformer Differential Protection

2.1 Protection Principle

Transformers are among the most important components in power transmission and distribution systems. Usually, current differential relays are applied as the main protection element of the transformer.

The current differential principle is based on Kirchhoff's law, i.e. the sum of the currents entering a node must equal the sum of the currents leaving that node.



For each phase, expressed mathematically, this looks like:

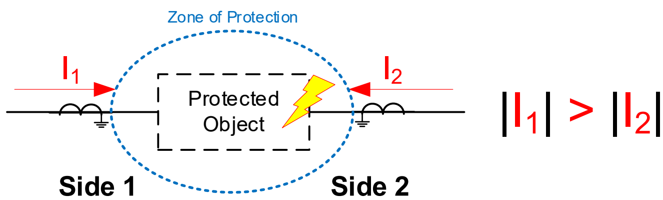
$$I_{diff} = \sum_{i=1}^{n} \bar{I}_i = \bar{I}_1 + \bar{I}_2 + \cdots + \bar{I}_n = 0$$

However, this is only valid if the CT ratios are the same on either side of the transformer windings. Given that transformers are frequently used to either step up or down the voltage, there must be a subsequent turns ratio that also affects the winding currents. The turns ratio and the vector group of a transformer, as well as the CT ratios and the positions of the CT star-points, will cause problems with the calculation of the current sums. Numerical differential relays can calculate these effects and, therefore, compensate for their influence. For electromechanical differential relays, interposing transformers have to be used instead.

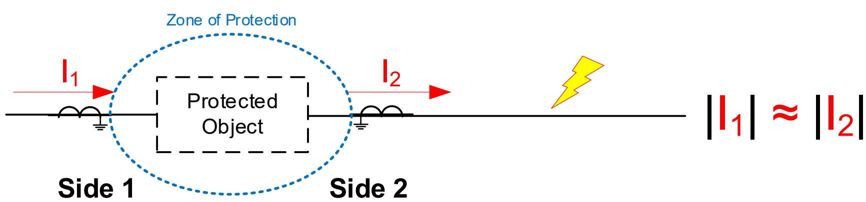
Note: The following parts of this document will only focus on current differential protection as applied commonly in numerical relays.

2.2 Operating Characteristic

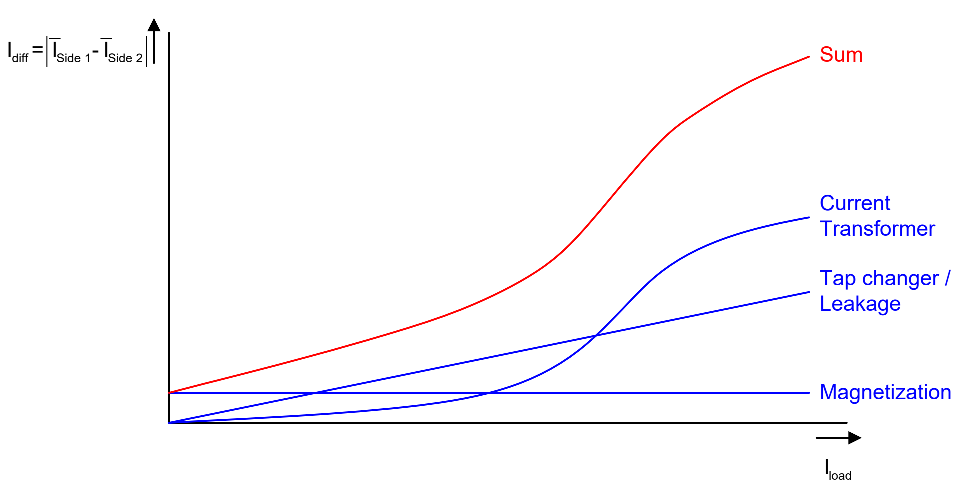
The objective of differential protection is to protect the transformer against internal faults that develop such as a short circuit on a winding. For an internal fault condition, the relay sees a certain amount of current flowing in but not a corresponding amount of current flowing out. If this difference exceeds a set amount (O87P), the differential element should **operate**.



During external faults, a large amount of current flows <u>through</u> the transformer which, after compensation, should equal zero. This would cause the differential element to **restrain from operating**.



However, with the fault case above, challenges are introduced due to the influence of other sources of error, such as CT issues (saturation, remanence, and tolerance), tap changer or leakage currents, and core magnetization.



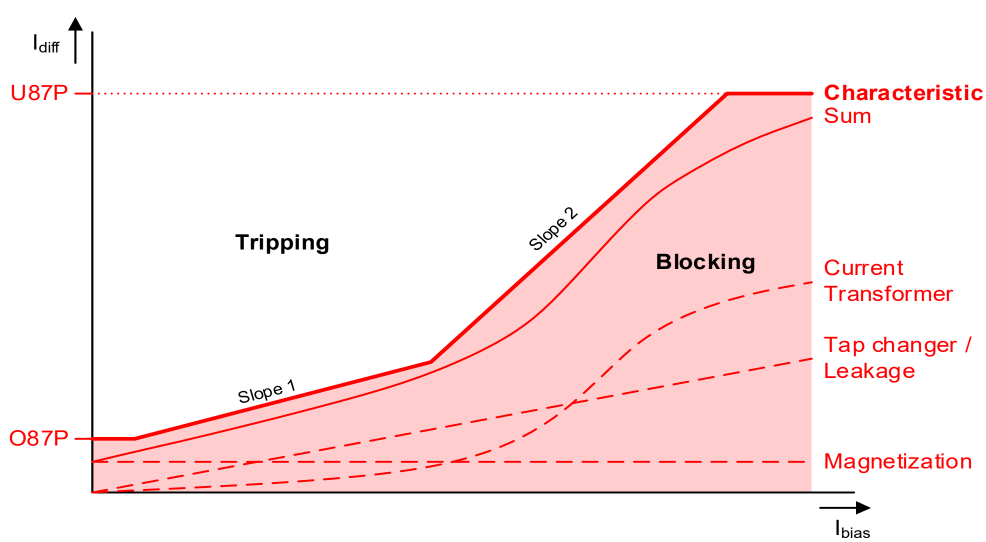
In this graph, it can be seen that the sum of these other sources of error depends on the transformer load current. The solution to this problem is to provide the differential protection with a bias (restraint) current. With this value, the construction of an operating characteristic is possible.

Note: The calculation method of the bias current depends on the relay manufacturer (see table)

Calculation Method	Manufacturer	Notes
$(I_{\text{Side 1}} - I_{\text{Side 2}})/K_1$	Various conventional (electromechanical) relays	only valid for two-winding transformers
$(\lvert I_{\text{Side 1}}\rvert + \lvert I_{\text{Side 2}}\rvert)/K_1$	SIEMENS (K_1=1) SEL 387, 787 (K_1=1) SEL 587 (k_1=2)	only valid for two-winding transformers
$\max(\lvert I_{\text{Side 1}}\rvert, \lvert I_{\text{Side 2}}\rvert)$	GE Multilin SR745	
$\sqrt{\lvert I_{\text{Side 1}}\rvert \cdot \lvert I_{\text{Side 2}}\rvert \cdot \cos\alpha}$	ABB	

The most common operating characteristic is called the dual-slope percent differential characteristic, which provides sensitivity when the current difference is low, and improves security in the high current region where CT saturation can occur. The settings consist of:

- **Minimum pickup** – Protects when the transformer is run under no load or lightly loaded conditions. Provides security against CT error and remanence. Usually between 0.25 and 0.4 pu.
- **Slope 1** – Region that protects against transformer internal faults, for normal load current conditions up to the breakpoint. Typically set between 25-40% to provide security against false tripping due to CT accuracy and LTC (load tap changer) applications, if used.
- **Breakpoint** – The limit of bias current between slope 1 and slope 2 operation, to discriminate between internal and external faults. Typically set anywhere between 1.5 to 4 times the transformer FLC (full load current).
- **Slope 2**– Region that prevents differential element from operating under worst case CT saturation conditions. Typically set between 70-95%

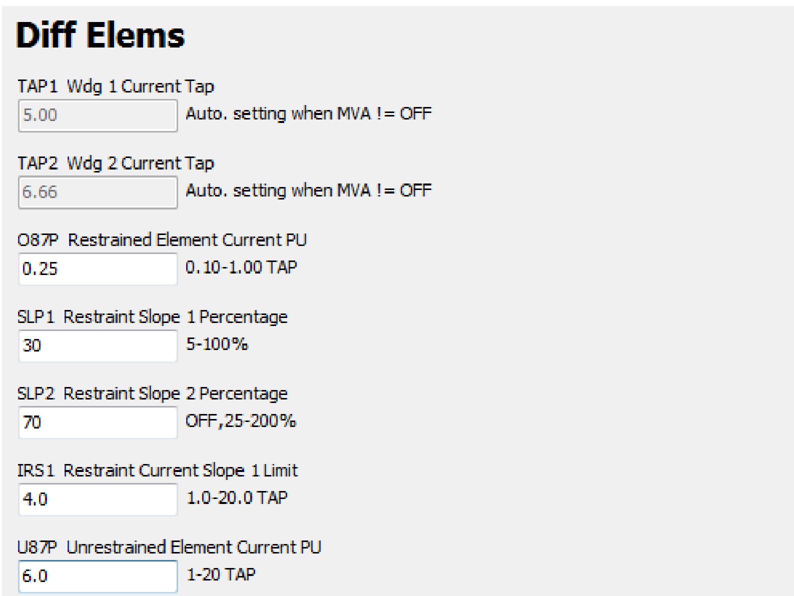


As shown above, the operating characteristic is set slightly higher than the sum of all the contributions of error, thus enabling the relay to determine between blocking and operating (tripping).

The relay calculates an operating signal for the current differential element as follows:

- In the **minimum pickup** region: If $I_{diff} \geq O87P$, the differential element will trip.
- In the **Slope 1** region: If $\frac{I_{diff}}{I_{bias}} \geq SLP1\%$, the differential element will trip. Otherwise it will block.
- In the **Slope 2** region: If $\frac{I_{diff}}{I_{bias}} \geq SLP2\%$, the differential element will trip. Otherwise it will block.

For the following example, the SEL 387 is used. See below for the settings and resulting characteristic.



Diff Elems

TAP1 Wdg 1 Current Tap
5.00 Auto. setting when MVA != OFF

TAP2 Wdg 2 Current Tap
6.66 Auto. setting when MVA != OFF

O87P Restrained Element Current PU
0.25 0.10-1.00 TAP

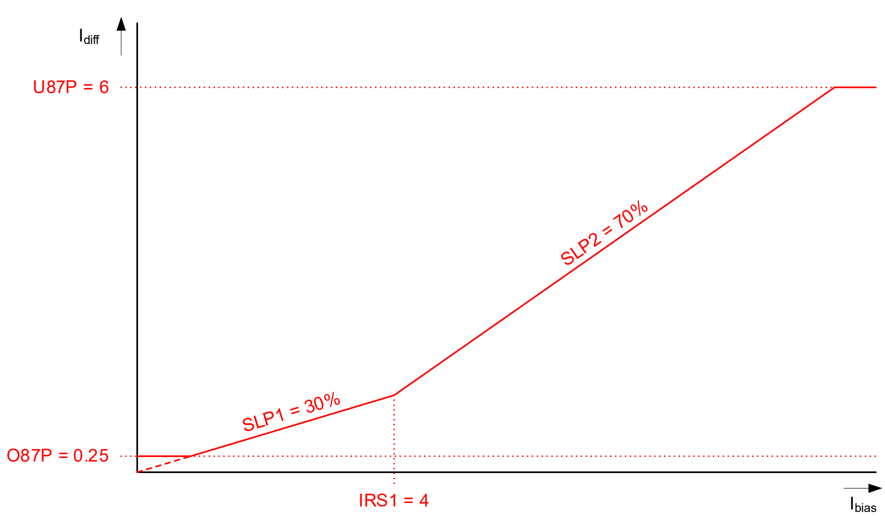
SLP1 Restraint Slope 1 Percentage
30 5-100%

SLP2 Restraint Slope 2 Percentage
70 OFF,25-200%

IRS1 Restraint Current Slope 1 Limit
4.0 1.0-20.0 TAP

U87P Unrestrained Element Current PU
6.0 1-20 TAP

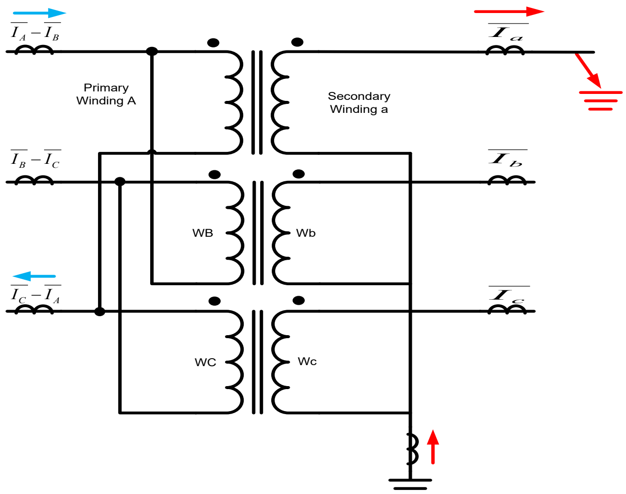
Relay settings for the operating characteristic (SEL-387)



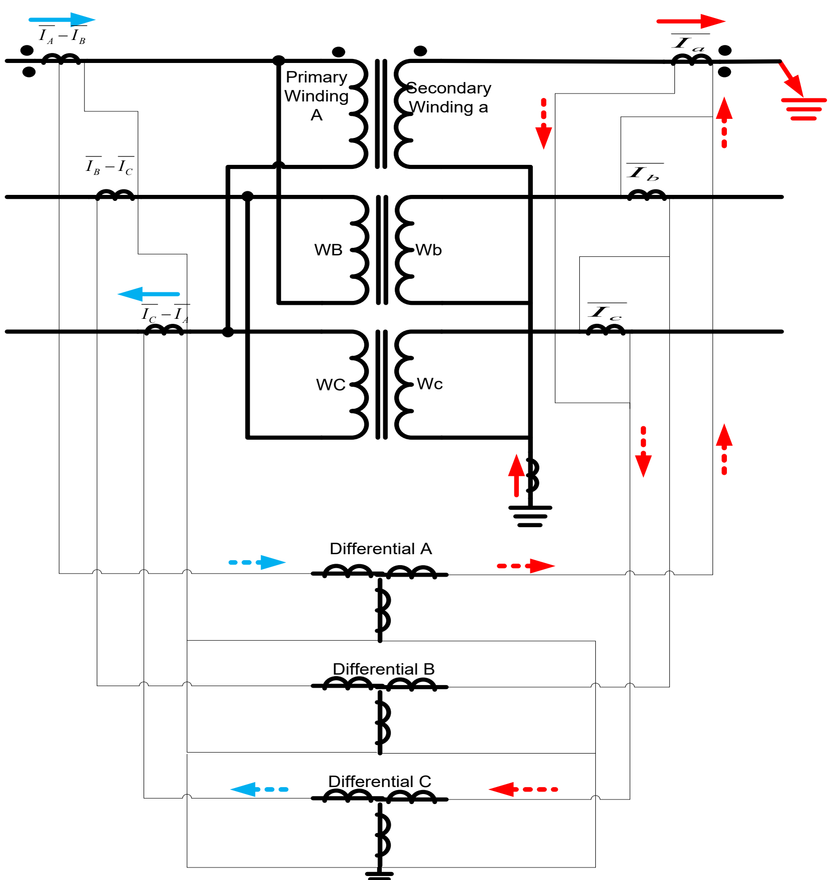
Operating characteristic for the SEL-387

2.3 Zero Sequence Elimination

In all grounded wye connected windings, the ground provides a way for current to enter the differential zone without being measured by a phase differential CT. This can unbalance the differential during external phase to ground faults. If the differential protection is to resist improperly tripping for external faults, this ground current must be removed from differential calculations.



The way the elimination is achieved differs between electromechanical and numerical relays.



In **electromechanical** relays, the CT secondaries on the wye-connected winding are connected in delta. This straightforward method eliminates the zero-sequence currents seen by the relay.

This is shown in the diagram to the left.

In **numerical** relays with wye connected CT secondary circuits, **it is possible** for the ground current to be removed numerically. This is done by either converting the currents to delta quantities or by directly subtracting calculated zero sequence current from the differential quantity.

2.4 Transformer Inrush

Inrush is a phenomenon which commonly takes place directly after a transformer is energized, due to saturation of its magnetic core. This saturation causes high power losses which lead to high currents. As they only flow on one side of the transformer, the relay will interpret them as differential currents, which will lead to an unwanted trip, if the relay is not stabilized against inrushes. The three phase currents during an inrush are shown in Figure 13.

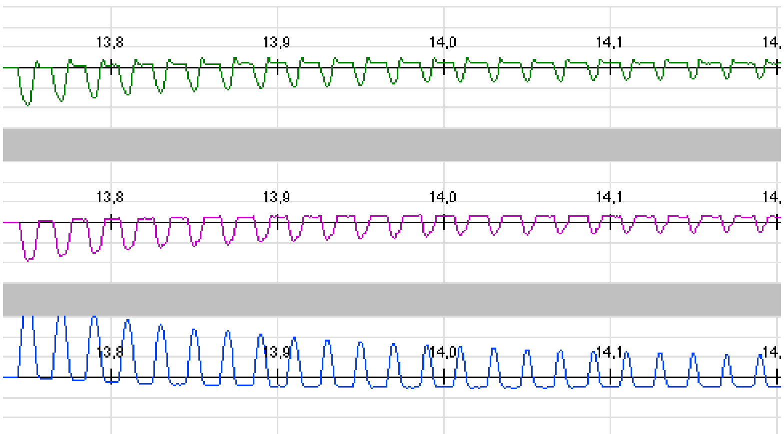
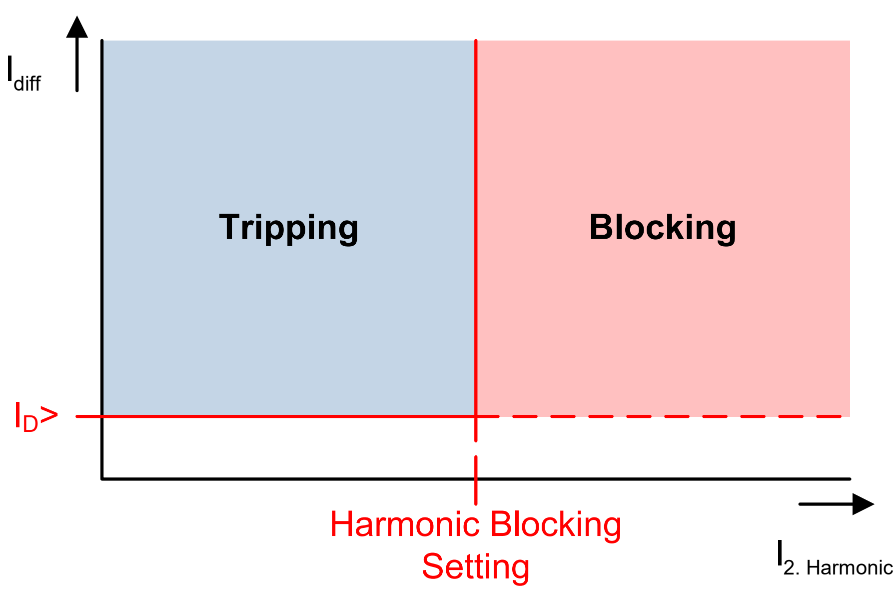


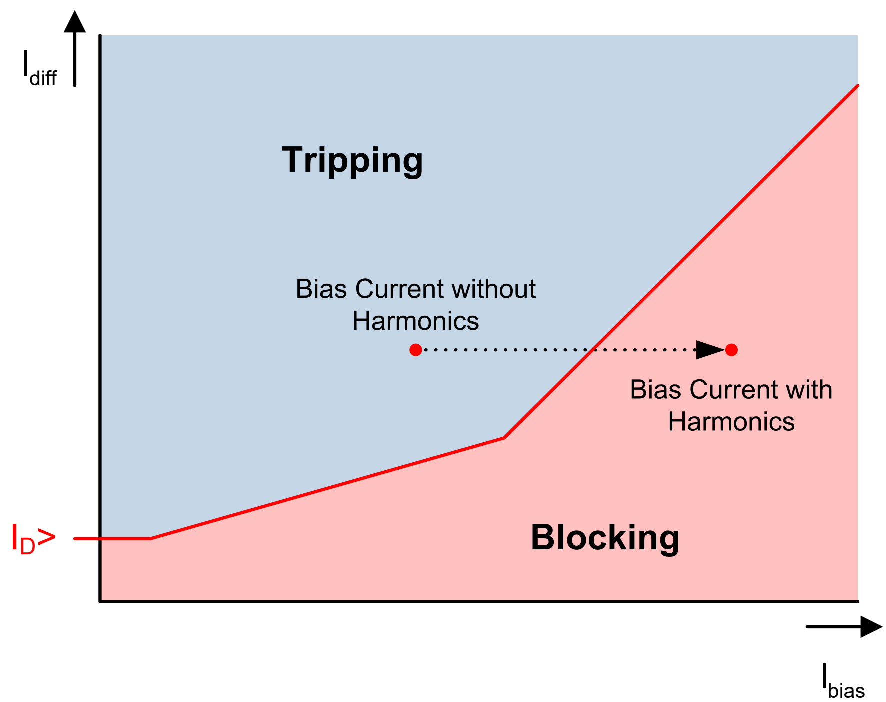
Figure 1: Transient record of a transformer inrush

This inrush current has a unique wave form which is characterized by a high percentage of even harmonics – especially of the second and fourth harmonic. There are different ways of stabilizing a relay against inrush currents, which use frequency analysis or time signal analysis. The most common methods are described in the following section.

> **Harmonic Blocking:** Whenever the percentage of the second harmonic current exceeds the setting value, the relay will block as shown in Figure 14.



> **Harmonic Restraint:** The second and fourth harmonic currents will be added to the bias current. Figure 15 shows that the increased bias current will prevent the relay from tripping during inrushes.



3 Practical Introduction to Transformer Differential Protection Testing

The *Advanced Differential* test modules are designed for testing any kind of three-phase current differential protection functions, for assets such as transformers, motors, generators, busbars, lines and cables. These test modules are:

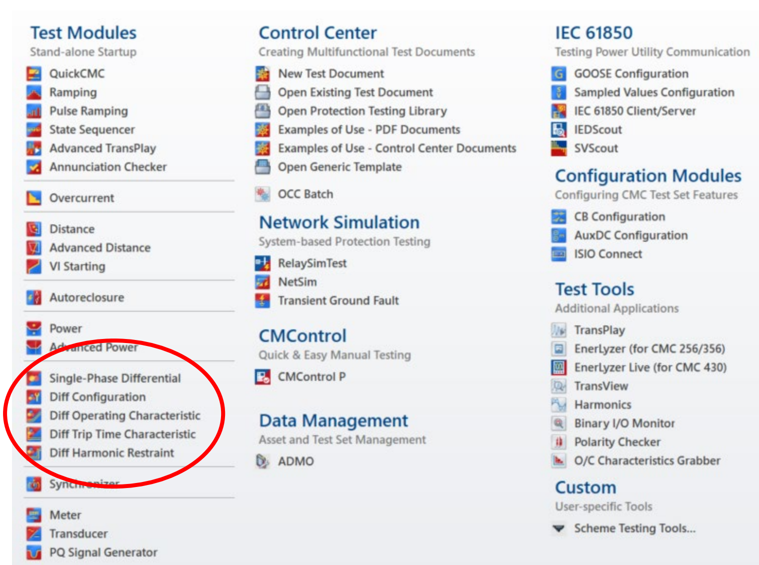
> The *Diff Configuration* module for testing the configuration of the differential protection which consists of the wiring and the relay parameters such as transformer data, CT data and zero sequence elimination.

> The *Diff Operating Characteristic* module for testing the operating characteristic of the differential protection.

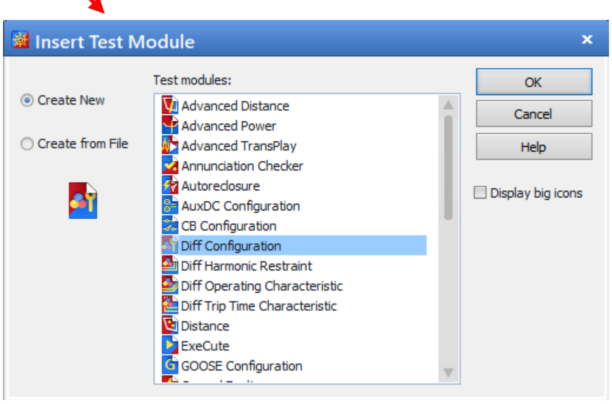
> The *Diff Trip Time Characteristic* module for testing the trip times of the differential protection.

> The *Diff Harmonic Restraint* module for testing the blocking of the differential trip due to current harmonics.

These test modules can be found on the *Start Page* of the OMICRON *Test Universe*. They can also be inserted into an OCC File (*Control Center* document).

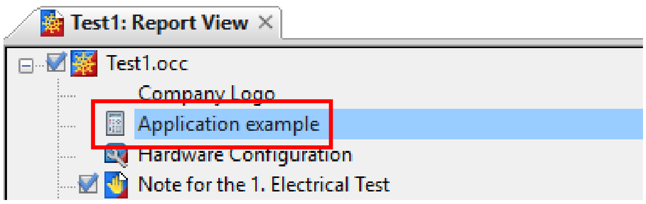


Test Module on *Control Center*'s **Insert** tab



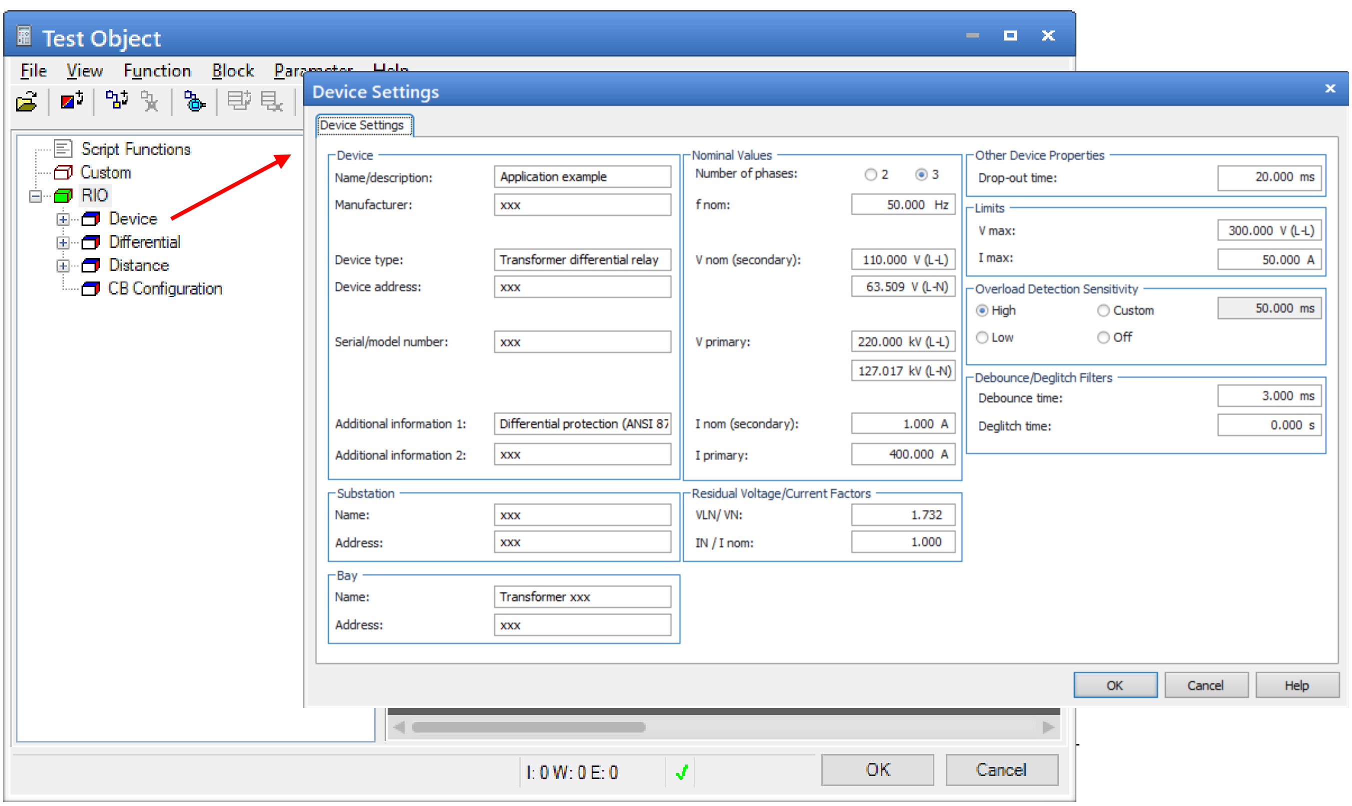
3.1 Defining the Test Object

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



3.1.1 Device Settings

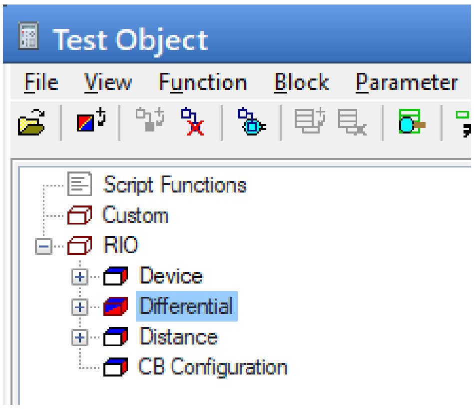
General relay settings (for example, relay type, relay ID, substation details) are entered in the **RIO** function **Device**. The CT data is not entered in this **RIO** function. It will be entered in the **RIO** function **Differential** (see chapter 3.1.2).



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 Differential Protection Parameters

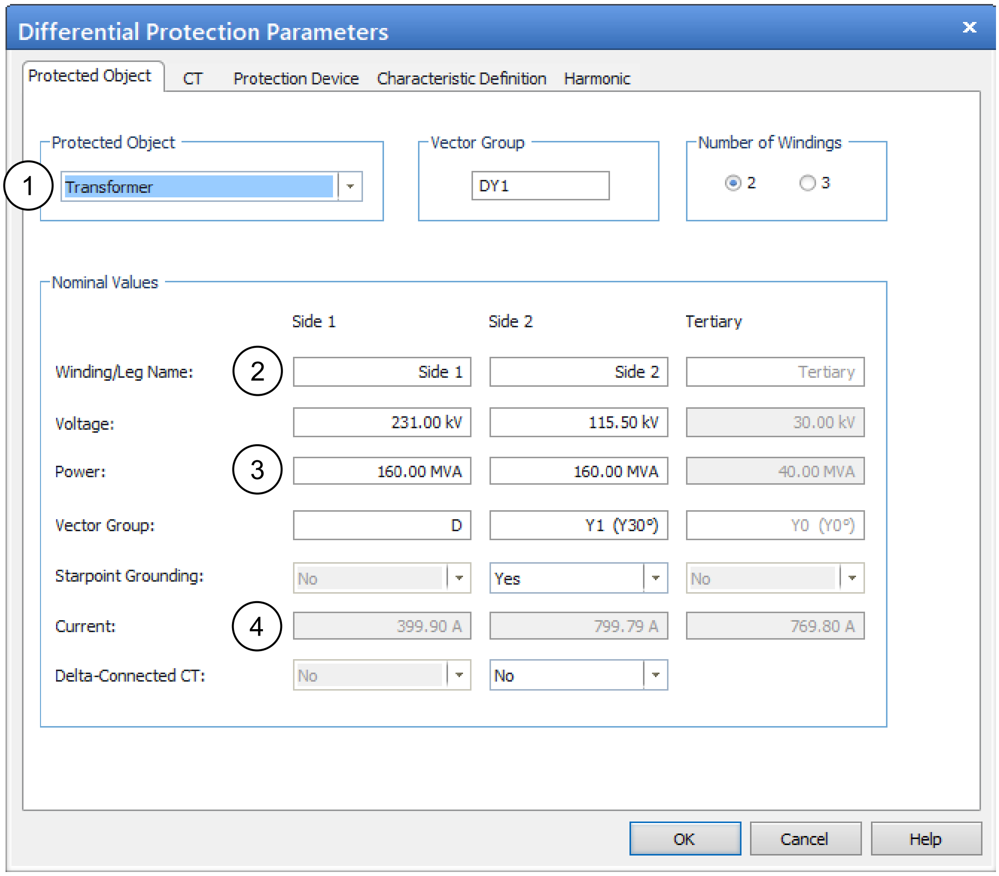
More specific data concerning the transformer differential relay can be entered in the **RIO** function **Differential**. This includes the transformer data, the CT data, general relay settings, the operating characteristic, as well as the harmonic restraint definition.



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

Protected Object

Here you define the primary equipment that is protected by the relay.

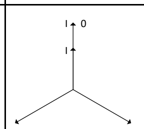
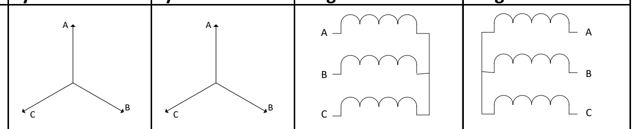
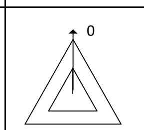
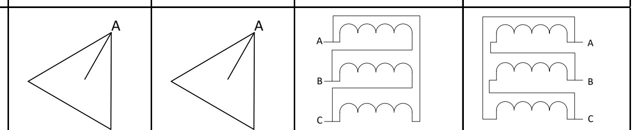
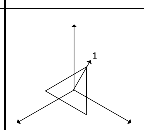
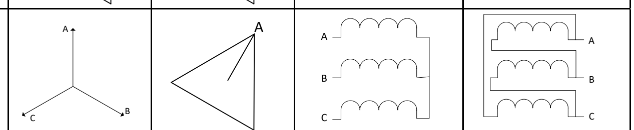
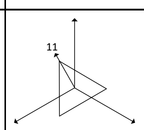
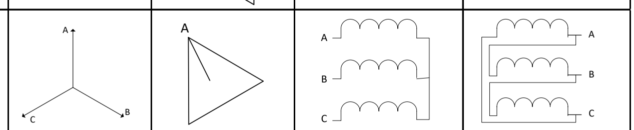
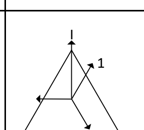
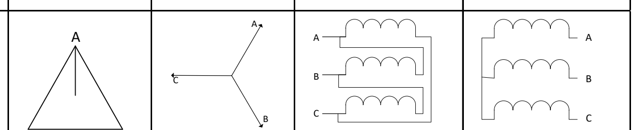
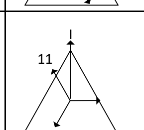
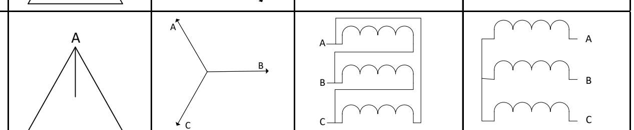
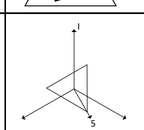
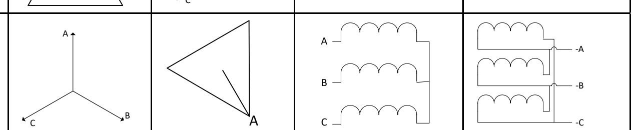
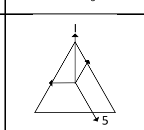
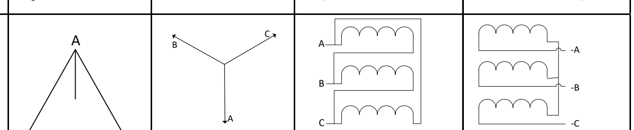
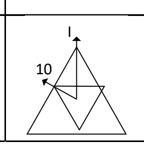
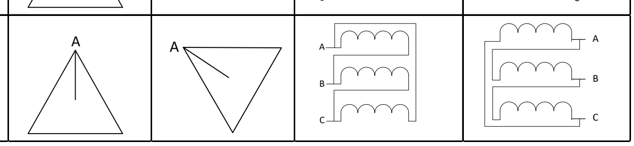


1. As a transformer differential protection is to be tested, select **Transformer**.
2. The names of the transformer windings can be entered here. They can be chosen freely and once they are set, they will appear in the respective test modules.
3. Here, enter the transformer data. For each winding, the nominal voltage and the nominal power have to be defined. Also, the vector group of the transformer must be entered. *(see the table on following page for a conversion chart)* For each Y winding the star-point grounding can be defined. This setting has influence on the currents during single-phase faults.

   Note: If the nominal power of the different transformer windings is not equal, the reference winding of the relay must be entered in the first column.

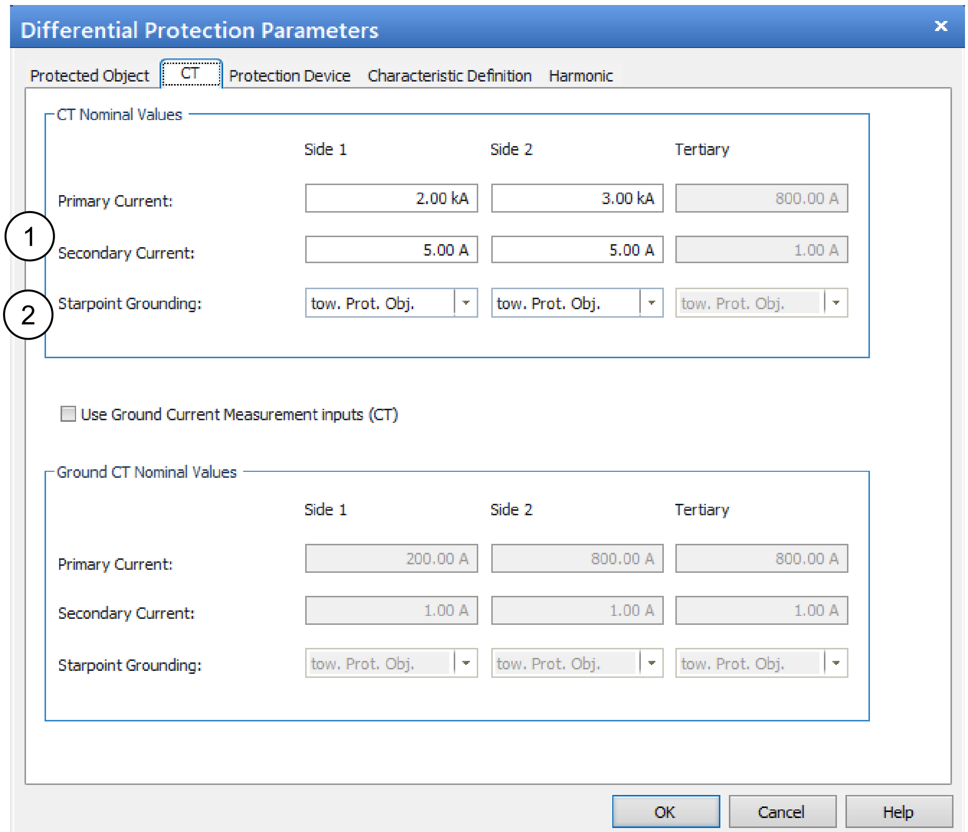
4. The nominal current of each winding is calculated automatically. It can be used to check if the transformer settings have been entered correctly.

Conversion Chart for IEC Vector Groups

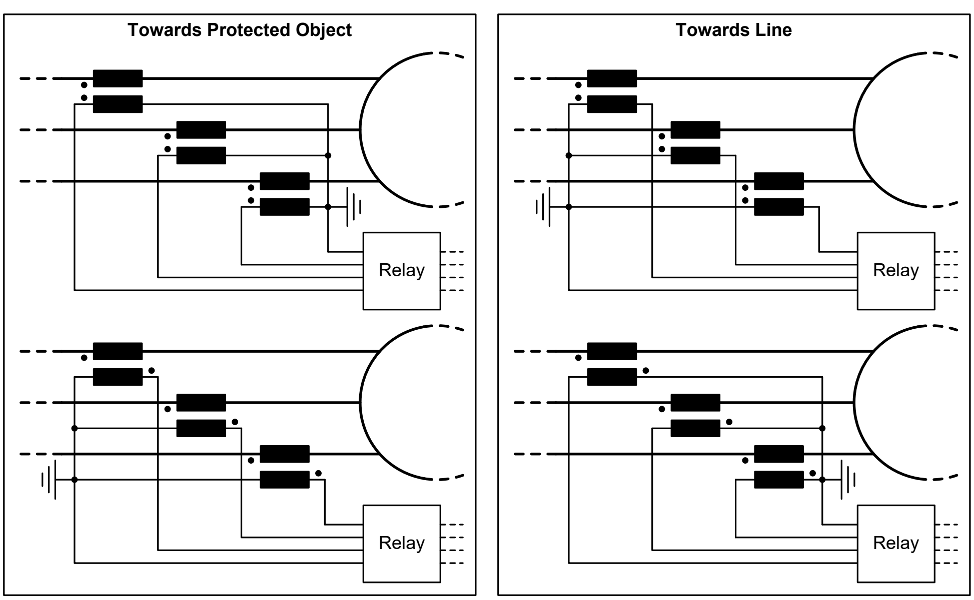
IEC (OMICRON) Connection	IEC Diagram	Winding H Connection	Winding X Connection	Common Symbol	Common Symbol	H Connection Diagram	X Connection Diagram
Yy0		Y	Y				
Dd0		Dac	Dac				
Yd1		Y	Dac				
Yd11		Y	Dab				
Dy1		Dab	Y				
Dy11		Dac	Y				
Yd5		Y	Inv. Dab				
Dy5		Dac	Inv. Y				
Dd10		Dac	Dab				

CT

Here you enter the data of the current transformers.



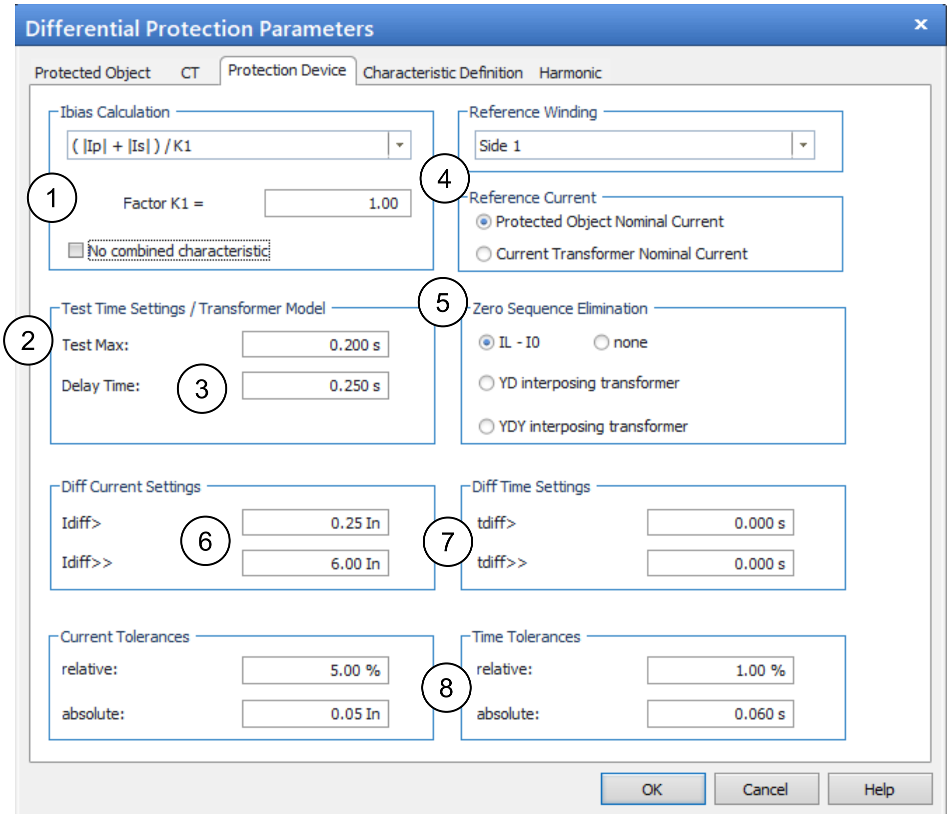
1. Enter the nominal currents of the CTs here.
2. Here, select the CT star-point direction according to the wiring of the CTs.



Definition of the CT star-point direction

Protection Device

Here you enter the basic settings of the protection device.

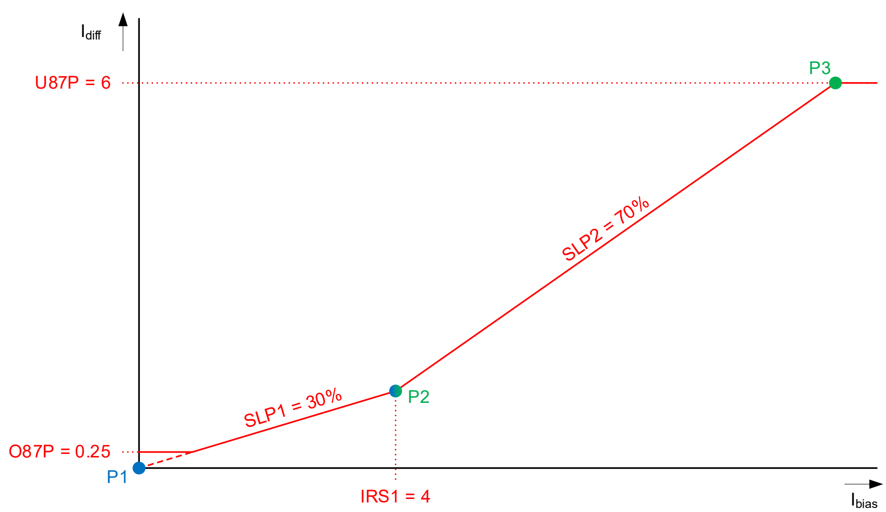


1. Select the calculation method of the bias current. This method depends on the relay type and Table 2 shows some examples of how to set these parameters. Select **No combined characteristic** if the relay uses only the phase with the highest current magnitude for the differential and bias current calculation. For the AREVA P633 this option remains cleared as the relay calculates these currents in all three phases simultaneously.
2. **Test Max:** is the test shot time if the relay does not trip. It should be set higher than the expected relay trip time but shorter than possible trip times of additional protection functions (for example, overcurrent protection). Since a differential relay typically trips instantaneously this time can be set quite low in this case (for example, 0.2 s) to speed up the test.
3. The **Delay Time** defines the pause between two test shots and during this time no currents will be generated. Therefore, this time may be increased to prevent overheating of electromechanical relays.
4. As all differential current settings are entered relative to the nominal current, this current has to be defined. With the settings **Reference Winding** and **Reference Current**, the nominal current which will be used as the reference current can be selected. In this example the reference current is the nominal current of the transformer on side 1.
5. As described in chapter 2.3, the **Zero Sequence Elimination** has an influence on the currents during phase-to-ground faults. Select **IL - I0**, if the relay uses numerical zero sequence elimination.
6. The setting **Idiff>** defines the pick-up of the differential protection function. The relay will not trip if the differential current does not exceed this setting. **Idiff>>** defines the high differential current element. If the differential current exceeds this value the relay will always trip. See Figure 4 and Figure 6 in the previous section for reference. SEL defines the **Idiff>** as **O87P** and **Idiff>>** as **U87P.**
7. The time settings **tdiff>** and **tdiff>>** define the trip times of the differential elements.
8. The current and time tolerances can be obtained from the relay manual.

Characteristic Definition

The operating characteristic of the relay can be defined in this tab. The line segments of this characteristic are set by entering their corner points. The necessary steps to enter an operating characteristic are shown below with the example settings from the previous section:

1. When opening the tab for the first time it will show a default operating characteristic. Click **Remove All** to clear the default line segment.
2. The corner points of the characteristic have to be calculated now. For this it is advantageous to visualize the characteristic and its corner points first (below).



Operating Characteristic for the SEL 387

3. Calculate the first line segment using known values. We will need start and end points. Unknown parameters are replaced by variables like a, b, c etc.:

   P1 = (0 , 0) P2 = (4 , **a**) P3 = (**b** , 6)

   Since Test Universe automatically cuts in the differential pickup (O87P) for us, we can start with the first line segment from the origin, P1.

   Using the formula for a slope:

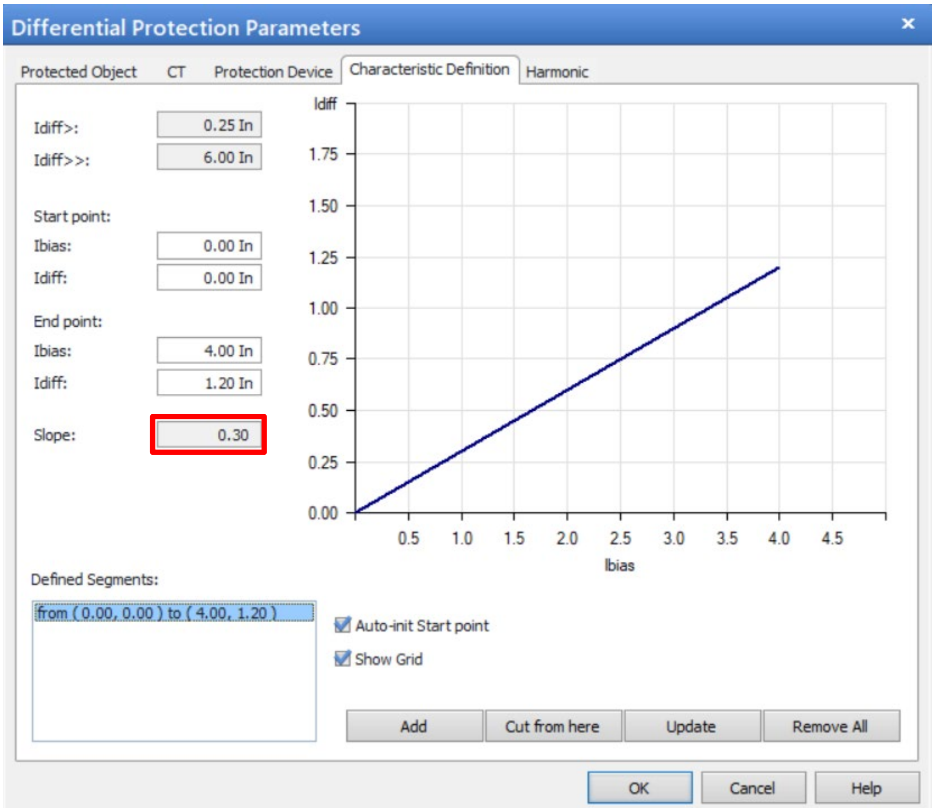
   $$SLP1 = \frac{a-0}{4-0} \rightarrow\ 0.3 = \frac{a}{4} \rightarrow \boldsymbol{a} = \mathbf{1.2}$$ Therefore $\boldsymbol{P2 = (4, 1.2)}$

   Now, we can calculate P3:

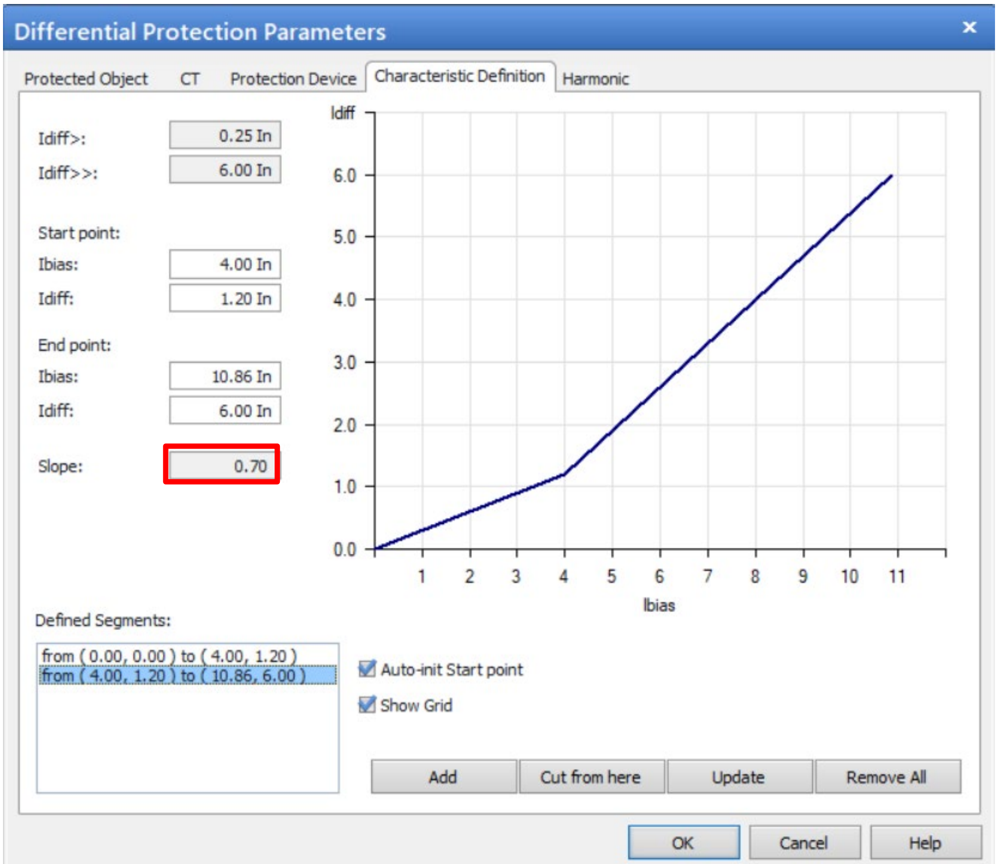
   $$SLP2 = \frac{6-1.2}{b-4} \rightarrow\ b-4 = \frac{4.8}{0.7} \rightarrow \boldsymbol{b} = \mathbf{10.86}$$ Therefore $\boldsymbol{P3 = (10.86, 6)}$

4. Enter the calculated points as the start and end points of the line segments:

- Enter the values of P1 at the **Start point:** and the values of P2 at the **End point:** and click **Add** to define the first line segment. The slope can be used to check if the settings have been entered correctly:



- Enter the values of P2 at the **Start point:** and the values of P3 at the **End point:** and click **Add** to define the second line segment. The slope can be used to check if the settings have been entered correctly:

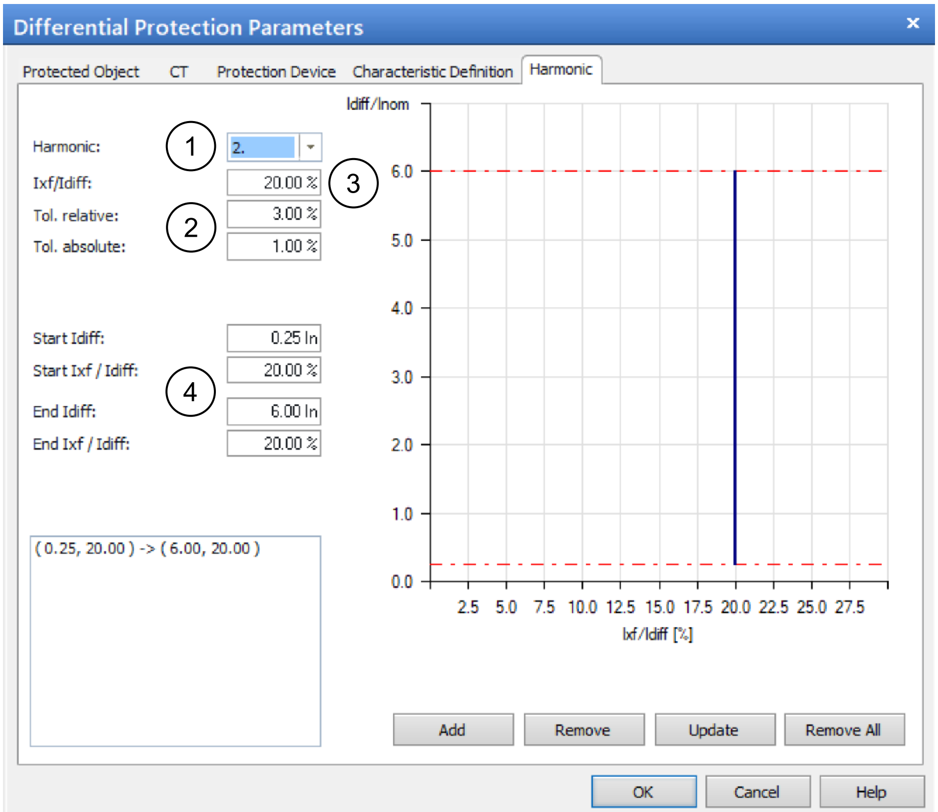


Note: It is not necessary to define the horizontal line segments represented by Idiff> and Idiff>>. These values will be added to the resulting operating characteristic automatically.

A Protection Testing Library (PTL) can be found in the OMICRON Customer Portal (my.omicronenergy.com). It contains relay specific test files where these calculations are already implemented.

Harmonic

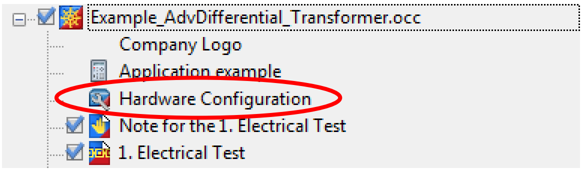
In this tab the harmonic blocking characteristic can be entered.



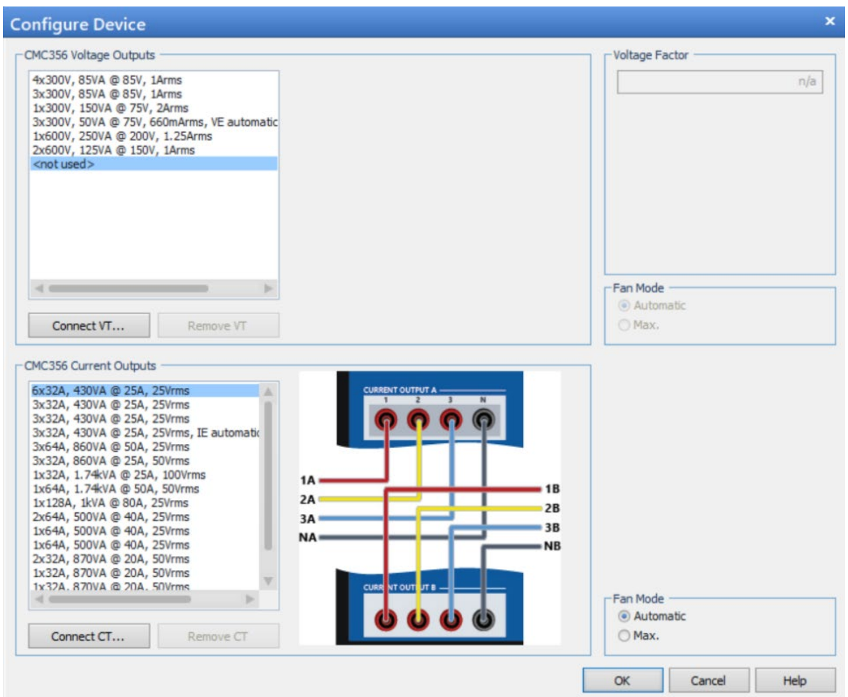
1. Select the number of the harmonic that blocks the differential protection. After applying the settings to one harmonic, the other harmonics can subsequently be adjusted.
2. Enter the tolerances as specified in the relay manual.
3. Enter the harmonic blocking threshold value and click **Update**, if the harmonic blocking scheme is a straight vertical line from Idiff> to Idiff>> (Test Object parameters).
4. Otherwise a characteristic can be created by entering line segments with start and end points. This works in the same way as it was shown with the operating characteristic.

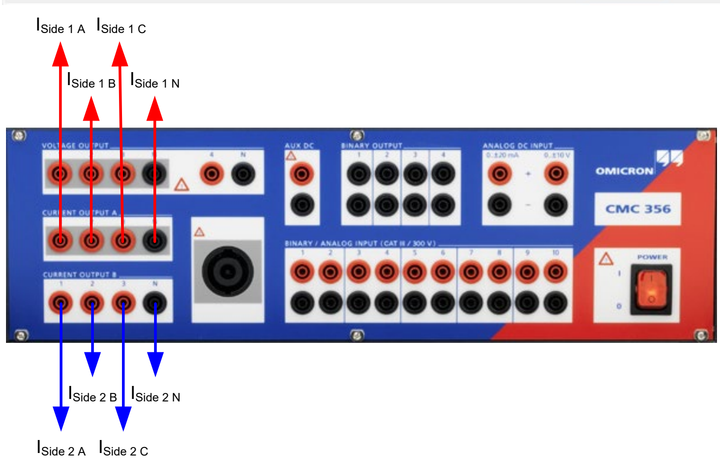
3.2 Global Hardware Configuration of the CMC Test Set

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 Differential Protection Relays





Wiring of the analog outputs of the CMC test set.

3.2.2 Analog Outputs

General | **Analog Outputs** | Binary / Analog Inputs | Binary Outputs | DC Analog Inputs | Time Source

		CMC356 I A				CMC356 I B			
Display Name	**Connection Terminal**	**1**	**2**	**3**	**N**	**1**	**2**	**3**	**N**
I Side 1 A		X							
I Side 1 B			X						
I Side 1 C				X					
I Side 2 A						X			
I Side 2 B							X		
I Side 2 C								X	

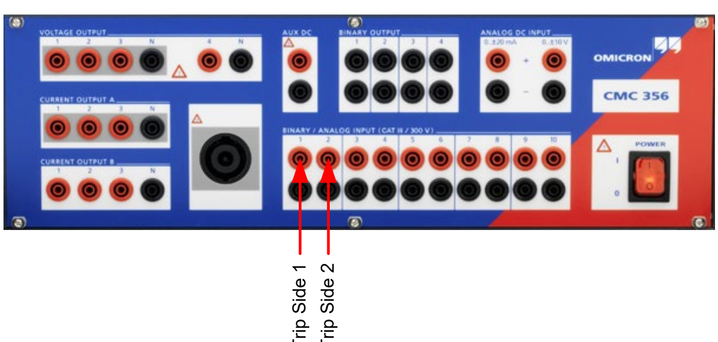
The analog outputs, binary inputs and outputs can all be activated individually in the local **Hardware Configuration** of the specific test module (see chapter 3.3).

3.2.3 Binary Inputs

General | Analog Outputs | **Binary / Analog Inputs** | Binary Outputs | DC Analog Inputs | Time Source

	Function	Binary		Binary		Binary		Binary	
	Potential Free	☐		☐		☐		☐	
	Nominal Range	110 V		110 V		110 V		110 V	
	Clamp Ratio								
	Threshold	77 V		77 V		77 V		77 V	
Display Name	**Connection Terminal**	**1+**	**1-**	**2+**	**2-**	**3+**	**3-**	**4+**	**4-**
Trip Side 1		X							
Trip Side 2				X					
Bin. in 3						X			
Bin. in 4								X	

1. If the relay uses multiple commands to trip the circuit breakers of the transformer, all trip contacts have to be connected to a binary input. The binary inputs 1 to 10 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 inputs etc. will not be used for the following tests.

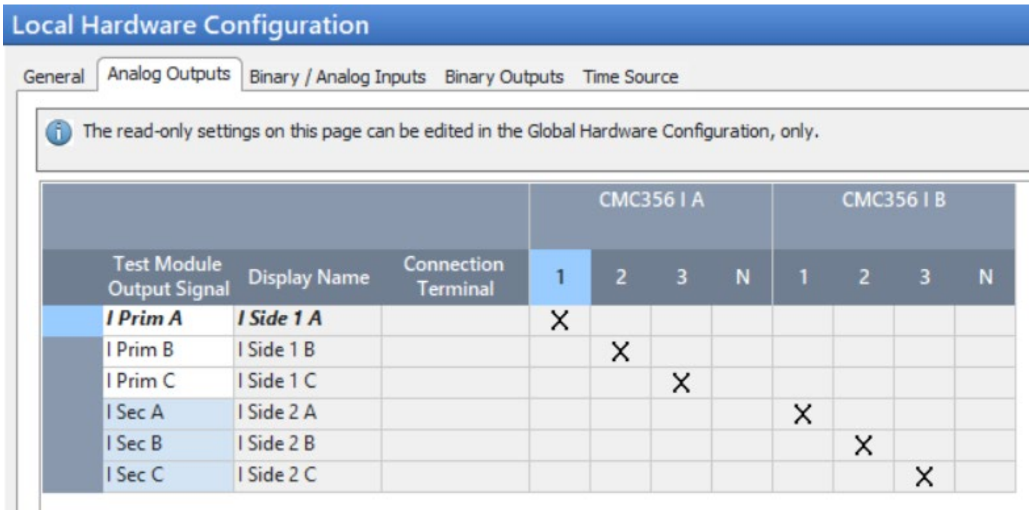


Wiring of the binary inputs of the CMC test set.

3.3 Local Hardware Configuration for Differential Protection Testing

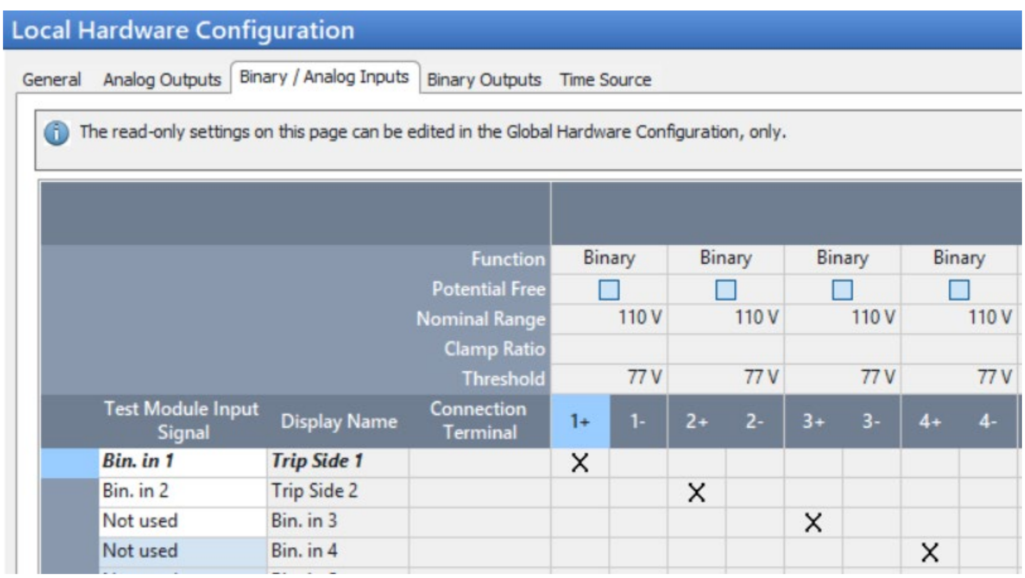
The local **Hardware Configuration** activates the outputs/inputs of the CMC test set for the selected test module. Therefore, define it separately for each individual test module. Click **Hardware Configuration** on the **Home** tab.

3.3.1 Analog Outputs



			CMC356 I A				CMC356 I B			
Test Module Output Signal	Display Name	Connection Terminal	1	2	3	N	1	2	3	N
I Prim A	***I Side 1 A***		X							
I Prim B	I Side 1 B			X						
I Prim C	I Side 1 C				X					
I Sec A	I Side 2 A						X			
I Sec B	I Side 2 B							X		
I Sec C	I Side 2 C								X	

3.3.2 Binary Inputs



		Function	Binary		Binary		Binary		Binary	
		Potential Free	☐		☐		☐		☐	
		Nominal Range	110 V		110 V		110 V		110 V	
		Clamp Ratio								
		Threshold	77 V		77 V		77 V		77 V	
Test Module Input Signal	Display Name	Connection Terminal	1+	1-	2+	2-	3+	3-	4+	4-
Bin. in 1	***Trip Side 1***		X							
Bin. in 2	Trip Side 2				X					
Not used	Bin. in 3						X			
Not used	Bin. in 4								X	

3.4 Defining the Test Configuration

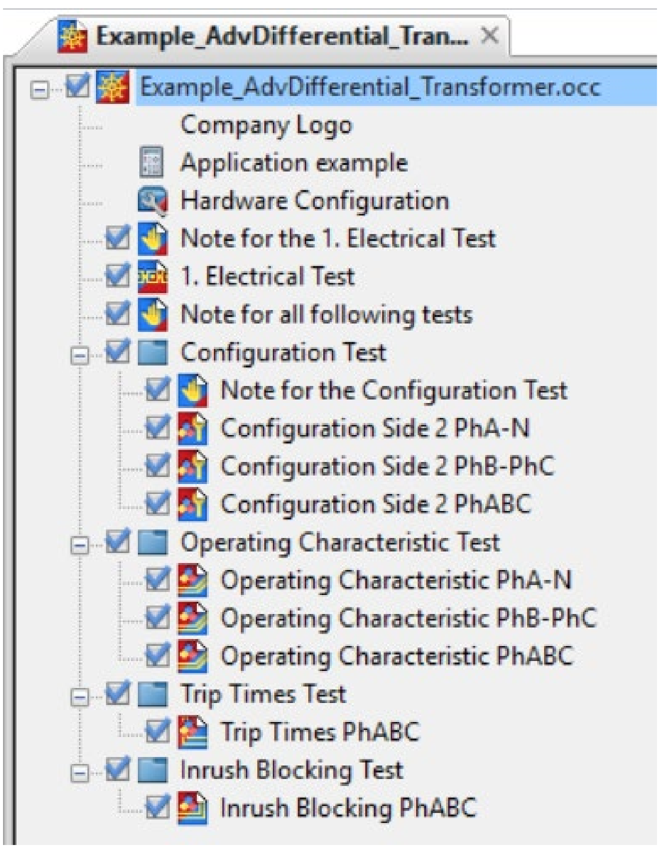
3.4.1 General Approach

When testing the differential protection, the following steps are recommended:

> **Configuration Test:** Testing the wiring and the configuration parameters of the differential protection including transformer data, CT data and zero sequence elimination.
> **Operating Characteristic Test:** Verifying the position of all operating characteristic line segments.
> **Trip Times Test**: Verifying the trip times of the differential protection elements.
> **Inrush Blocking Test**: Verifying the inrush blocking characteristic.

These tests can be performed with the advanced differential test modules:

> *Diff Configuration*
> *Diff Operating Characteristic*
> *Diff Trip Time Characteristic*
> *Diff Harmonic Restraint*

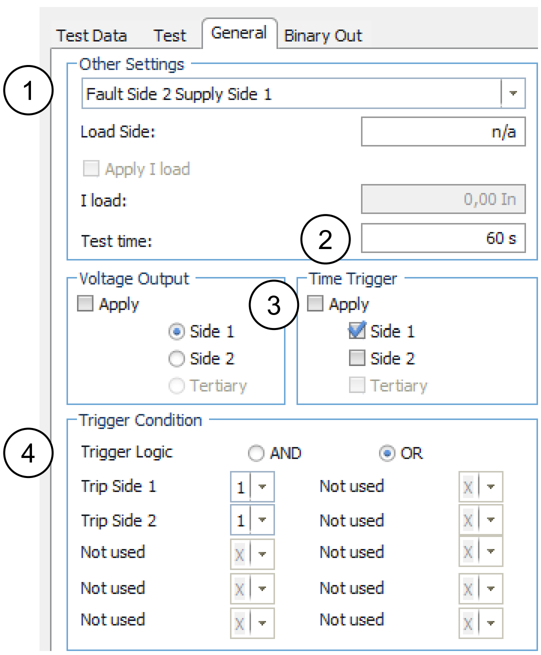


3.4.2 Configuration Test

Differential protection relays are usually set to be very sensitive. Therefore, even small differential currents will lead to a trip. If the wiring is incorrect or if parameters such as the nominal voltages, the zero sequence elimination, the CT ratios or the CT star-point directions are not set correctly, currents flowing through the protected area may lead to an unwanted operation. The configuration test simulates external faults with fault currents flowing through the protected area. During these faults the relay must not trip and therefore, this test confirms that the wiring, as well as the above mentioned parameters, are correct.

General

General settings of the test are entered in this tab.

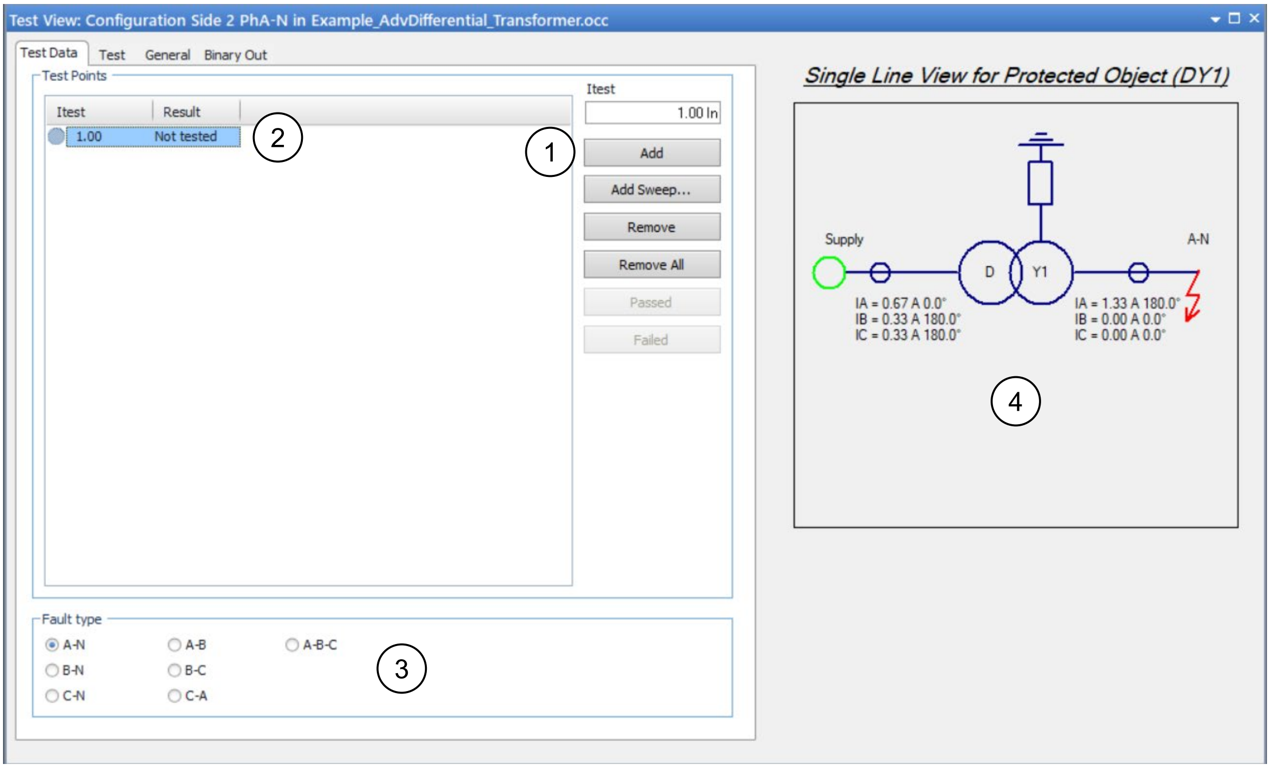


1. This setting defines on which side of the transformer the fault and the source should be located for the fault simulation.
2. The test time should be set long enough to allow the measured currents from the relay to be read.
3. These settings define if the CMC should generate voltages and whether the test should be time synchronized via GPS or IRIG-B. In this example neither of these will be necessary.
4. The Trigger Logic has to be defined according to the relay configuration.

Note: If the relay uses multiple trip contacts, they should be linked with **OR**. This way the test will be assessed as failed if any of the trip contacts are triggered.

Test Data

In this tab the test points can be entered.



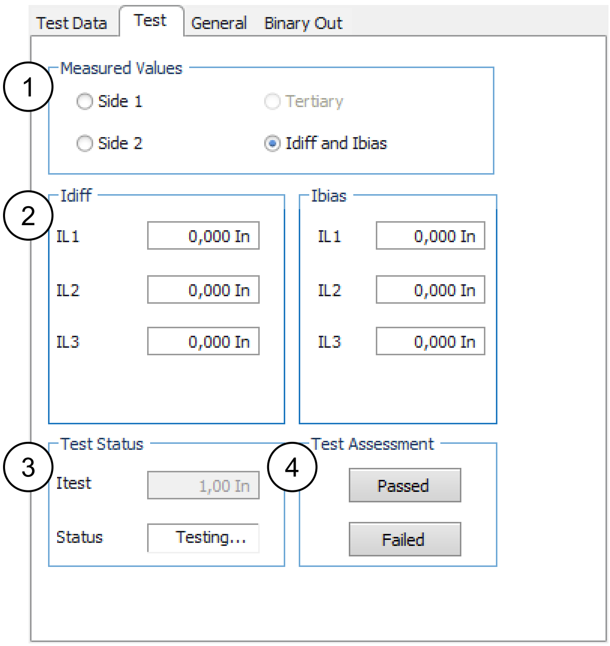
1. Enter the test current and click **Add** to set a test point. The test current will be relative to the nominal current of the fault side.
2. The new test point appears in the test point list.
3. Here you define the **Fault Type**.

   Note: Only one fault type can be set per test module. Add more test modules to the OCC file, if multiple fault types are to be tested.

4. The current outputs of the CMC are shown in the single line view.

Test

This tab is used to assess and document the test.



1. Define whether you want to enter the measured phase currents or the calculated differential and bias currents. For most of the digital differential relays the option **Idiff and Ibias** is the easiest way to assess the relay behavior.
2. Start the test by clicking the **Start/continue test** button on the toolbar.
   This activates the input fields for the measured currents. Now the measured currents can be read from the relay and entered here. It should be kept in mind that the current output will be stopped after the test time is elapsed.
3. Here, the test current and the test status are displayed.
4. Here, you can assess the test manually. If a trip occurs during the test time, the test will automatically be assessed as failed.

Note: To test the numerical zero sequence elimination, it is recommended that at least one phase-to-ground fault is placed at the grounded side of the transformer.

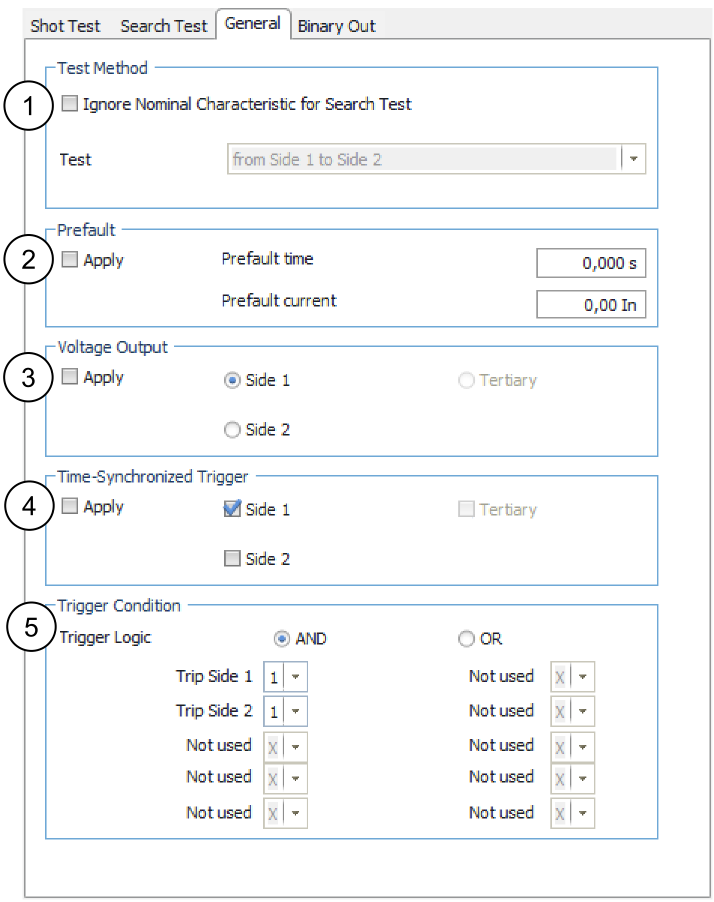
In order to assess the test, the differential and bias currents that should be measured by the relay must be calculated. The necessary formulae can be obtained from the relay manual. If these theoretically calculated currents match the currents read out from the relay, the test can be assessed as passed. During the test the differential current must be zero in each phase.

3.4.3 Operating Characteristic Test

This test confirms the operating characteristic of the differential relay. Test shots are placed in the operating characteristic diagram and if they are above the operating characteristic, the relay must trip. If they are below the characteristic the relay must not trip.

General

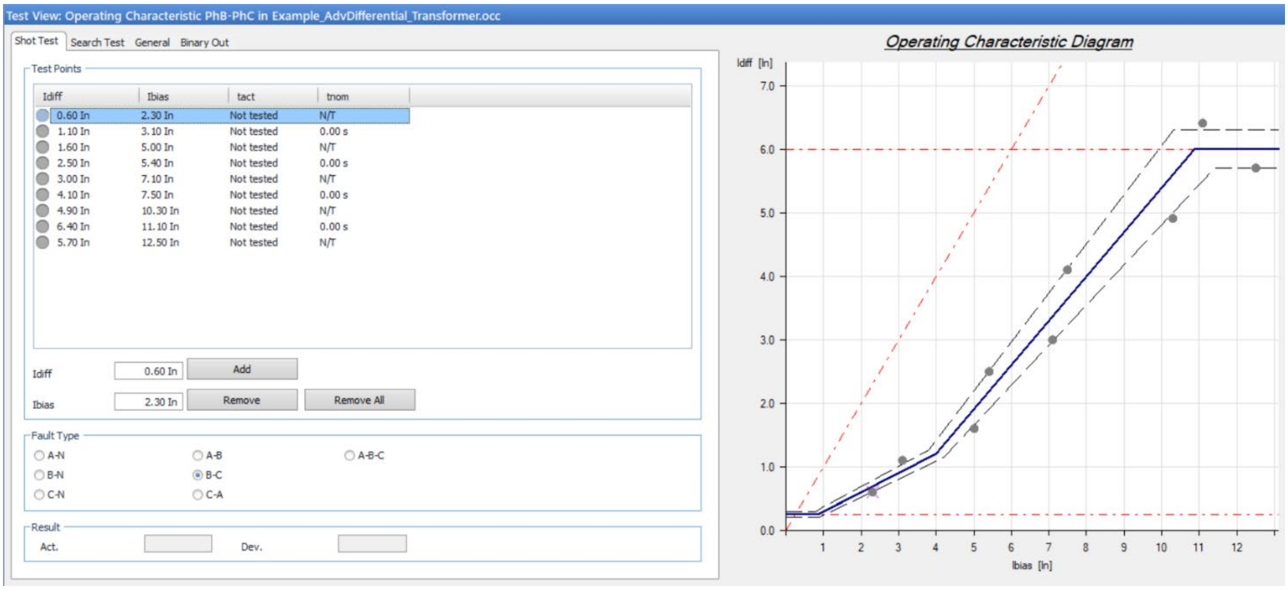
General settings of the test are entered in this tab.



1. If this option remains unselected, a search test will only search within the specified tolerances.
   If, however, this option is selected, the search test will also search outside of the tolerance band. In this case the test will always be assessed as passed.
2. A pre-fault current can be applied before each test shot.
3. This setting activates a voltage output during the test. In this example it is not necessary to select the voltage output.
4. Select this option if the test should be time synchronized via GPS or IRIG-B.
5. For the operating characteristic test, the Trigger Logic has to be defined according to the relay configuration.

   Note: If the relay uses multiple trip contacts, they should be linked with **AND**. This way a test shot will only be assessed as tripped if all of the trip contacts are triggered.

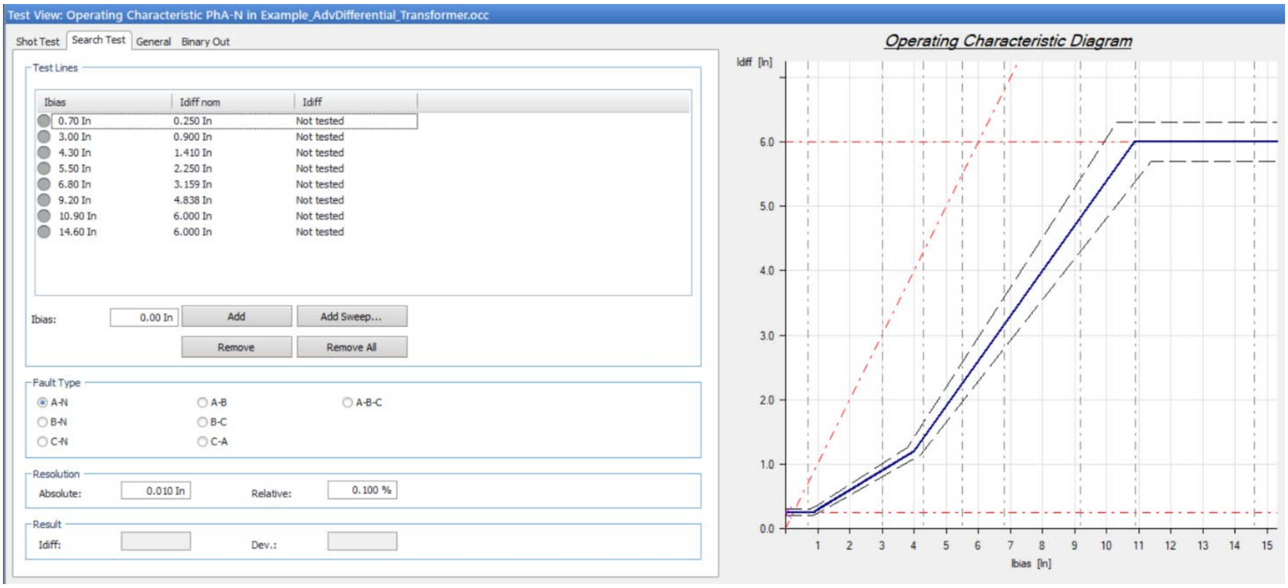
Shot Test



With the shot test, test shots can be placed in the operating characteristic diagram. To do so, click the operating characteristic diagram, then click **Add** to set the previously clicked test shot. Alternatively, set the test shots by entering the currents **Idiff** and **Ibias** manually.

To test the operating characteristic, test shots can be placed above and below the operating characteristic outside the tolerance band. In order to confirm that the operating characteristic is within the specified tolerances, it is recommended that test shot pairs are placed close to the boundary of the tolerance band.

Search Test



With the search test, vertical search lines can be added by clicking the operating characteristic diagram and then clicking **Add** or by manually entering the current **Ibias** of the search line. The test module will automatically place test shots along this line to search for the exact position of the operating characteristic.

With the search test, the exact position of the operating characteristic can be found, whereas with the shot test, it can be quickly confirmed whether the operating characteristic is within the specified tolerance band.

Note: It is not possible to do a shot test and a search test in the same test module. Remove all test shots before adding search lines or vice versa.

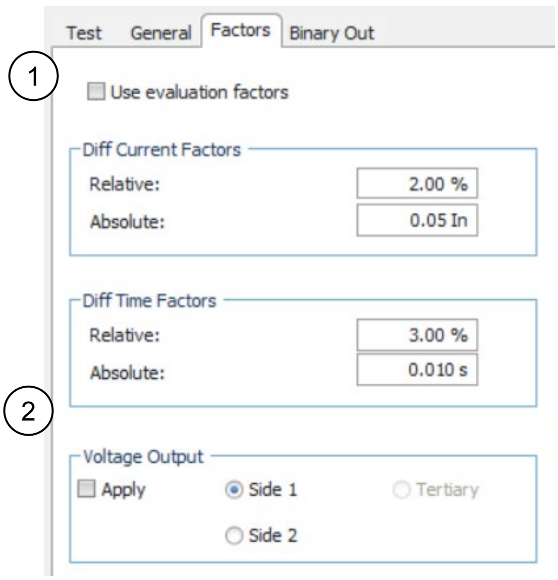
Only one fault type can be set per test module. If multiple fault types are to be tested, add more test modules to the OCC file.

When testing the operating characteristic it is recommended that each line segment is tested at two different positions (if possible). These test positions should not be too close to each other and also not too close to the corner points of the operating characteristic. This ensures that the characteristic settings are assessed properly.

3.4.4 Trip Times Test

This test confirms the trip times of the differential protection function. Therefore, test shots with different differential currents are applied to measure the corresponding trip times.

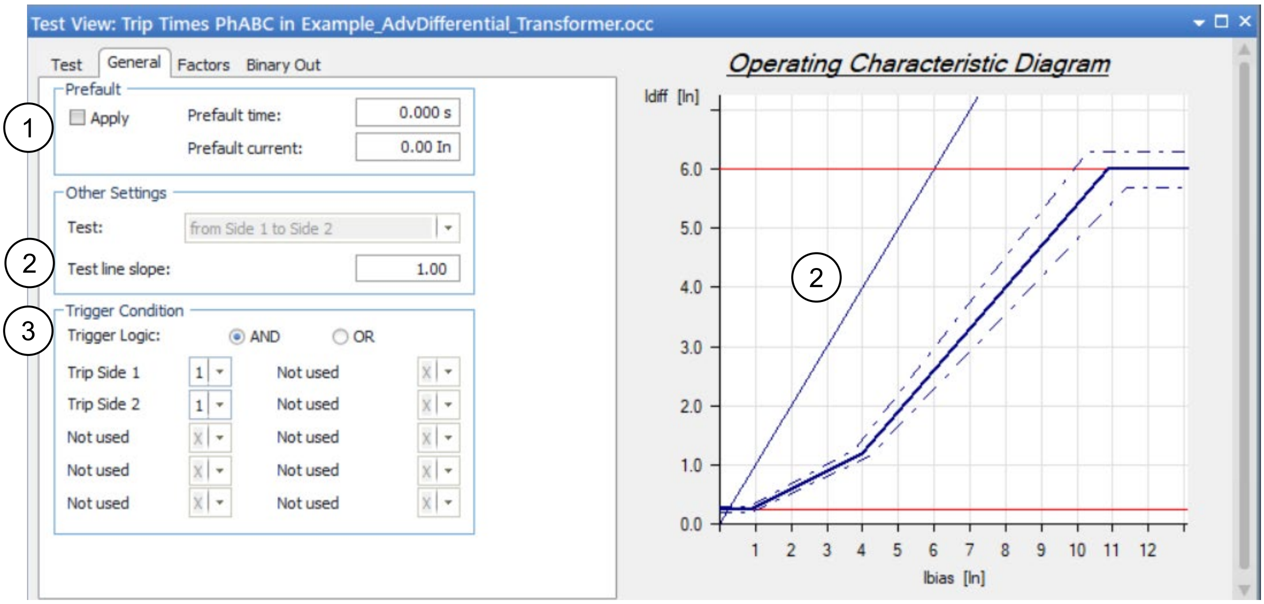
Factors



1. Select **Use evaluation factors** to overwrite the test object tolerances. The new tolerances can be entered below as **Diff Current Factors** and **Diff Time Factors**. In this example it is not necessary to select this function.

2. **Voltage Output**
This setting activates a voltage output during the test. In this example it is not necessary to select the voltage output.

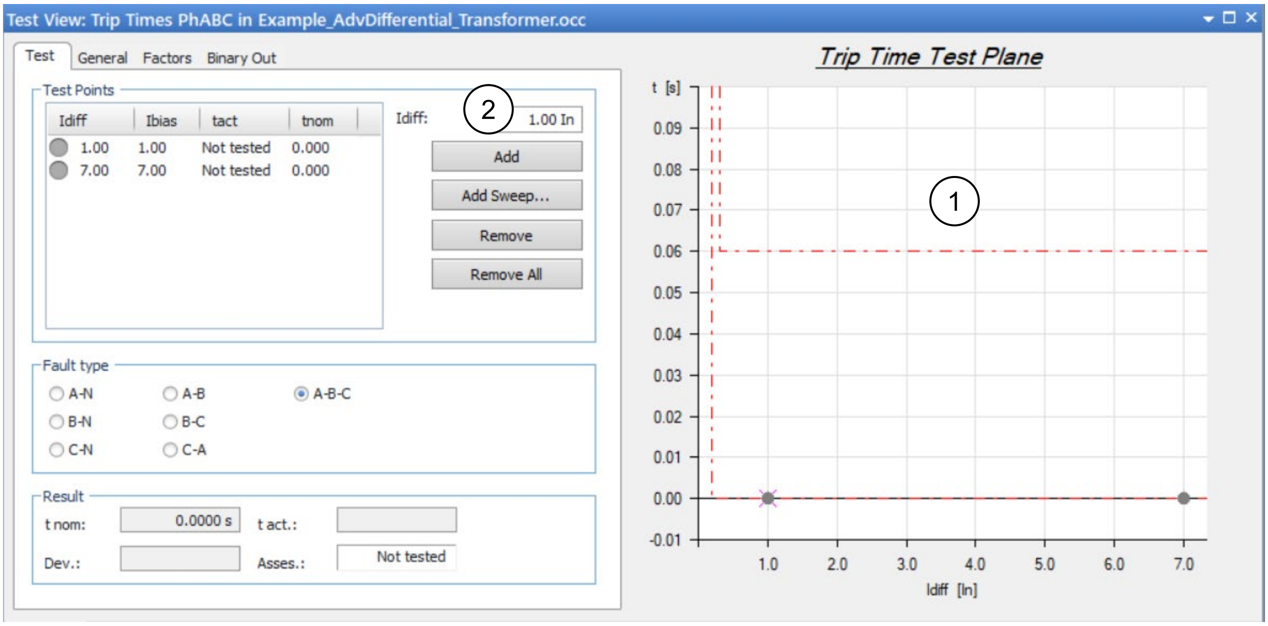
General



1. A pre-fault current can be applied before each test shot.
2. This setting defines the slope of the test line. The resulting test line is also shown in the operating characteristic diagram. All the test shots in this test module will be placed on this line. Therefore, it is advantageous to have not more than one intersection with the operating characteristic. For the majority of differential relays this setting can remain at the default value.
3. For the trip times test, the **Trigger Logic** has to be defined according to the relay configuration.

   Note: If the relay uses multiple trip contacts, they should be linked with **AND**. This way a test shot will only be assessed as tripped if all of the trip contacts are triggered.

Test



In the test tab the test shots are defined. To place a new test shot, either click on the trip time test plane **(1)** or enter the differential current manually **(2)** and then click **Add**.

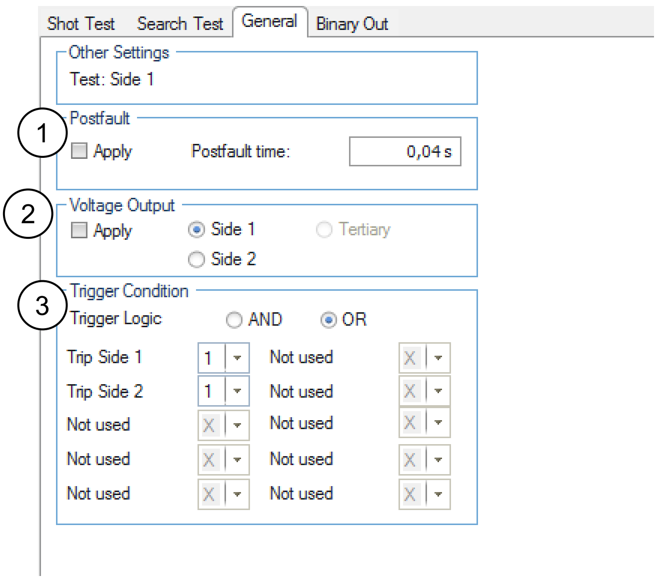
Note: Only one fault type can be set per test module. If multiple fault types are to be tested, add more test modules to the OCC file.

In order to test the trip time settings of the relay, it is recommended that one test shot is placed above Idiff> and one above Idiff>> (Test Object parameters). This ensures that the trip times corresponding to each differential current element are tested.

3.4.5 Inrush Blocking Test

This test confirms the operation of the inrush blocking function. The test module generates differential currents which contain harmonics which allows the inrush blocking characteristic to be tested.

General



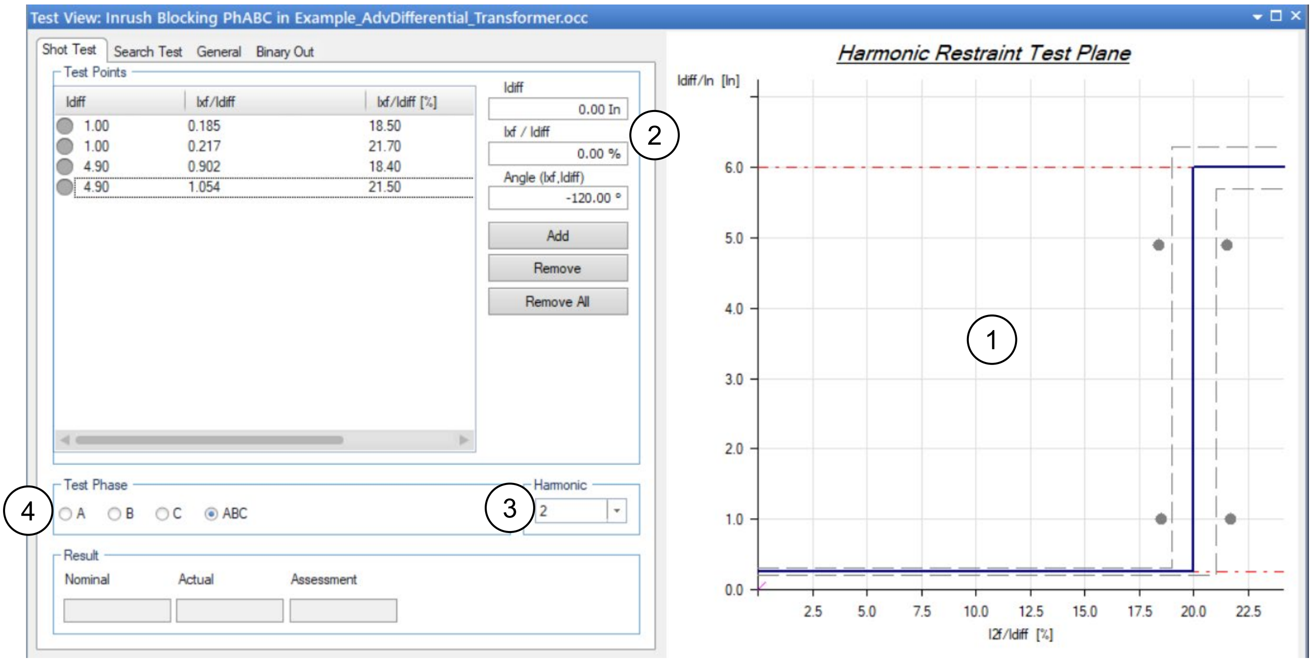
1. Select this option to apply a post-fault after each test shot. During the post-fault period, only fundamental frequency currents without harmonics will be generated.

   Note: If the relay trips during the post-fault, the test will be assessed as passed.

2. This setting activates a voltage output during the test. In this example it is not necessary to select this function.
3. For the inrush blocking test, the Trigger Logic has to be defined according to the relay configuration.

   Note: If the relay uses multiple trip contacts, they should be linked with **OR**. This way a test shot will only be assessed as blocked if none of the trip contacts are triggered.

Shot Test

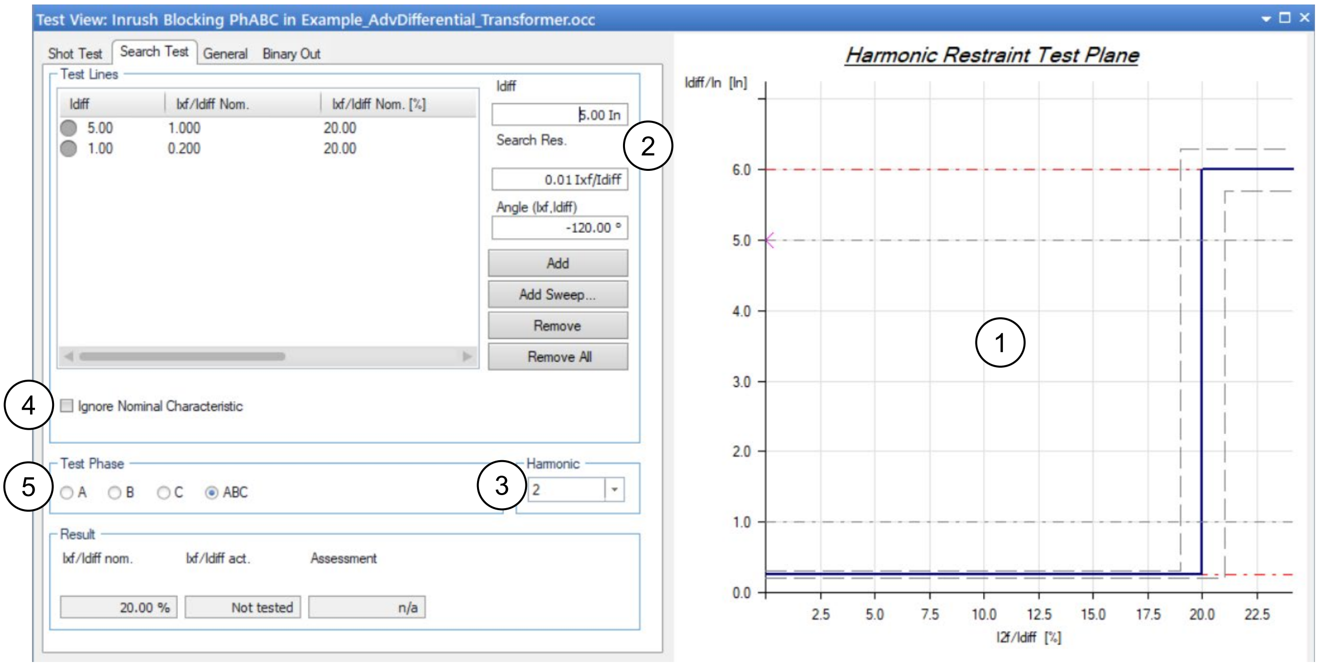


The shot test applies test shots to the harmonic restraint test plane. This plane shows the harmonic blocking characteristic with the differential current and the percentage of the harmonic current.

1. To set a new test shot click the test plane and then click **Add**.
2. Enter the differential current and the harmonic percentage. Then click **Add** to define the test shot.
3. Use the option **Harmonic** to define the number of the harmonic to be tested. For the inrush blocking of this example, this will be the second harmonic.
4. Here you define the **Test Phase**.

   Note: Only one test phase can be set per test module. If different phases are to be tested, add more test modules to the OCC file.

Search Test



The search applies test shots along horizontal search lines in order to determine the harmonic blocking characteristic.

1. To apply search lines, click into the characteristic, then click **Add**.
2. Alternatively, enter the differential current of the search line manually, then click **Add**.
3. Use the option **Harmonic** to define the number of the harmonic to be tested. For the inrush blocking of this example, this will be the second harmonic.
4. If the option **Ignore Nominal Characteristic** remains cleared, a search test will only search within the specified tolerances.
   If the option **Ignore Nominal Characteristic** is selected, the search test will also search outside the tolerance band. In this case the test will always be assessed as passed.
5. Here you define the **Test Phase**.

   Note: Only one test phase can be set per test module. If different phases are to be tested, add more test modules to the OCC file.

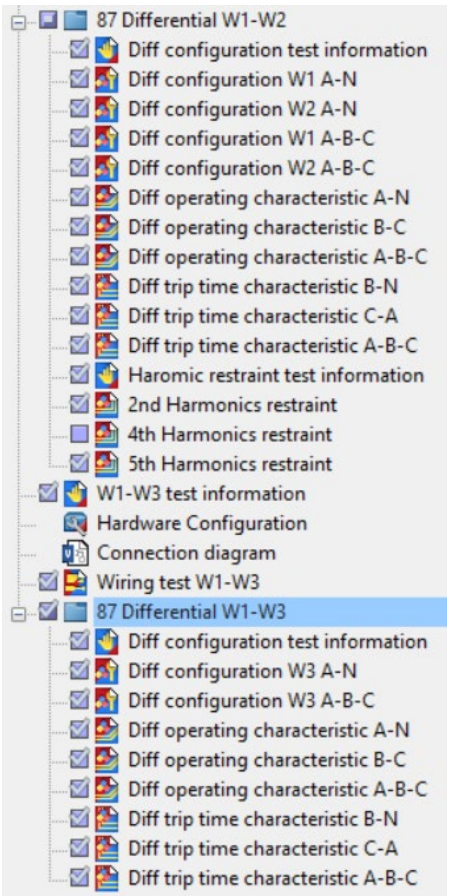
Note: It is not possible to do a shot test and a search test in the same test module. Remove all test shots before adding search lines or vice versa.

When testing the operating characteristic, it is recommended that the characteristic is tested outside the tolerance band just above Idiff> and just below Idiff>> (or at any other parameter that limits the harmonic blocking).

3.4.6 Testing Three-Winding Transformer Differential Protection

A test for three-winding transformer differential protection devices uses the same basic steps as the test for two-winding transformer differential protection devices.

Note: For most three-winding transformer differential relays, it is sufficient to perform the trip times test and the inrush blocking test once. However, the stability test and the operating characteristic test must cover each winding of the transformer.



Side 1 to Side 2:

> Stability Test
> Operating Characteristic Test
> Trip Times Test
> Inrush Blocking Test

Side 1 to Side 3:

> Stability Test
> Operating Characteristic Test

Note: To test from Side 1 to Side 3 the relay has to be rewired. Additionally, the global Hardware Configuration and the local Hardware Configurations of each test module have to be adapted.

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