

## FUNCTION BLOCK DESCRIPTION

# Transformer differential protection

*Functionblock versions 5 and up*

ANSI 87T, IEC 31dT >





## VERSION INFORMATION

The versions of the document also represent the version of the Function block.

VERSION	DATE	MODIFICATION	COMPILED BY
5.0	2024-04-09	First edition based on version 3.5 of the original description (ID: PP-13-21650) Modifications and general overhaul according to FB version 5	Bíró
10.0	2024-12-18	<ul style="list-style-type: none"> <li>• Reference/notes added for previous function block versions               <ul style="list-style-type: none"> <li>• Extended description of the matrix equations added to Appendix</li> </ul> </li> <li>• IEC61850 info added</li> <li>• Further notes for testing added, updated; XRIO info moved to the notes of the previous versions,</li> <li>• Update to version 10:               <ul style="list-style-type: none"> <li>○ Graphical analogue inputs</li> <li>○ Additional signals in online data</li> <li>○ Signal name prefixes changed from DIF87 to DIF87T</li> </ul> </li> </ul>	Erdős

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## Used Symbols



Additional information



Useful information for settings.



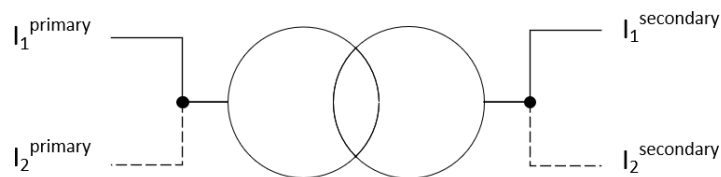
Important part for proper usage.

## 1 Operation principle

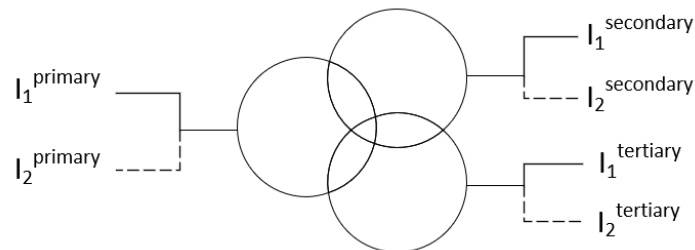
The Transformer differential protection function provides main protection for transformers. This document describes the following basic versions of the function:

- The version DIF87T3 can be applied to protect three-winding transformers.
- The simpler version DIF87T2 does not process analogue inputs from the tertiary side.
- Both of the two- and three-winding functions have multibranch versions, which can handle a maximum of 2 branches per side. The function can be adapted to the actual topology in the configuration of the IED.

This document contains all parameters, inputs, and outputs of the three-winding multibranch transformer version, but it hints necessary changes in application with two sides and one branch per side only.



1-1. Figure Two winding multibranch transformer



1-2. Figure Three winding multibranch transformer

### 1.1 Variants (Delta and Auto)

As far as the operation principle goes, there are two main variants (see more about the versions in Chapter 3.2.1):

- Versions 3 and below:** these always use delta-transformation (see Chapter 3.1.2) regardless the vector group, so the utilized transformation matrices are always the same.
- Versions 5 and up:** these versions transform to the primary side, so their set of transformation matrices vary based on the type of the primary winding.

This description is about Version 10. Versions 3 and below are described in a separate document (ID: PP-13-21650) dedicated to them (see Protecta website).

### 1.2 Structure of the differential protection algorithm

The figure below shows the structure of the Transformer differential protection (DIF87T3) algorithm.

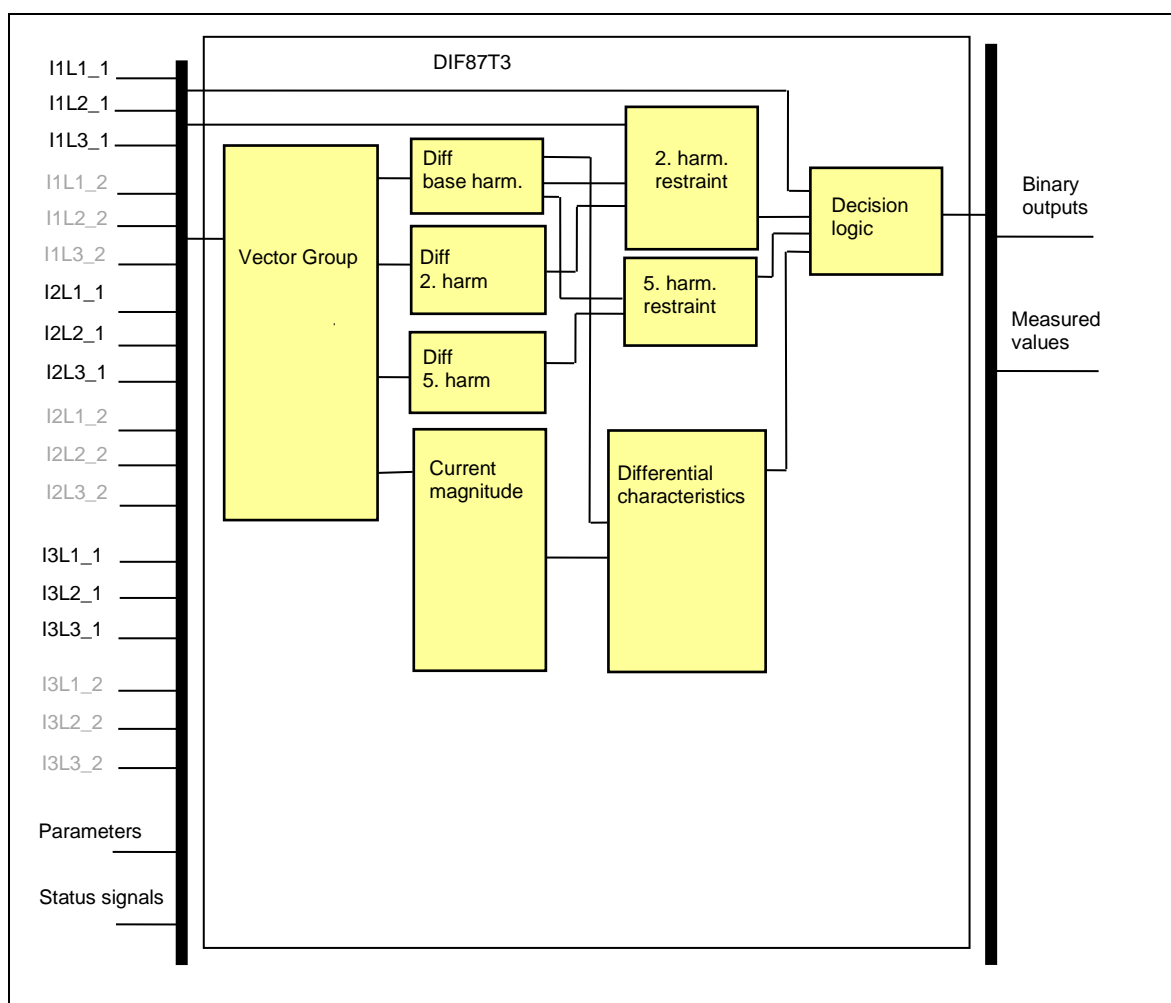


Figure 1-3 Structure of the differential protection algorithm

#### The **inputs** are

- the sampled values of three (or six in case of two branches) primary phase currents,
- the sampled values of three (or six in case of two branches) secondary phase currents,
- the sampled values of three (or six in case of two branches) tertiary phase currents (in DIF87T3 version only),
- parameters
- status signal.

#### The **outputs** are

- the binary output status signals,
- the measured values for displaying.

The **software modules** of the differential protection function:

#### **Vector group**

This module compensates the phase shift and turn's ratio of the transformer. The results of this calculation are the "sampled values" of the phase-shifted phase currents for all branches of all three (two) sides of the transformer and those of the three differential currents.

#### **Diff base harm.**

This module calculates the basic Fourier components of the three differential currents. These results are needed for the high-speed differential current decision and for the second and fifth harmonic restraint calculation.

#### **Diff 2. harm.**

This module calculates the second harmonic Fourier components of the three differential currents. These results are needed for the second harmonic restraint decision.

**Diff 5. harm.**

This module calculates the fifth harmonic Fourier components of the three differential currents. These results are needed for the fifth harmonic restraint decision.

**2. harm. restraint.**

The differential current can be high in case of transformer energizing, due to the current distortion caused by the transformer iron core asymmetric saturation. In this case the second harmonic content of the differential current is applied in this module to disable the operation of the differential protection function.

The differential current can be high in case of external faults, due to the current distortion caused by saturated CT on the faulty side. Additional usage of the second harmonic restraint in these cases can help to disable the operation of the differential protection function.

The result of this calculation is needed for the decision logic.

**5. harm. restraint.**

The differential current can be high in case of over-excitation of the transformer, due to the current distortion caused by the transformer iron core symmetric saturation. In this case the fifth harmonic content of the differential current is applied in this module to disable the operation of the differential protection function. The result of this calculation is needed for the decision logic.

**Current magnitude**

This module calculates the magnitude of the phase-shifted phase currents and that of the differential currents. The result of this calculation is needed for the differential characteristic evaluation.

**Differential characteristics**

This module performs the necessary calculations for the evaluation of the “percentage differential characteristics”. The result of this calculation is needed for the decision logic.

**Decision logic**

The decision logic module decides if the differential current of the individual phases is above the characteristic curve of the differential protection function. This curve is the function of the restraint current, which is calculated based on the magnitude of the phase-shifted phase currents in all branches. This module calculates the second and fifth harmonic ratio of the differential current, relative to the basic harmonic content. The result can restrain the operation of the differential protection function. The high-speed overcurrent protection function based on the differential currents is performed in this module too.

The following description explains the details of the individual components.

## 1.3 Turn's ratio matching and vector shift compensation (Vector group)

The three-phase power transformers transform the primary current to the secondary side according to the turn's ratio and the vector group of the transformers. The Y (star) D (delta) or Z (zig-zag) connection of the three phase coils on the primary and on the secondary side causes vector shift of the currents. The conventional electromechanical or static electronic devices of the differential protection compensate the vector shift with appropriate connection of the current transformer coils. The numerical differential protection function applies matrix transformation to the directly measured currents of one side of the transformer to match them with the currents of the other side(s).

In the Transformer differential protection of Protecta the software module „Vector\_group” calculates the matrix transformation and the turn's ratio matching. **The target of the matrix transformation is always the primary side of the transformer.** For example, if the vector group is Yd1, then the algorithm transforms the currents of every side to Y-connection, and if it is Dy1, then to D-connection.

### 1.3.1 Turn's ratio matching

In the transformer, the magnitude of the current is transformed according to the turn's ratio (and the vector group) of the transformers. In practical terms this transformation is expressed as the voltage ratio(s). For the calculation, the rated voltages of the transformation are to be declared: “Un Primary”, “Un Secondary” and in case of transformer with three voltage levels also “Un Tertiary”.

The Transformer differential protection function also needs a reference current. The specific points of the differential characteristic are expressed as percentage of this reference current. This value is calculated internally, based on the rated power of the transformer. It is usual that for transformers with three voltage levels – where the rated power for all three sides can be different – the value for the primary side is to be set as a parameter. NOTE: when selecting other values, the scaling of the differential characteristic also changes.

The summary of the parameters needed for turn's ratio matching are summarized in Table 1-1.

#### Floating point parameters

Table 1-1 The floating-point parameters for the turn's ratio compensation

PARAMETER NAME	TITLE	DIM.	MIN	MAX	DEFAULT
Rated power (primary side) of the transformer					
DIF87T_Sn_FPar_	Sn	MVA	1.00	1000.00	125.00
Rated voltages $Un1$ , $Un2$ (and $Un3$ if tertiary side also available)					
DIF87T_UTRPri_FPar_	Un Primary	kV	1.00	1000.00	132.00
DIF87T_UTRSec_FPar_	Un Secondary	kV	1.00	1000.00	22.00
DIF87T_UTRter_FPar_	Un Tertiary	kV	1.00	1000.00	11.50

Based on these parameters, the reference current for the high voltage primary side of the transformer is calculated with the well-known formula:

$$I_{reference\_1} = \frac{S_n}{\sqrt{3} Un1}$$

Where:

$I_{reference\_1}$  is the reference current for the high voltage primary side of the transformer,  
 $S_n$  is the set rated power of the transformer (usually the primary side value),  
 $Un1$  is the rated voltage of the primary side of the transformer.

This reference current can be transformed to the secondary or to the tertiary sides of the transformer with the rated voltage values. For the relay, these reference values are transmitted by the current transformers, according to the CT turn's ratios. This information is set in the CT modules of the device as parameter values.

### 1.3.2 Mathematical modeling of the current transformer's vector group connection

The numerical differential protection function applies numerical matrix transformation for compensation of the phase shift of the transformer.

In the vector shift compensation, the sampled  $L1$ ,  $L2$ ,  $L3$  currents of each branches of the primary side ( $I1L1$ ,  $I1L2$ ,  $I1L3$  and the same for the second branch if there is on the primary side) and those of the secondary and tertiary side ( $I2L1$ ,  $I2L2$ ,  $I2L3$  and the same for the second branch if there is on the secondary side) and ( $I3L1$ ,  $I3L2$ ,  $I3L3$  and the same for the second branch if there is on the tertiary side)) are transformed to ( $I1L1shift$ ,  $I1L2shift$ ,  $I1L3shift$  and the same for the second branch if there is on the primary side) ( $I2L1shift$ ,  $I2L2shift$ ,  $I2L3shift$  and the same for the second branch if there is on the secondary side) and ( $I3L1shift$ ,  $I3L2shift$ ,  $I3L3shift$  and the same for the second branch if there is on the tertiary side) values of the sides respectively, using matrix transformation. The method of transformation is defined by the Pri-Sec Vector Group and Pri-Ter Vector Group parameters, identifying the transformer vector group connection.

### 1.3.3 The matrix equations

In the Transformer differential protection, the transformation caused by the vector shift is implemented with the help of matrix equations. In the following chapters some examples are explained. Note that although only primary and secondary will be mentioned here, all these can be applied in respect of primary and tertiary sides.

#### 1.3.3.1 Yy0 vector group

In case of Yy0 vector group, there is no phase shift between the two sides of the transformer, so the currents of both sides can be transformed by a unit matrix:

$$\begin{bmatrix} I1L1Shift \\ I1L2Shift \\ I1L3Shift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} I1L1 \\ I1L2 \\ I1L3 \end{bmatrix}$$

$$\begin{bmatrix} I2L1Shift \\ I2L2Shift \\ I2L3Shift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} I2L1 \\ I2L2 \\ I2L3 \end{bmatrix}$$

#### 1.3.3.2 Dy1 vector group

In case of Dy1 vector group, the target of the transformation is the D side. Therefore, on the primary (D) side no shift is applied, the phase currents are multiplied by a unit matrix:

$$\begin{bmatrix} I1L1Shift \\ I1L2Shift \\ I1L3Shift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} I1L1 \\ I1L2 \\ I1L3 \end{bmatrix}$$

The cyclical subtraction of the phase currents for the secondary side models delta connected current transformers, and it means that the zero-sequence current is eliminated on this side that way – no extra Io-subtraction is needed.

$$\begin{bmatrix} I2L1Shift \\ I2L2Shift \\ I2L3Shift \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} * \begin{bmatrix} I2L1 \\ I2L2 \\ I2L3 \end{bmatrix}$$

The delta connection of the primary side of the transformer eliminates the zero-sequence current physically, so normally there is no need to care about it on that side. The only exception can be if there is a neutral grounding transformer on the primary (D) side in the protected zone, through which zero-sequence current can flow in case of external earth fault. This case is explained in details in chapter 1.3.4.

#### 1.3.3.3 Yd1 vector group

In the case of Yd1 vector group, the target of the transformation is the Y side. If the starpoint is isolated, then on the primary (Y) side no shift is applied, the phase currents are multiplied by a unit matrix:

$$\begin{bmatrix} I1L1Shift \\ I1L2Shift \\ I1L3Shift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} I1L1 \\ I1L2 \\ I1L3 \end{bmatrix}$$

If, however, the starpoint is earthed, then zero-sequence current can flow on the primary (Y) side in case of external earth fault, which is eliminated on the secondary side due to the delta connection, so this shall be subtracted from each phases also on the primary side. This subtraction is solved in the transformation matrix for that case:

$$\begin{bmatrix} I1L1Shift \\ I1L2Shift \\ I1L3Shift \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} * \begin{bmatrix} I1L1 \\ I1L2 \\ I1L3 \end{bmatrix}$$

Therefore, the real starpoint grounding of the primary side must be set by the parameter “Primary starpoint”. The setting of “Secondary starpoint” (or “Tertiary starpoint”) parameter would not matter in this case, and they become hidden in such conditions.

The currents of the delta connected secondary side are shifted by cyclic subtraction to match the phases of the currents of the Y-connected primary side:

$$\begin{bmatrix} I_{2L1Shift} \\ I_{2L2Shift} \\ I_{2L3Shift} \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} * \begin{bmatrix} I_{2L1} \\ I_{2L2} \\ I_{2L3} \end{bmatrix}$$

The cyclic subtraction includes also a zero-sequence elimination, so in this case the neutral grounding transformer on the delta side cannot cause any issue.

#### 1.3.3.4 Dd0 vector group

In case of Dd0 vector group, there is no phase shift between the two sides of the transformer, so the currents of both sides can be transformed by a unit matrix:

$$\begin{bmatrix} I_{1L1Shift} \\ I_{1L2Shift} \\ I_{1L3Shift} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} I_{1L1} \\ I_{1L2} \\ I_{1L3} \end{bmatrix}$$

$$\begin{bmatrix} I_{2L1Shift} \\ I_{2L2Shift} \\ I_{2L3Shift} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} I_{2L1} \\ I_{2L2} \\ I_{2L3} \end{bmatrix}$$

#### 1.3.3.5 Calculation of differential current

The differential currents are calculated using the (*I...shift*) values and the rated currents *I\_reference\_1*, *I\_reference\_2* (and *I\_reference\_3* if this is applicable). These currents are calculated internally, using the rated power and rated voltages, as given by parameters. (The positive direction of the currents is flowing IN on both sides.)

$$\begin{aligned} \begin{bmatrix} IdL1 \\ IdL2 \\ IdL3 \end{bmatrix} &= \begin{bmatrix} I_{1L1shift}' \\ I_{1L2shift}' \\ I_{1L3shift}' \end{bmatrix} + \begin{bmatrix} I_{2L1shift}' \\ I_{2L2shift}' \\ I_{2L3shift}' \end{bmatrix} = \\ &= \frac{1}{I_{reference\_1}} \begin{bmatrix} I_{1L1shift} \\ I_{1L2shift} \\ I_{1L3shift} \end{bmatrix} + \frac{1}{I_{reference\_2}} \begin{bmatrix} I_{2L1shift} \\ I_{2L2shift} \\ I_{2L3shift} \end{bmatrix} \end{aligned}$$

This means that the differential currents (and the phase shifted currents marked with the character apostrophe ' as well) are "per unit currents", and the reference values are the calculated reference currents.

If there are more branches on a side, then the shifted currents of those branches are also added to the differential currents.

### 1.3.4 Operation with the zero-sequence current in case of phase-to-ground fault on the delta side

On the secondary side of a high voltage/medium voltage transformer which is connected in delta on the medium voltage side, an additional neutral grounding transformer is applied. Between the neutral point of this grounding transformer and the ground, either a grounding resistor is connected to limit the single phase to ground fault currents below 100 A (in some cases 200 A), or here a Petersen coil is applied which limits the single-phase fault currents to a small value of some Amps.

In these cases, there are two locations for the current transformers on the delta side to supply the differential protection. In one case the neutral grounding transformer is located inside the protected zone of the differential protection (in Figure 1-4 and Figure 1-5 it is the location "Z"), in the other case the neutral grounding transformer is outside the protected zone (in Figure 1-4 and Figure 1-5 this is the application of the current transformers on location „Y”).

If the neutral grounding transformer is in the protected zone, then the current distribution depends on the location of the supplying generator. In these cases, if the connection of primary coil is Y, then the target of transformation is the Y side, and the algorithm subtracts zero-sequence current automatically. In the cases of vector group Dy and Dz, setting of Neutral grounding transf. parameter could be necessary, if the characteristic line of differential protection function is too sensitive to avoid mal-operation. Otherwise, the subtraction of zero-sequence current may cause unsensitive operation. This additional transformation „replaces” the measuring location to the point („Y”), where no zero-sequence current can flow, so these transformed currents do not include the zero-sequence current of the neutral grounding transformer.

### 1.3.4.1 Power supply at the Y side

As the zero-sequence current component of the delta side can influence the behavior of the differential protection (sensitive setting), this chapter analyses the current distribution in case of single phase to ground fault at the delta side.

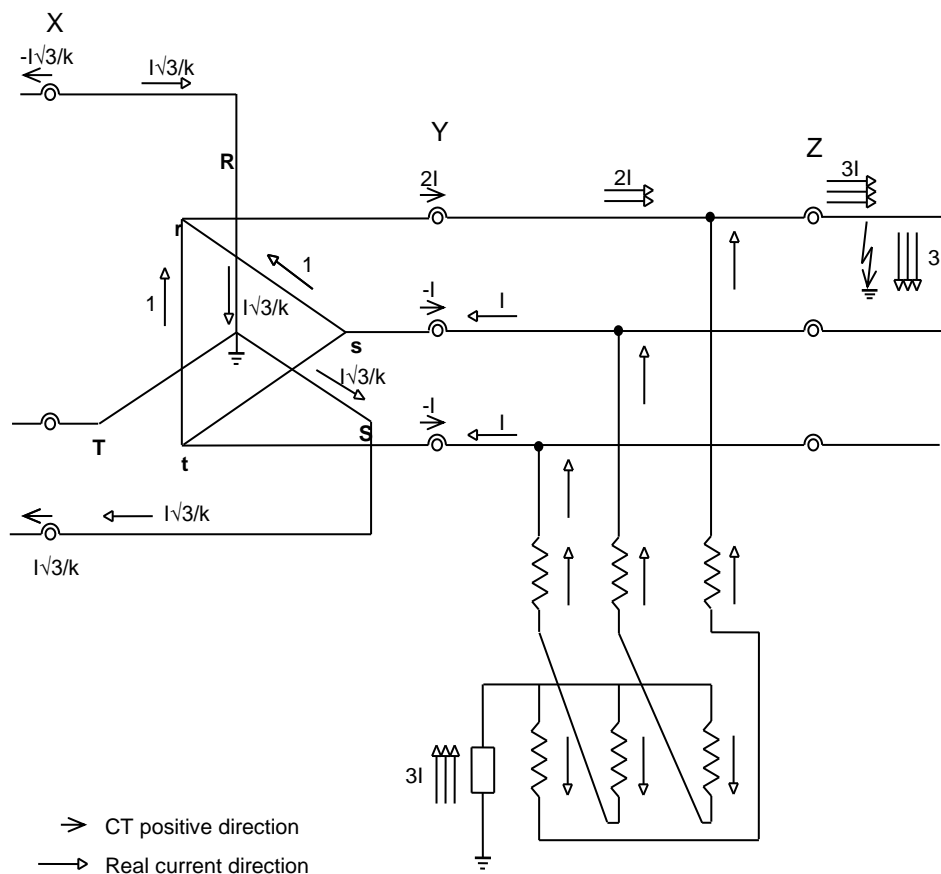


Figure 1-4 Current distribution at external single phase to ground fault, Y side power supply

For the current distribution an external „r” phase fault is assumed, and at the fault location the current is  $I_r = 3I_0$ . The arrows indicating the real currents can be constructed at this starting point.

Based on the figure above, with positive directions out of the transformer the currents in the CTs are:

On the Y side (location X in Figure 1-4):

$$\begin{bmatrix} I_{1L1In} \\ I_{1L2In} \\ I_{1L3In} \end{bmatrix} = I * \frac{\sqrt{3}}{k} \begin{bmatrix} -1 \\ 1 \\ 0 \end{bmatrix}$$

The delta side currents at the location „Y”:

$$\begin{bmatrix} I_{2L1In} \\ I_{2L2In} \\ I_{2L3In} \end{bmatrix} = I \begin{bmatrix} 2 \\ -1 \\ -1 \end{bmatrix}$$

If the current is measured at location „Z” then the node - which must fulfill the Kirchhoff's node law - is extended by the neutral grounding transformer, but the current flowing between the neutral point and the ground is not measured and not added to the current summation. This current is the  $3I_0$  zero sequence component, which can be calculated as the sum of the phase

currents. At location „Z” the zero-sequence component has no other path to flow, but the neutral grounding transformer.

The delta side currents at the location „Z”:

$$\begin{bmatrix} I_{2L1In} \\ I_{2L2In} \\ I_{2L3In} \end{bmatrix} = I \begin{bmatrix} 3 \\ 0 \\ 0 \end{bmatrix}$$

In this case the zero-sequence current is I. If the vector group compensation is for the delta side, then the transformation does not change this current, on the high voltage side however there is no zero-sequence component. But anyhow the transformation would filter this component out.

In the practice, this zero-sequence current component is always below the rated current of the transformer, but in case of sensitive setting of the differential protection, or at mechanical application of a relay test set without any logic control this can result faulty operation of the differential protection in case of external fault.

To avoid this faulty operation there is a binary parameter in the differential protection, the effect of which is to subtract the zero-sequence current component from the phase currents, if it is needed:

$$\begin{bmatrix} I_{2L1In} \\ I_{2L2In} \\ I_{2L3In} \end{bmatrix} = \begin{bmatrix} I_{2L1In'} - I_{20} \\ I_{2L2In'} - I_{20} \\ I_{2L3In'} - I_{20} \end{bmatrix} = I \begin{bmatrix} 3 \\ 0 \\ 0 \end{bmatrix} - I \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} = I \begin{bmatrix} 2 \\ -1 \\ -1 \end{bmatrix}$$

It means that based on the currents of the CT-s located at „Z” the current is calculated, which could be measured at location „Y”.



**REMARK:** This zero-sequence current subtraction could be applied without any consequences in case of current transformers at location „Y” too, because in case of external faults, at this location no zero-sequence current can be detected. In case of internal fault, however, this decreases the faulty phase current by 2/3. This could worsen the sensitivity of the differential protection in case high impedance internal faults. The application of the mentioned binary parameter can disable the subtraction of the zero-sequence current in case of measurement at location „Y”.

### 1.3.4.2 Power supply at the delta side

If on a medium voltage network with neutral grounding transformer connects distributed generators, a possible state of operation can be that the transformer is disconnected at the high voltage Y side. On the Y side no current can flow, and if the differential protection measures the currents on the medium voltage side at location „Z” (Figure 1-7) then in case of sensitive setting of the characteristic lines or at testing, the differential protection can generate a faulty trip command. The current distribution according to Figure 1-5 is as follows:

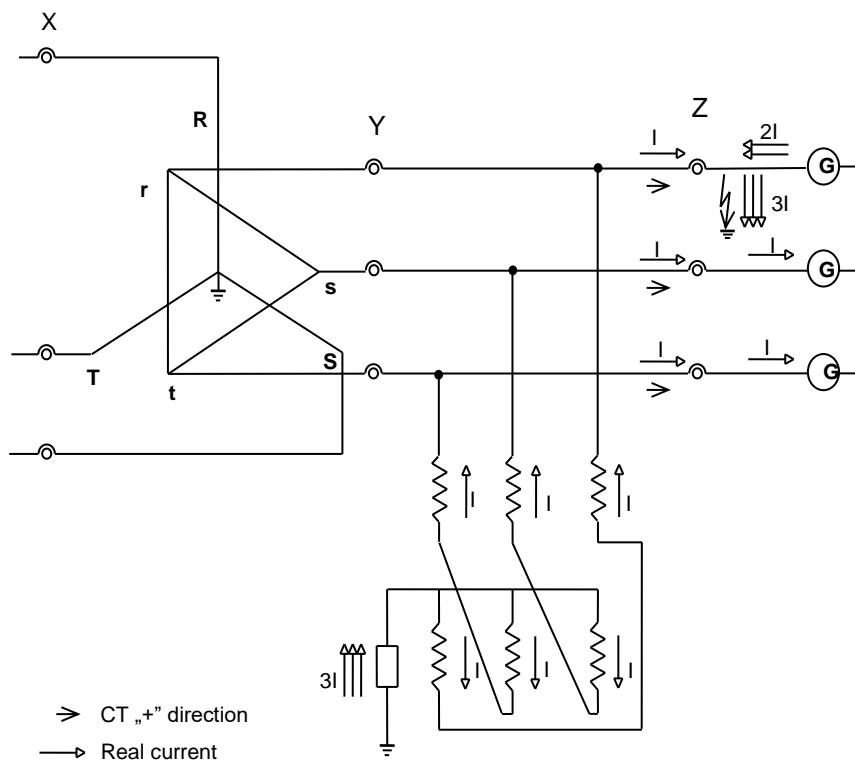


Figure 1-5 Current distribution in case of delta side single phase fault, supply at the delta side

In this case no current is detected at the point „X” (CB open):

$$\begin{bmatrix} I1L1In \\ I1L2In \\ I1L3In \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

The measured currents at „Z” can be seen in the figure:

$$\begin{bmatrix} I2L1In \\ I2L2In \\ I2L3In \end{bmatrix} = I \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}$$

To avoid mal-operation (trip) at external fault a binary parameter is applied, the effect of which is to subtract the zero-sequence current at the delta side:

$$\begin{bmatrix} I2L1In \\ I2L2In \\ I2L3In \end{bmatrix} = \begin{bmatrix} I2L1In' - I20 \\ I2L2In' - I20 \\ I2L3In' - I20 \end{bmatrix} = I \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - I \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

It means that based on the currents of the CT-s located at „Z” the current is calculated, which could be measured at location „Y”.

With this transformation the unwanted trip is avoided.

### 1.3.5 The principal scheme of the vector group compensation

Figure 1-6 shows the principal scheme of the vector shift compensation.

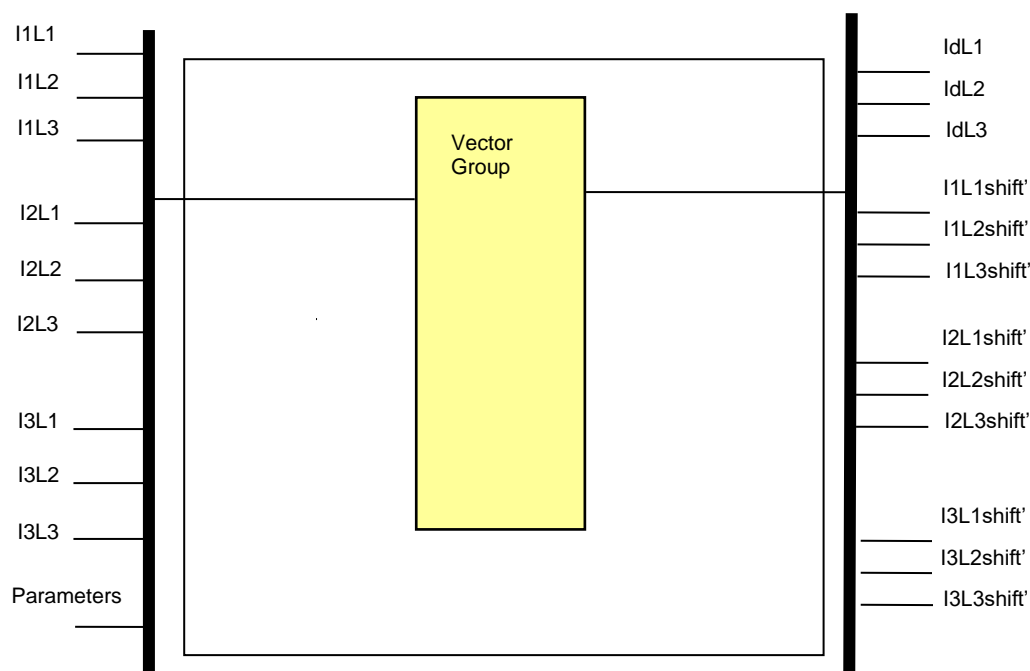


Figure 1-6 Principal scheme of the vector shift compensation.

Note: if there are more branches on a side of the transformer, the phase currents  $I_{xL1}$ ,  $I_{xL2}$ ,  $I_{xL3}$  include both branches.

The **inputs** are the sampled values of:

- The three phase currents of the primary side (I1L1, I1L2, I1L3)
- The three phase currents of the secondary side (I2L1, I2L2, I2L3)
- The three phase currents of the tertiary side (I3L1, I3L2, I3L3 in DIF87T3 version only)
- Parameters for vector shift and turn's ratio compensation.

**Enumerated parameters** for the vector shift compensation:

Table 1-2 Enumerated parameters for the vector shift compensation

Parameter name	Title	Selection range	Default
Parameter to select connection group of the transformer coils in primary-secondary relation:			
DIF87T_VGrSec_EPar_	Pri-Sec Vector Group*	Dy1,Dy5,Dy7,Dy11,Dd0,Dd6,Dz0,Dz2,Dz4,Dz6,Dz8,Dz10,Yy0,Yy6,Yd1,Yd5,Yd7,Yd11	Dd0
Parameter to select connection group of the transformer coils in primary-tertiary relation:			
DIF87T_VGrTer_EPar_	Pri-Ter Vector Group*	Dy1,Dy5,Dy7,Dy11,Dd0,Dd6,Dz0,Dz2,Dz4,Dz6,Dz8,Dz10,Yy0,Yy6,Yd1,Yd5,Yd7,Yd11	Dd0
Parameters to select the grounding mode**			
DIF87T_PrimStar_EPar_	Primary starpoint	Isolated, Earthed	Isolated
DIF87T_SecStar_EPar_	Secondary starpoint	Isolated, Earthed	Isolated
DIF87T_TerStar_EPar_	Tertiary starpoint	Isolated, Earthed	Isolated

\* If the connection of the primary winding in primary-secondary and primary tertiary relation is selected in contradiction, then the protection function is automatically disabled, and the function generates a warning signal.

\*\*These parameters are hidden if the connection of the primary winding is not Y.



For special order zig-zag vector groups could be available (Yz1, Yz5, Yz7, Yz11). At zig-zag vector groups, the algorithm transforms to the D side. Therefore, in this case the setting of Neutral grounding transf. parameter might be necessary even with Yz vector group.

**Boolean parameter** for the vector shift compensation:

**Table 1-3 The Boolean parameter for the vector shift compensation**

Parameter name	Title	Default	Explanation
DIF87T_0Seq_BPar_	Neutral grounding transf.	True	See Chapter 1.3.4

Neutral grounding transf. parameter has effect only in Dy and Dz vector groups, because in case of Y primary coil the target of transformation is the Y side, and if on secondary side there is delta connection, the transformation matrix eliminates zero-sequence current. By Y connection coils the starpoint grounding parameter determines the handling of zero-sequence current. If the connection of primary coil is Y, this parameter is hidden.



**REMARK:** This zero-sequence current subtraction could be applied without any consequences in case of current transformers at location „Y” in Figure 1-4 and Figure 1-5 too, because in case of external faults, at this location no zero-sequence current can be detected. In case of internal fault however this decreases the faulty phase current by 2/3. This could worsen the sensitivity of the differential protection in case of high impedance internal faults. The application of the mentioned binary parameter can disable the subtraction of the zero-sequence current in case of measurement at location „Y”.

The **outputs** are the “sampled values” of the phase-shifted currents:

- The differential currents after phase-shift  $\begin{bmatrix} IdL1 \\ IdL2 \\ IdL3 \end{bmatrix}$
- The primary currents after phase-shift  $\begin{bmatrix} I1L1\_1shift' \\ I1L2\_1shift' \\ I1L3\_1shift' \end{bmatrix}$  and  $\begin{bmatrix} I1L1\_2shift' \\ I1L2\_2shift' \\ I1L3\_2shift' \end{bmatrix}$
- The secondary currents after phase-shift  $\begin{bmatrix} I2L1\_1shift' \\ I2L2\_1shift' \\ I2L3\_1shift' \end{bmatrix}$  and  $\begin{bmatrix} I2L1\_2shift' \\ I2L2\_2shift' \\ I2L3\_2shift' \end{bmatrix}$
- The tertiary currents after phase-shift (in DIF87T3 version only)  $\begin{bmatrix} I3L1\_1shift' \\ I3L2\_1shift' \\ I3L3\_1shift' \end{bmatrix}$  and  $\begin{bmatrix} I3L1\_2shift' \\ I3L2\_2shift' \\ I3L3\_2shift' \end{bmatrix}$

## 1.4 Harmonic analysis of the differential currents (**Diff basic harm.**), (**Diff 2. harm.**), (**Diff 5. harm.**)

### 1.4.1 The principle of calculation

The differential current can be high in case of transformer energizing, due to the current distortion caused by the transformer iron core asymmetric saturation. In this case the second harmonic content of the differential current is applied to disable the operation of the differential protection function.

The differential current can also be high in case of external faults, due to the current distortion caused by saturated CT on the faulty side. Additional usage of the second harmonic restraint in these cases disables the operation of the differential protection function.

The differential current can be high in case of over-excitation of the transformer, due to the current distortion caused by the transformer iron core symmetric saturation. In this case the fifth harmonic content of the differential current is applied to disable the operation of the differential protection function.

The harmonic analysis block of modules consists of three individual software modules.

#### **Diff base harm.**

This module calculates the basic Fourier components of the three differential currents. These results are needed for the high-speed differential current decision and for the second and fifth harmonic restraint calculation.

#### **Diff 2. harm.**

This module calculates the second harmonic Fourier components of the three differential currents. These results are needed for the second harmonic restraint decision.

#### **Diff 5. harm.**

This module calculates the fifth harmonic Fourier components of the three differential currents. These results are needed for the fifth harmonic restraint decision.

## 1.4.2 The principal scheme of the harmonic analysis

Figure 1-7 shows the structure of the harmonic analysis.

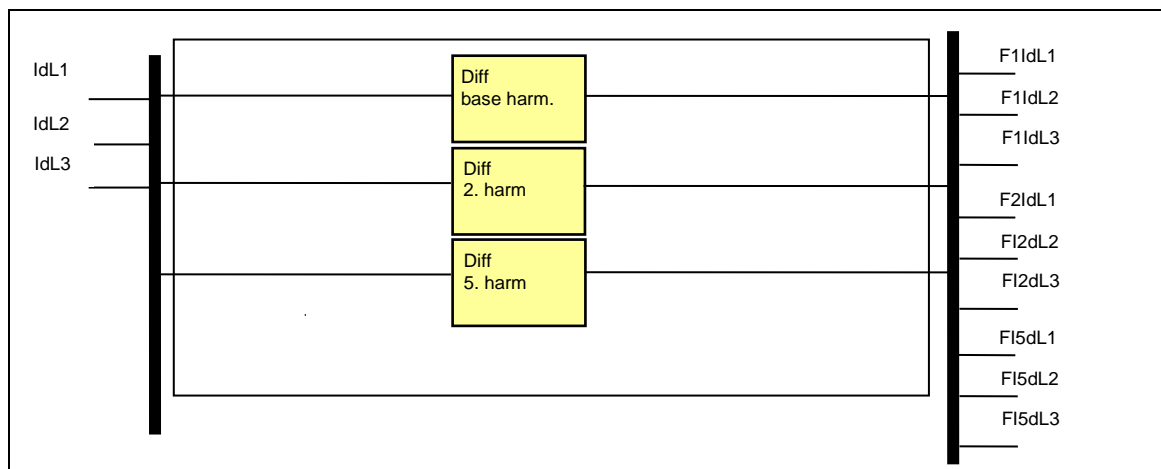


Figure 1-7 Principal scheme of the harmonic analysis.

The **inputs** are the “sampled values” of the differential currents, based on the phase-shifted currents:

- The differential currents after phase-shift  $\begin{bmatrix} IdL1 \\ IdL2 \\ IdL3 \end{bmatrix}$

The **outputs** are the basic, the second and the fifth harmonic Fourier components of the differential currents (also as p.u. of the reference current):

- The basic harmonic Fourier components of the differential currents  $\begin{bmatrix} F1dL1 \\ F1dL2 \\ F1dL3 \end{bmatrix}$
- The second harmonic Fourier components of the differential currents  $\begin{bmatrix} F2dL1 \\ F2dL2 \\ F2dL3 \end{bmatrix}$
- The fifth harmonic Fourier components of the differential currents  $\begin{bmatrix} F5dL1 \\ F5dL2 \\ F5dL3 \end{bmatrix}$

These values are processed by the software modules **2. harmonic restraint** and **5. harmonic restraint**

## 1.5 The harmonic restraint decision (2. harmonic restraint) and (5. harmonic restraint)

### 1.5.1 The principle of the restraint decision

The differential current can be high in case of transformer energizing, due to the current distortion caused by the transformer iron core asymmetric saturation. In this case the second harmonic content of the differential current is applied to disable the operation of the differential protection function.

The differential current can be high in case of external faults, due to the current distortion caused by saturated CT on the faulty side. Additional usage of the second harmonic restraint in these cases can help to disable the operation of the differential protection function.

The differential current can be high in case of over-excitation of the transformer as well, due to the current distortion caused by the transformer iron core symmetric saturation. In this case the fifth harmonic content of the differential current is applied to disable the operation of the differential protection function.

The harmonic analysis block of modules consists of two sub-blocks, one for the second harmonic decision and one for the fifth harmonic decision. Each sub-block includes three individual software modules for the phases.

The software modules evaluate the harmonic content relative to the basic harmonic component of the differential currents, and compare the result with the parameter values, set for the second and fifth harmonic. If the content is high, then the assigned status signal is set to “true” value. If the duration of the active status is at least 25 ms (or 20.83 ms on a 60 Hz system), then resetting of the status signal is delayed by additional 15 ms (12.5 ms on a 60 Hz system).

Depending on the dedicated Boolean parameter setting “Cross Blocking”, there are two modes of operation:

- If the “Cross Blocking” parameter is FALSE (not checked) then the three “measuring elements” operate individually. The internal output signal of the “measuring element” is blocked only if the own differential current contains harmonics (second and/or fifth) above the setting level, indicating inrush current or over-excitation. Other measuring element may generate trip requirement.
- If the “Cross Blocking” parameter is TRUE (checked) then the three blocking any of the “measuring elements” by harmonics (second and/or fifth) above the setting level blocks also the internal output signal of all three “measuring elements”. The function does not generate trip requirement.

The duration of the cross blocking is set by a dedicated parameter “Cross Blocking Limit”. This is the maximum duration of cross-blocking; after timeout, the cross-blocking resets even if there are high values of harmonics in another “measuring element(s)”. Note that the “measuring element(s)” with high values of harmonics will keep on self-blocking.

## 1.5.2 The principal scheme of the harmonic restraint decision

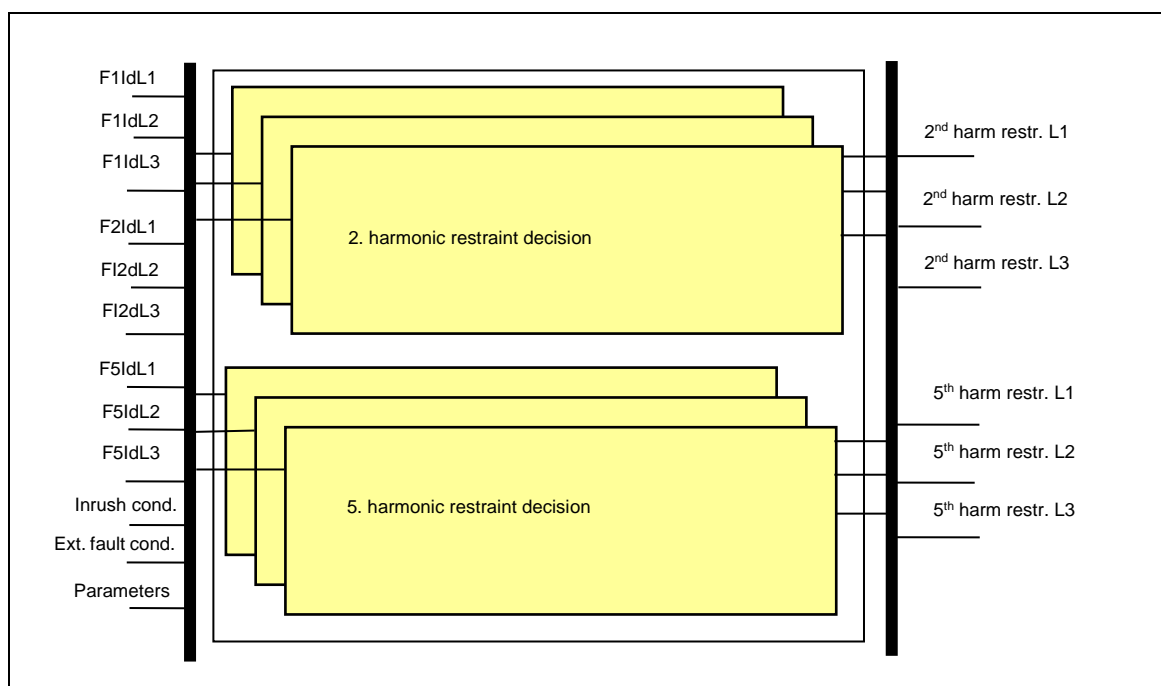


Figure 1-8 Principal scheme of the harmonic restraint decision

The **inputs** are the following:

- The basic harmonic Fourier components of the differential currents
 
$$\begin{bmatrix} F1dL1 \\ F1dL2 \\ F1dL3 \end{bmatrix}$$
- The second harmonic Fourier components of the differential currents
 
$$\begin{bmatrix} F2dL1 \\ F2dL2 \\ F2dL3 \end{bmatrix}$$
- The fifth harmonic Fourier components of the differential currents
 
$$\begin{bmatrix} F5dL1 \\ F5dL2 \\ F5dL3 \end{bmatrix}$$
- Inrush condition detection for 2<sup>nd</sup> harmonic decision
- External fault condition detection for 2<sup>nd</sup> harmonic decision
- Parameter settings for harmonic detection

The outputs of the modules are the status signals for each phase and for second and fifth harmonics separately, indicating the restraint status caused by high harmonic contents.

The **binary output status signals** of the harmonic restraint decision function are listed in Table 1-4.

**Table 1-4 The binary output status signals of the harmonic restraint decision function**

Binary output signals	Signal title	Explanation
Second harmonic restraint signals		
DIF87T_InrushL1_Grl_	Inrush. L1	Restraint in phase L1 caused by high second harmonic content in the differential current during inrush or external fault
DIF87T_InrushL2_Grl_	Inrush L2	Restraint in phase L2 caused by high second harmonic content in the differential current during inrush or external fault
DIF87T_InrushL3_Grl_	Inrush L3	Restraint in phase L3 caused by high second harmonic content in the differential current during inrush or external fault
DIF87T_Inrush_Grl_	Inrush.	Restraint caused by high second harmonic content in any of the differential currents during inrush or external fault
DIF87T_2HBIkL1_Grl_	2nd harm. content L1	There is second harmonic content detected in phase L1.
DIF87T_2HBIkL2_Grl_	2nd harm. content. L2	There is second harmonic content detected in phase L2.
DIF87T_2HBIkL3_Grl_	2nd harm. content. L3	There is second harmonic content detected in phase L3.
Fifth harmonic restraint signals		
DIF87T_5HarmL1_Grl_	5th harm Restr. L1	Restraint in phase L1 caused by high fifth harmonic content in the differential current
DIF87T_5HarmL2_Grl_	5th harm Restr. L2	Restraint in phase L2 caused by high fifth harmonic content in the differential current
DIF87T_5HarmL3_Grl_	5th harm Restr. L3	Restraint in phase L3 caused by high fifth harmonic content in the differential current
DIF87T_5HBIk_Grl_	5th Harm Restr.	Restraint caused by high fifth harmonic content in any of the differential currents
DIF87T_5HBIkL1_Grl_	5th harm. content L1	There is fifth harmonic content detected in phase L1.
DIF87T_5HBIkL2_Grl_	5th harm. content L2	There is fifth harmonic content detected in phase L2.
DIF87T_5HBIkL3_Grl_	5th harm. content L3	There is fifth harmonic content detected in phase L3.

**Integer parameters** of the harmonic restraint decision function are listed in Table 1-5.

**Table 1-5 The integer parameters of the harmonic restraint decision function**

Parameter name	Title	Unit	Min	Max	Step	Default
Parameter of the second harmonic restraint:						
DIF87T_2HRat_IPar_	2nd Harm Ratio	%	5	100	1	15
Parameter of the fifth harmonic restraint:						
DIF87T_5HRat_IPar_	5th Harm Ratio	%	5	100	1	25

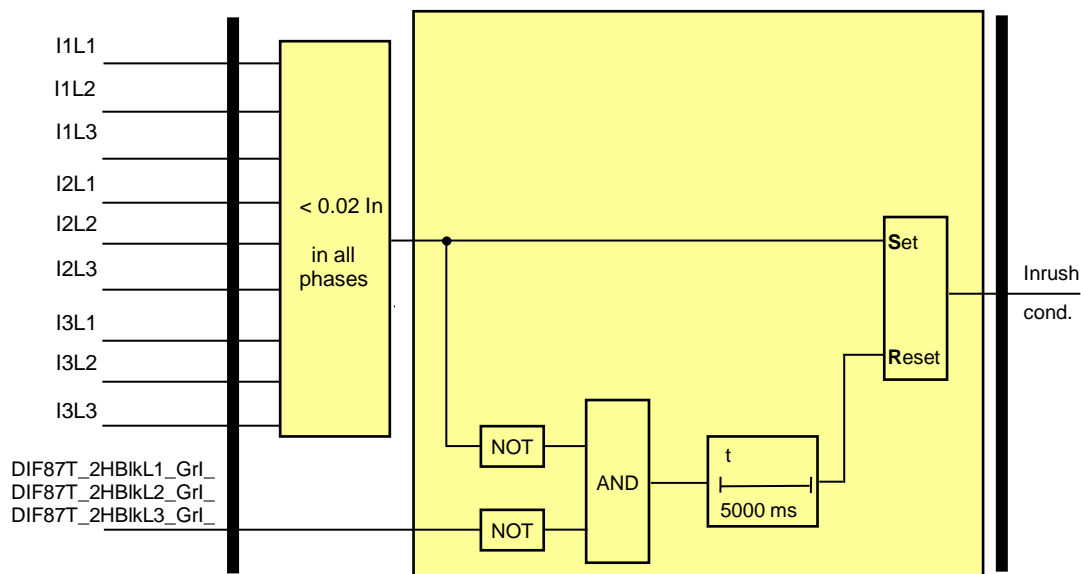
(% related to the 1st harmonic of the differential current)

### 1.5.2.1 Inrush condition for 2<sup>nd</sup> harmonic block

For blocking the differential protection function during inrush, the second harmonic restraint is evaluated if the transformer is detected to be either off or recently switched on. The **Inrush condition** signal indicates this state.

The inrush condition deactivates after a *5 seconds delay (or 4.167 seconds on a 60 Hz system)* if the following two conditions are fulfilled:

- any of the phase currents exceed 2%,
- there are no 2<sup>nd</sup> harmonics detected, see Figure 1-11 and the figure below:



*\*the value is linked to the cycle time of 50 Hz. For 60 Hz applications it becomes lower: 4166.67 ms*

Figure 1-9 Logic scheme of the inrush condition

Note: if there are more branches on a side of the transformer, the phase currents  $I_{xL1}$ ,  $I_{xL2}$ ,  $I_{xL3}$  include both branches.

### 1.5.2.2 External fault condition for 2<sup>nd</sup> harmonic block

The second harmonic restraint is also evaluated for disabling the differential protection function during external faults with CT saturation. The **Ext. fault condition** signal indicates this state. This signal activates when the shifted and compensated currents between the two sides have at least an angle difference of **75 degrees**.

For valid angle measurement, it is required that the involved sides' shifted currents' magnitude is larger than **10%** (of the reference current, which is the transformer rated current).

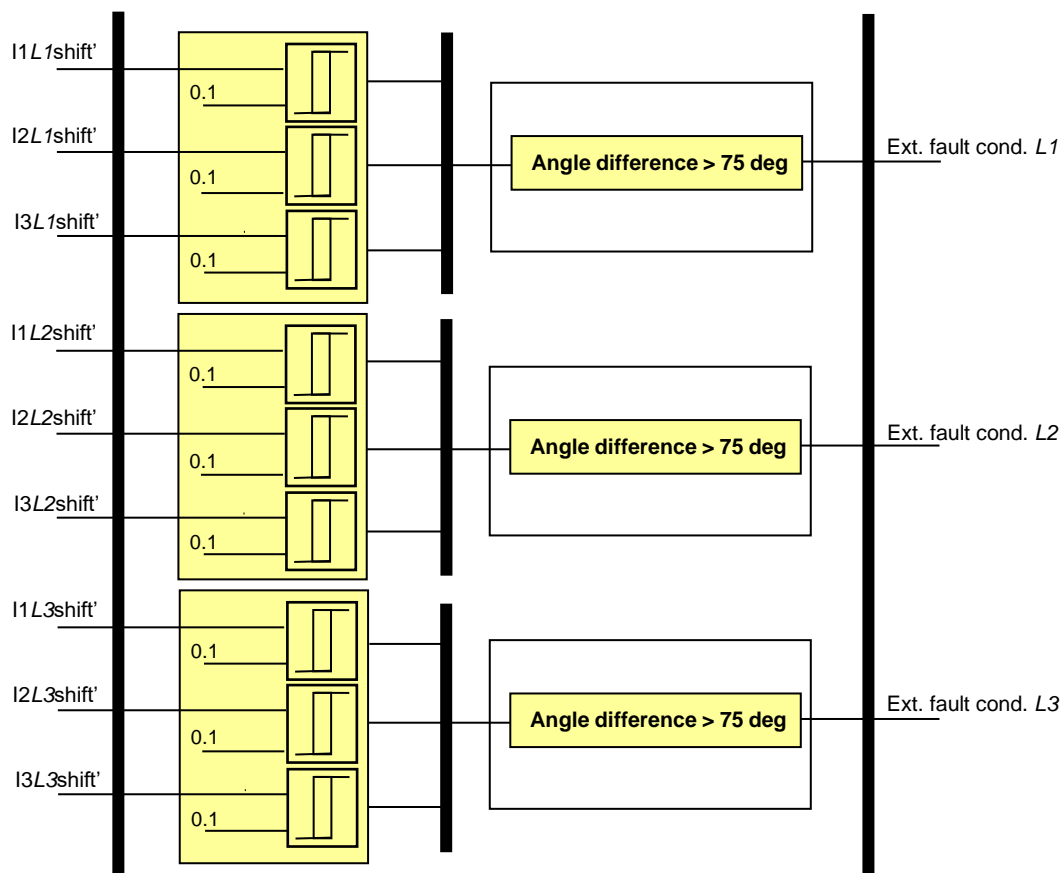
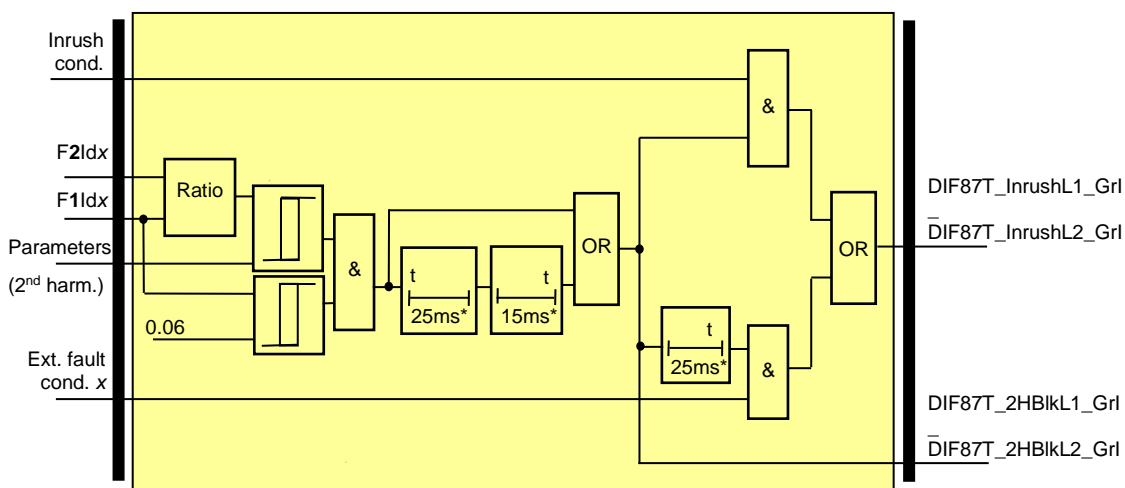


Figure 1-10 Logic scheme of the external fault condition

Note: if there are more branches on a side of the transformer, the shifted phase currents  $I_{xL1shift'}$ ,  $I_{xL2shift'}$ ,  $I_{xL3shift'}$  include both branches.

### 1.5.2.3 2<sup>nd</sup> harmonic blocking scheme

The 2<sup>nd</sup> harmonic restraint function follows the logic below:



\*the values are connected to the cycle time of 50 Hz. For 60 Hz applications these become lower: 20.83 ms and 12.5 ms

Figure 1-11 Logic scheme of the 2<sup>nd</sup> harmonic decision based on inrush or external fault

The logic scheme is repeated for the **second** harmonic restraint decision for all three phases (“measuring elements”) separately (x=L1, L2, L3).

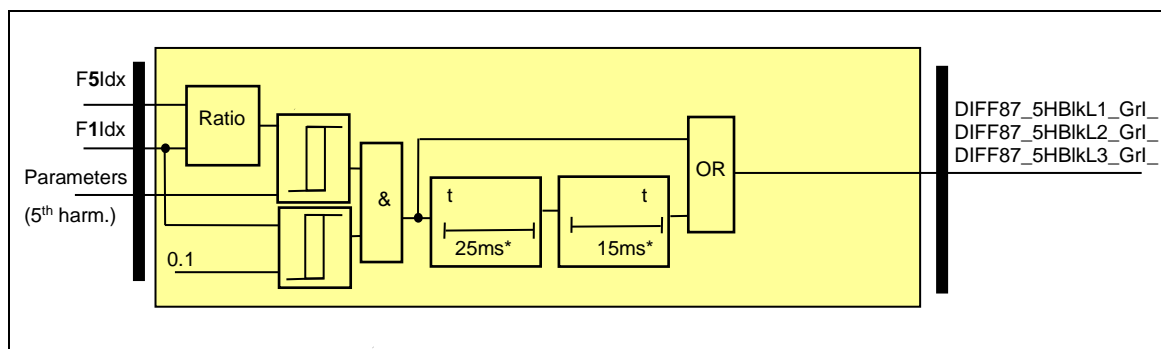
First the ratio of the harmonic and the base harmonic is calculated, and this ratio is compared to the parameter setting (second and fifth separately). In case of high ratio value, the restraint signal is generated immediately, and at the same time a timer is started. If the 25 ms (or 20.83 ms on a 60 Hz system) delay is over, and during the running time the high ratio was continuous, then a drop-off timer is started, which extends the duration of the restraint signal.

The restraint signal is generated if either the inrush condition or the external fault condition is active.

The decisions of the phases are connected in OR gate to result harmonic restraint status signal: DIF87T\_Inrush\_GrI\_ (Inrush). Note that the signal includes both cases where the 2<sup>nd</sup> harmonics are evaluated.

### 1.5.2.4 5<sup>th</sup> harmonic blocking scheme

The 5<sup>th</sup> harmonic restraint function follows the logic below:



\*the values are connected to the cycle time of 50 Hz. For 60 Hz applications these become lower: 20.83 ms and 12.5 ms

Figure 1-12 Logic scheme of the 5<sup>th</sup> harmonic restraint decision

The logic for the **fifth** harmonic restraint decision is almost like the second harmonic decision with the difference that there are no further conditions outside the minimum differential current.

### 1.5.2.5 Cross blocking logic

Depending on the dedicated Boolean parameter setting “Cross Blocking”, there are two modes of operation:

- If the “Cross Blocking” parameter is FALSE (not checked) then the three “measuring elements” operate individually. The internal output signal of the “measuring element” is blocked only if the own differential current contains harmonics (second and/or fifth) above the setting level, indicating inrush current or over-excitation. Other measuring element may generate trip requirement.
- If the “Cross Blocking” parameter is TRUE (checked) then the three blocking any of the “measuring elements” by harmonics (second and/or fifth) above the setting level blocks also the internal output signal of all three “measuring elements”. The function does not generate trip requirement.

The duration of the cross blocking is set by a dedicated parameter “Cross Blocking Limit”. This is the maximum duration of cross-blocking; after timeout, the cross-blocking resets even if there are high values of harmonics in another “measuring element(s)”. Note that the “measuring element(s)” with high values of harmonics will keep on self-blocking.

**Boolean parameter** of the harmonic restraint decision function is shown in Table 1-6:

Table 1-6 The Boolean parameter of the harmonic restraint decision function

Parameter name	Title	Default	Explanation
Harmonic cross blocking			
DIF87T_Cross_BPar_	Cross Blocking	True	The True setting enables cross-blocking for the maximum duration defined by the dedicated timer parameter

**Timer parameter** of the harmonic restraint decision function is shown in Table 1-7.

Table 1-7 The timer parameter of the harmonic restraint decision function

Parameter name	Title	Unit	Min	Max	Step	Default
Duration of the cross-blocking (if it is enabled):						
DIF87T_CrossLimit_TPar_	Cross Blocking Limit	ms	100	60000	1	5000

## 1.6 The current magnitude calculation (Current magnitude)

### 1.6.1 The principle of the current magnitude calculation

The module, which evaluates the differential characteristics, compares the magnitude of the differential currents and those of the restraint currents. For this calculation the current magnitudes are needed. These magnitudes are calculated in this module.

### 1.6.2 The principal scheme of the current magnitude calculation

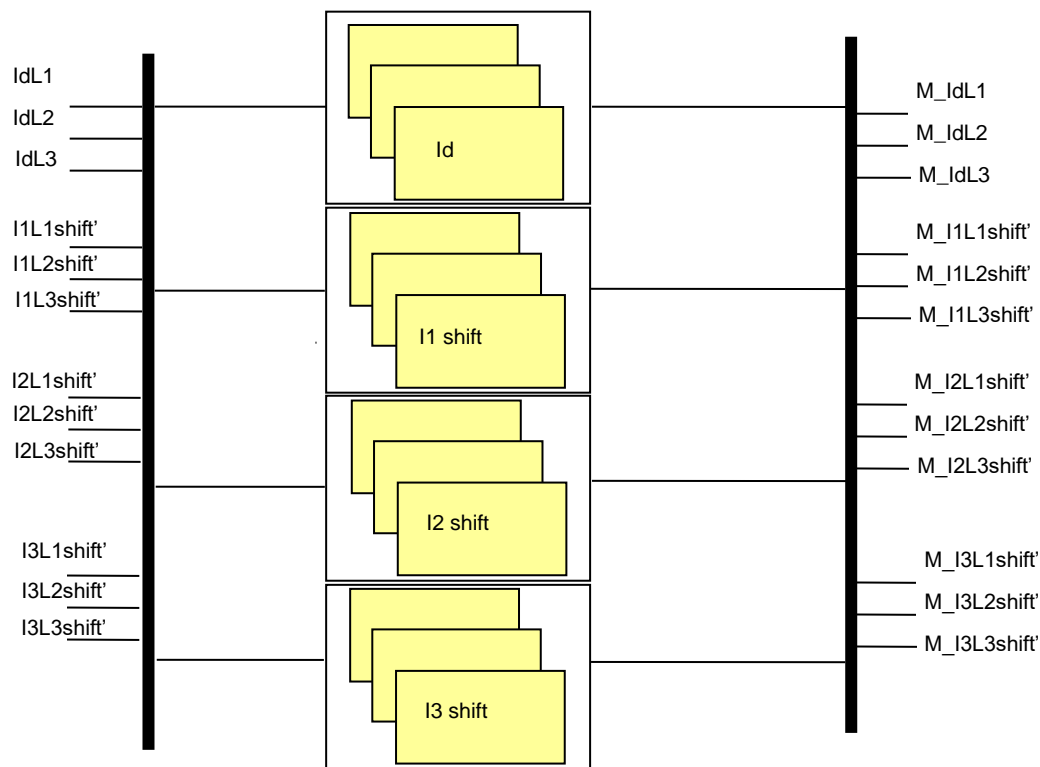


Figure 1-13 Principal scheme of the current magnitude calculation

Note: if there are more branches on a side of the transformer, the shifted phase currents  $I_{xL1shift'}$ ,  $I_{xL2shift'}$ ,  $I_{xL3shift'}$ , and their magnitudes  $M_{IxL1shift'}$ ,  $M_{IxL2shift'}$ ,  $M_{IxL3shift'}$  include both branches.

The **inputs** are the “sampled values” of the phase-shifted currents:

- The differential currents after phase-shift  $\begin{bmatrix} IdL1 \\ IdL2 \\ IdL3 \end{bmatrix}$
- The primary currents after phase-shift  $\begin{bmatrix} I1L1\_1shift' \\ I1L2\_1shift' \\ I1L3\_1shift' \end{bmatrix}$  and  $\begin{bmatrix} I1L1\_2shift' \\ I1L2\_2shift' \\ I1L3\_2shift' \end{bmatrix}$
- The secondary currents after phase-shift  $\begin{bmatrix} I2L1\_1shift' \\ I2L2\_1shift' \\ I2L3\_1shift' \end{bmatrix}$  and  $\begin{bmatrix} I2L1\_2shift' \\ I2L2\_2shift' \\ I2L3\_2shift' \end{bmatrix}$

- The tertiary currents after phase-shift (in DIF87T3 version only)  $\begin{bmatrix} I_{3L1\_1shift'} \\ I_{3L2\_1shift'} \\ I_{3L3\_1shift'} \end{bmatrix}$  and  $\begin{bmatrix} I_{3L1\_2shift'} \\ I_{3L2\_2shift'} \\ I_{3L3\_2shift'} \end{bmatrix}$

The **outputs** are the magnitude of the calculated currents

- The magnitudes of the differential currents after phase-shift  $\begin{bmatrix} M_{IdL1} \\ M_{IdL2} \\ M_{IdL3} \end{bmatrix}$
- The magnitudes of the primary currents after phase-shift  $\begin{bmatrix} M_{I1L1\_1shift'} \\ M_{I1L2\_1shift'} \\ M_{I1L3\_1shift'} \end{bmatrix}$  and  $\begin{bmatrix} M_{I1L1\_2shift'} \\ M_{I1L2\_2shift'} \\ M_{I1L3\_2shift'} \end{bmatrix}$
- The magnitudes of the secondary currents after phase-shift  $\begin{bmatrix} M_{I2L1\_1shift'} \\ M_{I2L2\_1shift'} \\ M_{I2L3\_1shift'} \end{bmatrix}$  and  $\begin{bmatrix} M_{I2L1\_2shift'} \\ M_{I2L2\_2shift'} \\ M_{I2L3\_2shift'} \end{bmatrix}$
- The magnitudes of the tertiary currents after phase-shift (in DIF87T3 version only)  $\begin{bmatrix} M_{I3L1\_1shift'} \\ M_{I3L2\_1shift'} \\ M_{I3L3\_1shift'} \end{bmatrix}$  and  $\begin{bmatrix} M_{I3L1\_2shift'} \\ M_{I3L2\_2shift'} \\ M_{I3L3\_2shift'} \end{bmatrix}$

## 1.7 The evaluation of the differential characteristics (Differential characteristics)

### 1.7.1 The principle of the differential characteristics

This module evaluates the differential characteristics. It compares the magnitude of the differential currents and those of the restraint currents. The restraint (bias) currents are calculated using the following formulas:

$$M\_IbiasL1 = \frac{M\_I1L1\_1shift' + M\_I1L1\_2shift' + M\_I2L1\_1shift' + M\_I2L1\_2shift' + M\_I3L1\_1shift' + M\_I3L1\_2shift'}{2}$$

$$M\_IbiasL2 = \frac{M\_I1L2\_1shift' + M\_I1L2\_2shift' + M\_I2L2\_1shift' + M\_I2L2\_2shift' + M\_I3L2\_1shift' + M\_I3L2\_2shift'}{2}$$

$$M\_IbiasL3 = \frac{M\_I1L3\_1shift' + M\_I1L3\_2shift' + M\_I2L3\_1shift' + M\_I2L3\_2shift' + M\_I3L3\_1shift' + M\_I3L3\_2shift'}{2}$$

Based on these values (denoted generally as “Ibias”) and the values of the differential current magnitudes (denoted generally as “Idiff”) the differential protection characteristics are shown on Figure 1-14.

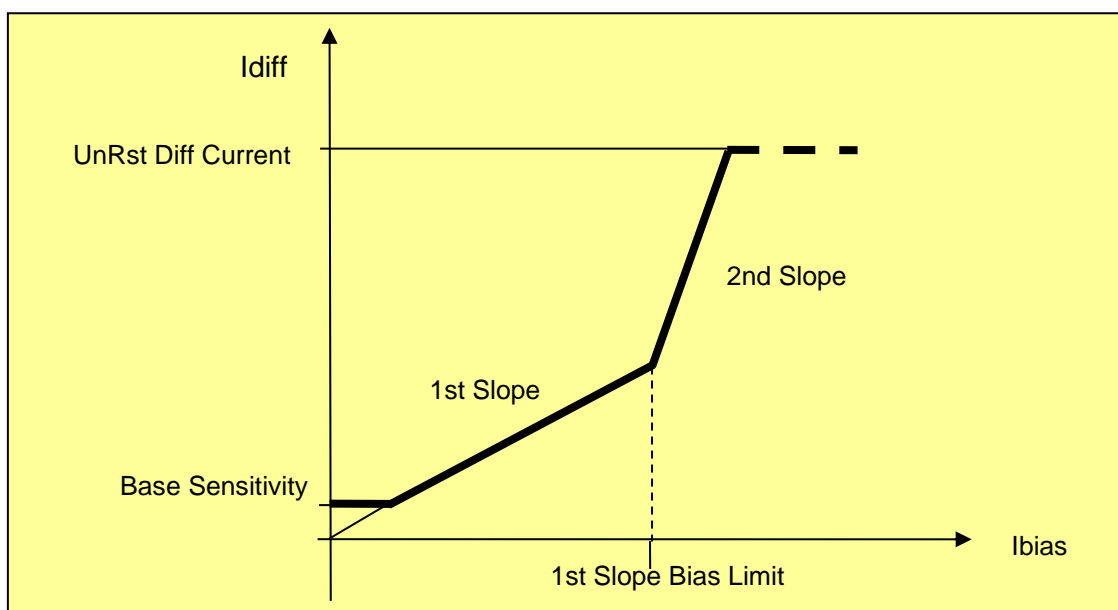


Figure 1-14 The differential protection characteristics

Additionally separate status-signals are set to “true” value if the differential currents in the individual phases are above the limit, set by parameter (see “Unrestrained differential function”).

## Integer parameters

Table 1-8 The integer parameters of the differential protection characteristics

Parameter name	Title	Unit	Min	Max	Step	Default
Base sensitivity:						
DIF87T_f1_IPar_	Base Sensitivity	%*	10	75	1	20
Slope of the second section of the characteristics:						
DIF87T_f2_IPar_	1st Slope	%**	10	100	1	20
Position of the third section of the characteristics:						
DIF87T_f3_IPar_	1st Slope Bias Limit	%*	100	2000	1	200
Slope of the third section of the characteristics:						
DIF87T_Slope2_IPar_	2nd Slope	%**	20	200	1	200
Unrestrained differential protection current level:						
DIF87T_HCurr_IPar_	Unrestrained Diff Current	%*	300	3000	1	800
* % related to the reference current						
** % related to the bias current						

Table 1-9 The binary output status signals of the differential protection characteristics

Binary output signals	Signal title	Explanation
Differential characteristics		
DIF87T_L1St_Grl_i	Start L1	This internal status is true if the differential current in measuring element L1 at the restraint current is above the characteristic lines
DIF87T_L2St_Grl_i	Start L2	This internal status is true if the differential current in measuring element L2 at the restraint current is above the characteristic lines
DIF87T_L3St_Grl_i	Start L3	This internal status is true if the differential current in measuring element L3 at the restraint current is above the characteristic lines

### 1.7.2 The unrestrained differential function

If the calculated differential current is very high then the differential characteristic is not considered anymore, because separate status-signals for the phases are set to “true” value if the differential currents in the individual phases are above the limit, defined by parameter setting.

The decisions of the phases are connected in OR gate to result the general start status signal.

If an unrestrained start status signal occurs in one phase, it will generate restrained start signal in the same phase and activates General start – unrestrained and General start output signals in addition.

Integer parameter of the unrestrained differential function is shown in Table 1-10.

Table 1-10 The integer parameter of the unrestrained differential protection characteristics

Parameter name	Title	Unit	Min	Max	Step	Default
High-speed differential protection current level:						
DIF87T_HCurr_IPar_	Unrestrained Diff Current	%*	800	2500	1	800
* % related to the reference current						

Table 1-11 The binary output status signals of the unrestrained differential protection characteristics

Binary output signals	Signal title	Explanation
Unrestrained decision		
DIF87T_UnRL1St_GrI_i	Start L1 - unrestrained	This internal status is true if the differential current in measuring element L1 is above the high current setting
DIF87T_UnRL2St_GrI_i	Start L2 - unrestrained	This internal status is true if the differential current in measuring element L2 is above the high current setting
DIF87T_UnRL3St_GrI_i	Start L3 - unrestrained	This internal status is true if the differential current in measuring element L3 is above the high current setting

### 1.7.3 The principal scheme of the evaluation of differential characteristics

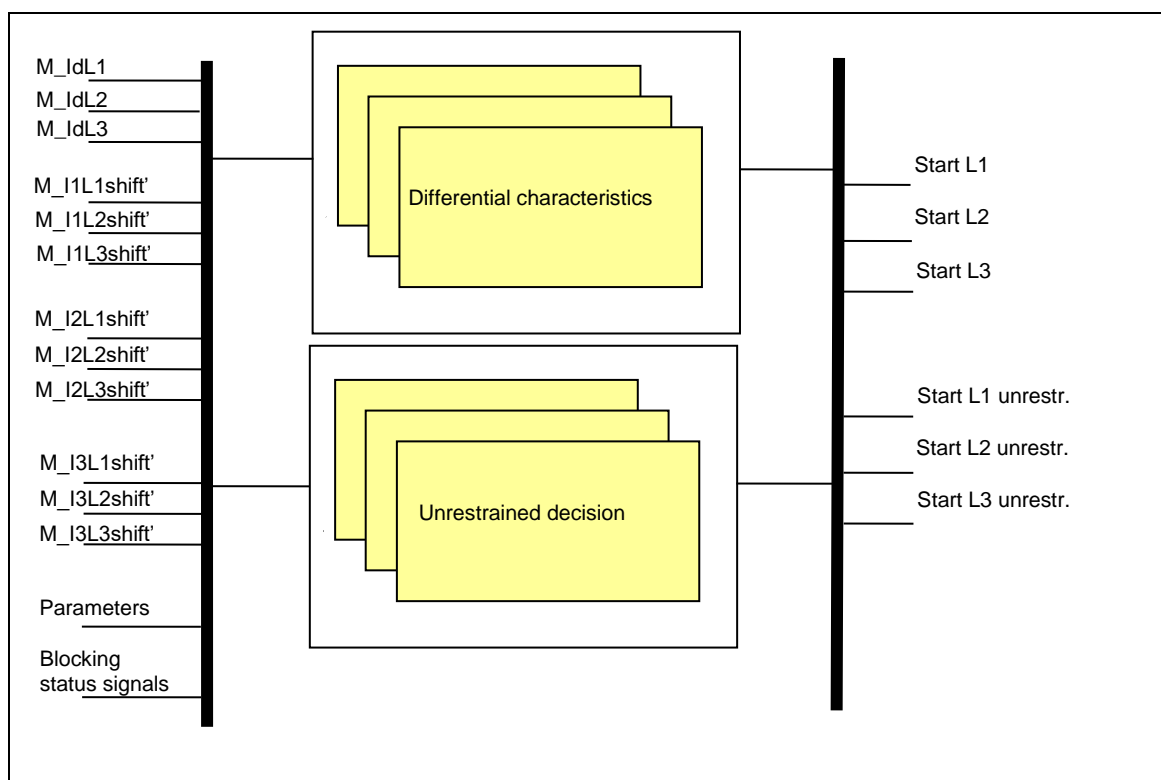


Figure 1-15 The Scheme of evaluation of differential protection characteristics.

Note: if there are more branches on a side of the transformer, the magnitudes of shifted phase currents  $M_{IxL1shift'}$ ,  $M_{IxL2shift'}$ ,  $M_{IxL3shift'}$  include both branches.

The **inputs** are the magnitude of the calculated currents:

- The magnitudes of the differential currents after phase-shift  $\begin{bmatrix} M_{IdL1} \\ M_{IdL2} \\ M_{IdL3} \end{bmatrix}$
- The magnitudes of the primary currents after phase-shift  $\begin{bmatrix} M_{I1L1\_1shift'} \\ M_{I1L2\_1shift'} \\ M_{I1L3\_1shift'} \end{bmatrix}$  and  $\begin{bmatrix} M_{I1L1\_2shift'} \\ M_{I1L2\_2shift'} \\ M_{I1L3\_2shift'} \end{bmatrix}$

- The magnitudes of the secondary currents after phase-shift  $\begin{bmatrix} M_{I2L1\_1shift'} \\ M_{I2L2\_1shift'} \\ M_{I2L3\_1shift'} \end{bmatrix}$  and  $\begin{bmatrix} M_{I2L1\_2shift'} \\ M_{I2L2\_2shift'} \\ M_{I2L3\_2shift'} \end{bmatrix}$
- The magnitudes of the tertiary currents after phase-shift (in DIF87T3 version only)  $\begin{bmatrix} M_{I3L1\_1shift'} \\ M_{I3L2\_1shift'} \\ M_{I3L3\_1shift'} \end{bmatrix}$  and  $\begin{bmatrix} M_{I3L1\_2shift'} \\ M_{I3L2\_2shift'} \\ M_{I3L3\_2shift'} \end{bmatrix}$

Table 1-12 The binary output status signals of the restrained and unrestrained differential protection characteristics

Binary output signals	Signal title	Explanation
Differential characteristics		
DIF87T_L1St_Grl_	Start L1	This status is true if the differential current in measuring element L1 at the restraint current is above the characteristic lines
DIF87T_L2St_Grl_	Start L2	This status is true if the differential current in measuring element L2 at the restraint current is above the characteristic lines
DIF87T_L3St_Grl_	Start L3	This status is true if the differential current in measuring element L3 at the restraint current is above the characteristic lines
Unrestrained decision		
DIF87T_UnRL1St_Grl_	Start L1 - unrestrained	This status is true if the differential current in measuring element L1 is above the high current setting
DIF87T_UnRL2St_Grl_	Start L2 - unrestrained	This status is true if the differential current in p measuring element L2 is above the high current setting
DIF87T_UnRL3St_Grl_	Start L3 - unrestrained	This status is true if the differential current in measuring element L3 is above the high current setting

## 1.8 The decision logic (Decision logic)

### 1.8.1 The principle of the decision logic

The decision logic combines the following binary signals:

- Start signals of the differential characteristic module
- Unrestrained start signals of the differential characteristic module
- Harmonic restraint signals of the 2. harmonic restraint decision
- Harmonic restraint signals of the 5. harmonic restraint decision
- Disabling status signal defined by the user, using graphic equation editor DIF87T\_BIk\_GrO\_

### 1.8.2 The principal scheme of the decision logic

The inputs are the calculated status signals of the **Differential characteristics** and **Unrestrained differential** modules, those of the **2.harmonic restraint** and **5.harmonic restraint modules** and binary input parameters.

Table 1-13 The binary input status signals of the decision logic

Binary input signals	Signal title	Explanation
Differential characteristics		
DIF87T_L1St_Grl_i	Start L1	This internal status is true if the differential current in measuring element L1 at the restraint current is above the characteristic lines
DIF87T_L2St_Grl_i	Start L2	This internal status is true if the differential current in measuring element L2 at the restraint current is above the characteristic lines
DIF87T_L3St_Grl_i	Start L3	This internal status is true if the differential current in measuring element e L3 at the restraint current is above the characteristic lines
Unrestrained decision		
DIF87T_UnRL1St_Grl_i	Start L1 - unrestrained	This internal status is true if the differential current in measuring element e L1 is above the high current setting
DIF87T_UnRL2St_Grl_i	Start L2 - unrestrained	This internal status is true if the differential current in measuring element L2 is above the high current setting
DIF87T_UnRL3St_Grl_i	Start L3 - unrestrained	This internal status is true if the differential current in measuring element L3 is above the high current setting
Second harmonic restraint signals		
DIF87T_InrushL1_Grl_	Inrush L1	Restraint in measuring element L1 caused by high second harmonic content in the differential current while either condition (inrush or external fault) is active
DIF87T_InrushL2_Grl_	Inrush L2	Restraint in measuring element L2 caused by high second harmonic content in the differential current while either condition (inrush or external fault) is active
DIF87T_InrushL3_Grl_	Inrush L3	Restraint in measuring element L3 caused by high second harmonic content in the differential current while either condition (inrush or external fault) is active
Fifth harmonic restraint signals		

DIF87T_5HBikL1_GrI –	5th Harmonic Restraint L1	Restraint in measuring element L1 caused by high fifth harmonic content in the differential current
DIF87T_5HBikL2_GrI –	5th Harmonic Restraint L2	Restraint in measuring element L2 caused by high fifth harmonic content in the differential current
DIF87T_5HBikL3_GrI –	5th Harmonic Restraint L3	Restraint in measuring element L3 caused by high fifth harmonic content in the differential current

### Blocking input signal

The differential protection function has a binary input signal, which serves disabling the function. **The conditions of disabling are defined by the user, applying the graphic equation editor for the signal DIF87T\_Blk\_GrO.**

Table 1-14 The blocking input status signal of the decision logic

Binary input signal	Explanation
DIF87T_Blk_GrO_	Output status of a graphic equation to disable the differential protection function. Only the measurements work and are displayed.

Table 1-15 The binary output status signals of the differential protection characteristics

Binary output signals	Signal title	Explanation
Differential characteristics		
DIF87T_L1St_Grl_	Start L1	This status is true if the differential current in measuring element L1 at the restraint current is above the characteristic lines and the function is not blocked
DIF87T_L2St_Grl_	Start L2	This status is true if the differential current in measuring element L2 at the restraint current is above the characteristic lines and the function is not blocked
DIF87T_L3St_Grl_	Start L3	This status is true if the differential current in measuring element L3 at the restraint current is above the characteristic lines and the function is not blocked
DIF87T_GenSt_Grl_	General Start	This status is true if the differential current in any measuring element at the restraint current is above the restrained characteristic lines and the function is not blocked
Unrestrained decision		
DIF87T_UnrL1St_Grl_	Start L1 - unrestrained	This status is true if the differential current in measuring element e L1 is above the high current setting and the function is not blocked
DIF87T_UnrL2St_Grl_	Start L2 - unrestrained	This status is true if the differential current in measuring element L2 is above the high current setting and the function is not blocked
DIF87T_UnrL3St_Grl_	Start L3 - unrestrained	This status is true if the differential current in measuring element L3 is above the high current setting and the function is not blocked
DIF87T_UnrGenSt_Grl_	General Start - unrestrained	This status is true if the differential current in any measuring elements is above the high current setting and the function is not blocked
Harmonic blocking		
DIF87T_Inrush_Grl_	Inrush	Restraint caused by high second harmonic content during inrush or external fault
DIF87T_5HBik_Grl_	5th Harmonic content	Restraint caused by high fifth harmonic content in any of the differential currents

The **GenSt** and **UnrGenSt** signals are processed by the trip logic of the device in the so-called Fast Logic (Fast Equations). These can be checked with the EuroCAP software in the .epc configuration file of the device in the Software Configuration → Equations → Fast Logic.

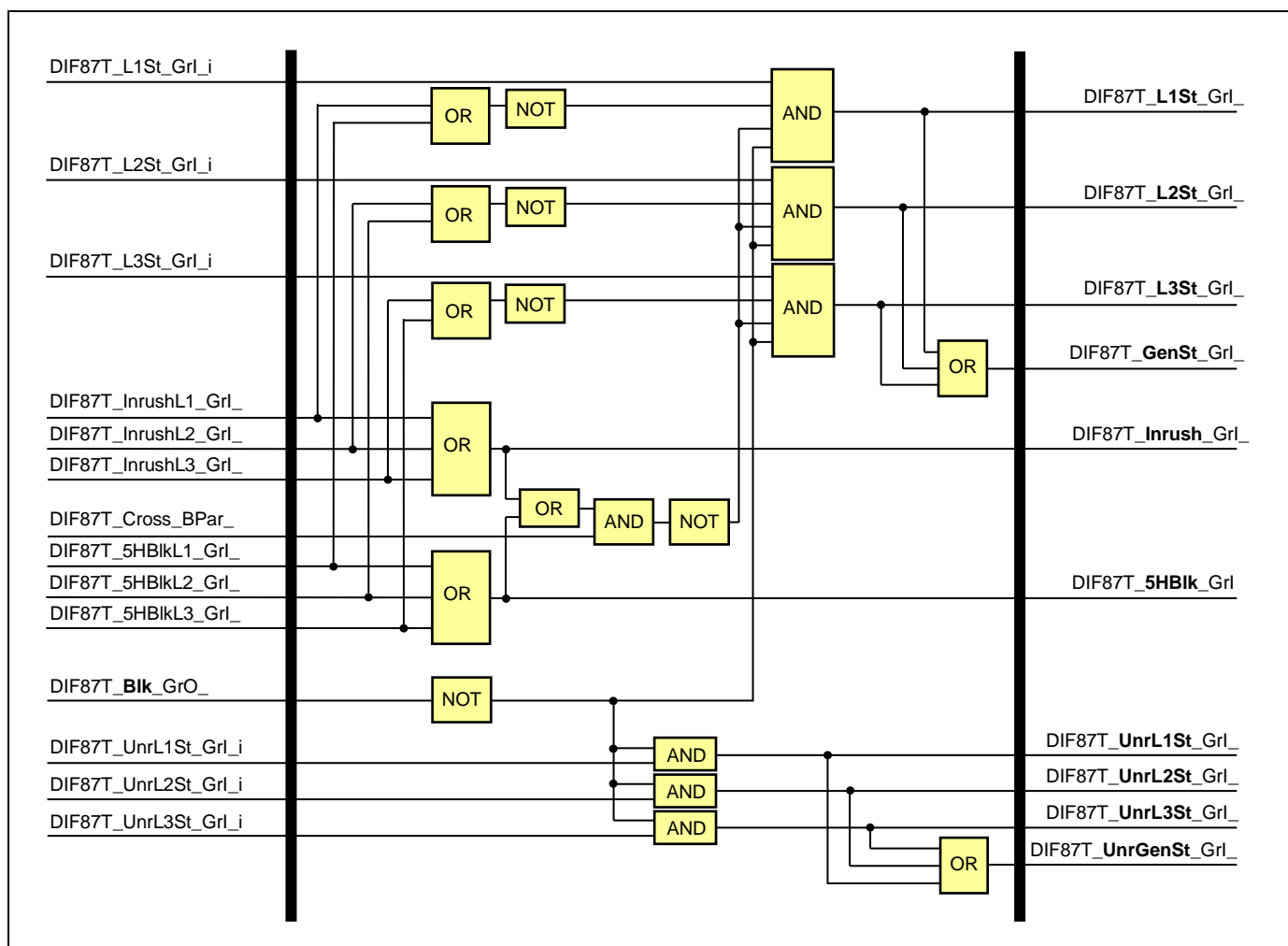


Figure 1-16 The decision logic schema of the differential protection function

### 1.8.3 Special measures for CT saturation during external faults

Basically, the 2<sup>nd</sup> slope of the differential characteristic is set to cover the errors caused by saturated CT, however, there are further methods implemented to stabilize the differential protection function even more in case of external faults (while keeping it sensitive for internal ones) with saturated CT. This chapter explains these two special functionalities and their conditions to activate.

- **Adaptive characteristics**

In case of external faults, the differential currents appear a little while after the CT has become saturated. In case of internal faults, these two events happen at the same time. Based on this principle, the differential protection function switches to a less sensitive characteristic if such sign of an external fault is detected.

*The condition: the measured Bias current in any phase is above  $1.25I_n$  for at least 3 milliseconds while the differential current is less than the set Base Sensitivity. This condition falls off if the Bias current drops below  $0.8I_n$ .*

*The characteristic: 1st slope 50% and 2nd slope 200%*

- **Usage of the 2<sup>nd</sup> harmonic restraint**

The second harmonic restraint decision is enabled if there is at least 75 degrees difference between the measured currents after vector shift compensation (indicating an external fault), see Chapter 1.5.

## 2 Differential protection function overview

The graphic appearance of the function blocks of the differential protection function for transformers of two or three voltage levels are shown on Figure 2-1. These blocks show all binary input and output status signals, which are applicable in the graphic equation editor.

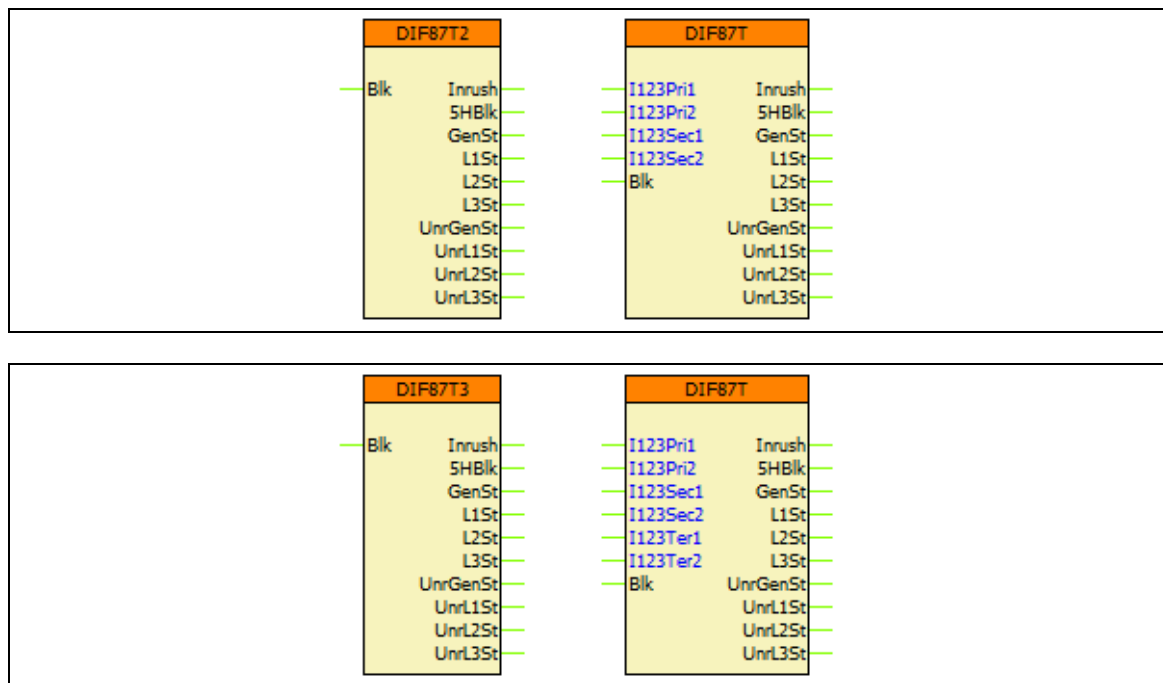


Figure 2-1 Graphic appearance of the function blocks of the differential protection function

## 2.1 Settings

### 2.1.1 Parameters

Table 2-1 Parameters of the differential protection function

TITLE	DIM	RANGE	STEP	DEFAULT	EXPLANATION
Operation	-	Off, On	-	Off	Enabling the differential protection function
<i>Parameters related to the protected transformer</i>					
Pri-Sec Vector Group	-	Dy1,Dy5,Dy7,Dy11, Dd0,Dd6,Dz0,Dz2, Dz4,Dz6,Dz8,Dz10, Yy0,Yy6,Yd1,Yd5, Yd7,Yd11	-	Dd0	Connection group of the transformer coils in primary-secondary relation
Pri-Ter Vector Group*	-	Dy1,Dy5,Dy7,Dy11, Dd0,Dd6,Dz0,Dz2, Dz4,Dz6,Dz8,Dz10, Yy0,Yy6,Yd1,Yd5, Yd7,Yd11	-	Dd0	Connection group of the transformer coils in primary-tertiary relation
Primary starpoint	-	Isolated, Earthed	-	Isolated	Starpoint grounding on primary side.
Secondary starpoint	-	Isolated, Earthed	-	Isolated	Starpoint grounding on secondary side.
Tertiary starpoint	-	Isolated, Earthed	-	Isolated	Starpoint grounding on tertiary side.
Neutral grounding transf.	-	FALSE, TRUE	-	FALSE	Check this when a neutral grounding transformer is applied in the protected zone on the delta side (see Chapter 1.3.4)
Sn	MVA	1.00 – 1000.00	0.01	125.00	Rated apparent power of the transformer
Un Primary	kV	1.00 – 1000.00	0.01	132.00	Rated voltage of the transformer primary side
Un Secondary	kV	1.00 – 1000.00	0.01	22.00	Rated voltage of the transformer secondary side
Un Tertiary	kV	1.00 – 1000.00	0.01	11.50	Rated voltage of the transformer tertiary side
<i>Parameters related to the harmonic restraint</i>					
Cross Blocking	-	FALSE, TRUE	-	FALSE	When selected, the harmonic restraint blocks all phases instead of only the affected ones (see Chapter 1.5.2)
2nd Harm Ratio	% (Idiff)	5 – 100	1	15	Second harmonic restraint ratio related to the <i>basic harmonic of the differential current</i>
5th Harm Ratio	% (Idiff)	5 – 100	1	15	Fifth harmonic restraint ratio related to the <i>basic harmonic of the differential current</i>
Cross Blocking Limit	msec	100 – 60000	1	5000	After expiration the phases that still have high harmonic content will remain blocked, the others are released

TITLE	DIM	RANGE	STEP	DEFAULT	EXPLANATION
<i>Parameters related to the differential characteristic</i>					
Base Sensitivity	% (In)	10 – 75	1	20	Base sensitivity - 1st section of the characteristic curve related to the <i>nominal current of the transformer</i>
1st Slope	% (Ibias)	10 – 50	1	20	1st Slope - 2nd section of the characteristic curve related to the <i>bias current</i>
1st Slope Bias Limit	% (In)	200 – 2000	1	200	Bias current limit of the 1st slope (2nd section) of the characteristic curve related to the <i>nominal current of the transformer</i>
2nd Slope	% (Ibias)	30 – 200	1	200	2nd Slope - 3rd section of the characteristic curve related to the <i>bias current</i>
Unrestrained Diff Current	% (In)	800 – 2500	1	800	Unrestrained differential current - 4th section of the characteristic curve related to the <i>nominal current of the transformer</i>

\* If the connection of the primary winding in primary-secondary and primary tertiary relation is selected in contradiction, then the protection function is automatically disabled, and the function (and the device itself) generates a warning signal.

### 2.1.2 Characteristics

The function uses a 2-slope characteristic with unrestrained section, see Figure 2-2.

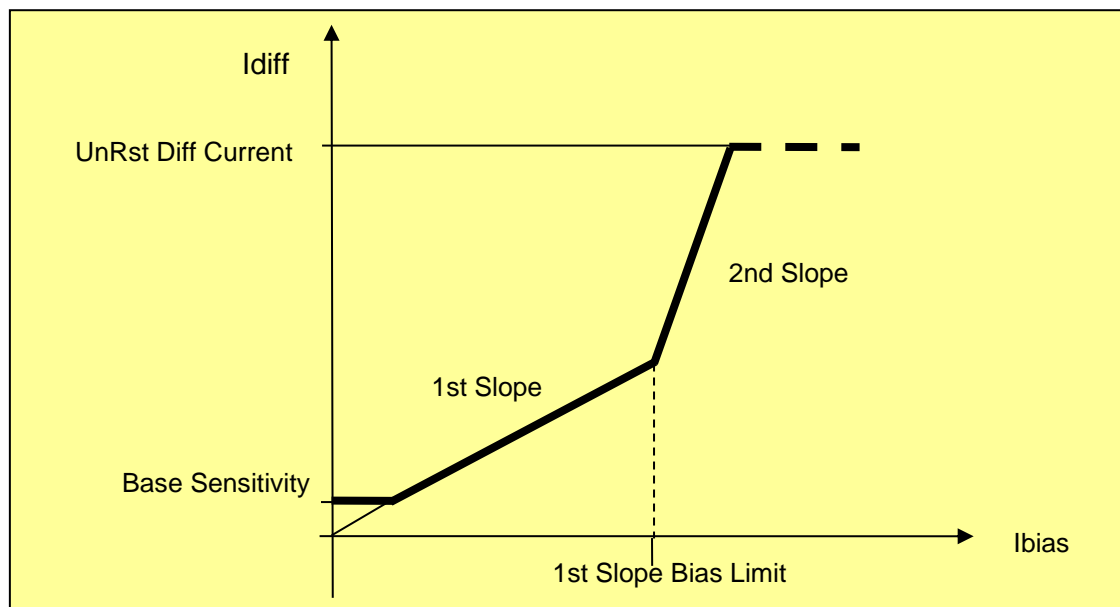


Figure 2-2 The differential protection characteristics

## 2.2 Function I/O

This section describes briefly the analogue and digital inputs and outputs of the function block.

### 2.2.1 Analogue inputs

The function uses the sampled values of the three phase currents of each side, allowing 2x3 phase currents to be connected for breaker-and-a-half topologies.

#### Graphic Analogue inputs (*only from firmware version 2.10.2.3010 and up*)

The sources of the analogue inputs are defined by the user, applying the graphic equation editor (*Logic Editor*). Parts written in **bold** are seen on the left side of the function block in the Logic editor.

The function uses the following analogue signals as inputs:

**Table 2-2 Analogue input signal of the negative sequence overcurrent protection function**

ANALOGUE INPUT SIGNAL	SIGNAL TITLE	EXPLANATION
DIF87T_I123Pri1_AnIn_	3phase current – Primary1	Input for 3-phase currents for the primary side
DIF87T_I123Pri2_AnIn_	3phase current – Primary2	Input for 3-phase currents for the primary side (2 <sup>nd</sup> group for breaker-and-a-half)
DIF87T_I123Sec1_AnIn_	3phase current – Secondary1	Input for 3-phase currents for the secondary side
DIF87T_I123Sec2_AnIn_	3phase current – Secondary2	Input for 3-phase currents for the secondary side (2 <sup>nd</sup> group for breaker-and-a-half)
DIF87T_I123Ter1_AnIn_	3phase current – Tertiary1	Input for 3-phase currents for the tertiary side
DIF87T_I123Ter2_AnIn_	3phase current – Tertiary2	Input for 3-phase currents for the tertiary side (2 <sup>nd</sup> group for breaker-and-a-half)

The applied analogue connectors must be identical to the analogue input type (i.e. current to current input etc.), Invalid connections are not allowed.

### 2.2.2 Analogue outputs (measurements)

The measured values of the differential protection function are listed in the table below.

**Table 2-3 The measured analogue values of the differential protection function**

MEASURED VALUE	DIMENSION	EXPLANATION
Differential current L1	In %	The calculated differential current in measuring element L1 (after vector group compensation)
Differential current L2	In %	The calculated differential current in measuring element L2 (after vector group compensation)
Differential current L3	In %	The calculated differential current in measuring element L3 (after vector group compensation)
Bias current L1	In %	The calculated restraint current in measuring element L1 (after vector group compensation)
Bias current L2	In %	The calculated restraint current in measuring element L2 (after vector group compensation)
Bias current L3	In %	The calculated restraint current in measuring element L3 (after vector group compensation)

Remark: The evaluated basic harmonic values of the measured input phase currents (without vector group compensation) help the commissioning of the differential protection function. These evaluations however are performed by an independent software measuring module, so this chapter excludes the description of these measurements.

### 2.2.3 Binary input signals (graphed output statuses)

The conditions of the inputs are defined by the user, applying the graphic equation editor (logic editor). The part written in **bold** is seen on the function block in the logic editor.

Table 2-4 The binary input signal of the differential protection function

BINARY INPUT SIGNAL	EXPLANATION
DIF87T_ <b>Bik</b> _GrO_	Output status of a graphic equation defined by the user to disable the differential protection function. Only the measurements work and are displayed.

### 2.2.4 Binary output signals (graphed input statuses)

The binary output status signals of the differential protection function. **Parts** written in **bold** are seen on the function block in the logic editor.

Table 2-5 The binary output status signals of the differential protection function

BINARY OUTPUT SIGNAL	SIGNAL TITLE	EXPLANATION
DIF87T_InrushL1_Grl_	Inrush. L1	Restraint in phase L1 caused by high second harmonic content in the differential current during inrush or external fault
DIF87T_InrushL2_Grl_	Inrush L2	Restraint in phase L2 caused by high second harmonic content in the differential current during inrush or external fault
DIF87T_InrushL3_Grl_	Inrush L3	Restraint in phase L3 caused by high second harmonic content in the differential current during inrush or external fault
DIF87T_ <b>Inrush</b> _Grl_	Inrush	Restraint caused by high second harmonic content in any of the differential currents during inrush or external fault
DIF87T_2HBikL1_Grl_	2nd harm. content L1	There is second harmonic content detected in phase L1.
DIF87T_2HBikL2_Grl_	2nd harm. content. L2	There is second harmonic content detected in phase L2.
DIF87T_2HBikL3_Grl_	2nd harm. content. L3	There is second harmonic content detected in phase L3.
DIF87T_5HarmL1_Grl_	5th harm Restr. L1	Restraint in phase L1 caused by high fifth harmonic content in the differential current
DIF87T_5HarmL2_Grl_	5th harm Restr. L2	Restraint in phase L2 caused by high fifth harmonic content in the differential current
DIF87T_5HarmL3_Grl_	5th harm Restr. L3	Restraint in phase L3 caused by high fifth harmonic content in the differential current
DIF87T_ <b>5HBik</b> _Grl_	5th Harmonic content	Restraint caused by high fifth harmonic content in any of the differential currents
DIF87T_5HBikL1_Grl_	5th harm. content L1	There is fifth harmonic content detected in phase L1.
DIF87T_5HBikL2_Grl_	5th harm. content L2	There is fifth harmonic content detected in phase L2.
DIF87T_5HBikL3_Grl_	5th harm. content L3	There is fifth harmonic content detected in phase L3.
DIF87T_ <b>GenSt</b> _Grl_	General Start	General start of the restrained differential protection function
DIF87T_ <b>L1St</b> _Grl_	Start L1	Start of the restrained differential protection function in measuring element L1 (after vector group compensation)
DIF87T_ <b>L2St</b> _Grl_	Start L2	Start of the restrained differential protection function in measuring element L2 (after vector group compensation)

DIF87T_L3St_Grl_	Start L3	Start of the restrained differential protection function in measuring element L3 (after vector group compensation)
DIF87T_UnRGenSt_Grl_	General Start - unrestrained	General start of the unrestrained differential protection function
DIF87T_UnRL1St_Grl_	Start L1 - unrestrained	Start of the unrestrained differential protection function in measuring element L1 (after vector group compensation)
DIF87T_UnRL2St_Grl_	Start L2 - unrestrained	Start of the unrestrained differential protection function in measuring element L2 (after vector group compensation)
DIF87T_UnRL3St_Grl_	Start L3 - unrestrained	Start of the unrestrained differential protection function in measuring element L3 (after vector group compensation)

### 2.2.5 On-line data

Visible values on the on-line data page:

**Table 2-6 On-line data of the differential protection function**

SIGNAL TITLE	DIMENSION	EXPLANATION
Differential current L1	In %	The calculated differential current in measuring element L1 (after vector group compensation)
Differential current L2	In %	The calculated differential current in measuring element L2 (after vector group compensation)
Differential current L3	In %	The calculated differential current in measuring element L3 (after vector group compensation)
Bias current L1	In %	The calculated restraint current in measuring element L1 (after vector group compensation)
Bias current L2	In %	The calculated restraint current in measuring element L2 (after vector group compensation)
Bias current L3	In %	The calculated restraint current in measuring element L3 (after vector group compensation)
Start L1	-	Start of the restrained differential protection function in measuring element L1 (after vector group compensation)
Start L2	-	Start of the restrained differential protection function in measuring element L2 (after vector group compensation)
Start L3	-	Start of the restrained differential protection function in measuring element L3 (after vector group compensation)
General Start	-	General start of the restrained differential protection function
Start L1 - unrestrained	-	Start of the unrestrained differential protection function in measuring element L1 (after vector group compensation)
Start L2 - unrestrained	-	Start of the unrestrained differential protection function in measuring element L2 (after vector group compensation)
Start L3 - unrestrained	-	Start of the unrestrained differential protection function in measuring element L3 (after vector group compensation)
General Start - unrestrained	-	General start of the unrestrained differential protection function
2nd harmonic content L1	-	There is second harmonic content detected in phase L1.
2nd harmonic content L2	-	There is second harmonic content detected in phase L2.
2nd harmonic content L3	-	There is second harmonic content detected in phase L3.
Inrush L1	-	Restraint caused by high second harmonic content in L1 differential current during inrush or external fault
Inrush L2	-	Restraint caused by high second harmonic content in L2 differential current during inrush or external fault
Inrush L3	-	Restraint caused by high second harmonic content in L3 differential current during inrush or external fault
5th harmonic content L1	-	There is fifth harmonic content detected in phase L1.



5th harmonic content L2	-	There is fifth harmonic content detected in phase L2.
5th harmonic content L3	-	There is fifth harmonic content detected in phase L3.
5th harmonic restraint L1	-	Restraint caused by high fifth harmonic content in L1 differential current
5th harmonic restraint L2	-	Restraint caused by high fifth harmonic content in L2 differential current
5th harmonic restraint L3	-	Restraint caused by high fifth harmonic content in L3 differential current
Primary current input 1 assignment	-	Status of the graphical analogue input (if exists) (Complete if OK, Missing if not connected)
Primary current input 2 assignment	-	Status of the graphical analogue input (if exists) (Complete if OK, Missing if not connected)
Secondary current input 1 assignment	-	Status of the graphical analogue input (if exists) (Complete if OK, Missing if not connected)
Secondary current input 2 assignment	-	Status of the graphical analogue input (if exists) (Complete if OK, Missing if not connected)
Tertiary current input 1 assignment	-	Status of the graphical analogue input (if exists) (Complete if OK, Missing if not connected)
Tertiary current input 2 assignment	-	Status of the graphical analogue input (if exists) (Complete if OK, Missing if not connected)

## 2.2.6 Events

The following events are generated in the event list, as well as sent to SCADA according to the configuration.

Table 2-7 Events of the differential protection function

EVENT	VALUE	EXPLANATION	IEC61850 DATA ATTRIBUTE
Inrush L1	off, on	Restraint in phase L1 caused by high second harmonic content in the differential current during inrush or external fault	-
Inrush L2	off, on	Restraint in phase L2 caused by high second harmonic content in the differential current during inrush or external fault	-
Inrush L3	off, on	Restraint in phase L3 caused by high second harmonic content in the differential current during inrush or external fault	-
General Start	off, on	General start of the restrained part of the differential protection function	TRPDIF1\$ST\$Str\$general TRPDIF1\$ST\$Op\$general
Start L1	off, on	Start of the restrained differential protection function in measuring element L1 (after vector group compensation)	TRPDIF1\$ST\$Str\$phsA
Start L2	off, on	Start of the restrained differential protection function in measuring element L2 (after vector group compensation)	TRPDIF1\$ST\$Str\$phsB
Start L3	off, on	Start of the restrained differential protection function in measuring element L3 (after vector group compensation)	TRPDIF1\$ST\$Str\$phsC
Start L1 – unrestrained	off, on	Start of the unrestrained differential protection function in measuring element L1 (after vector group compensation)	-
Start L2 – unrestrained	off, on	Start of the unrestrained differential protection function in measuring element L2 (after vector group compensation)	-
Start L3 – unrestrained	off, on	Start of the unrestrained differential protection function in measuring element L3 (after vector group compensation)	-
General Start – unrestrained	off, on	General start of the unrestrained part of the differential protection function	TRPDIF1\$ST\$Op\$Unr\$general

## 2.3 Technical data and notes

Table 2-8 Technical data of the transformer differential protection

FUNCTION	VALUE	ACCURACY
Operating characteristic	2 breakpoints	
Reset ratio	0,9	
Characteristic accuracy*		<3%
Operate time, unrestrained	Typically 20 ms	<10 ms
Reset time, unrestrained	Typically <55 ms	
Operate time, restrained	Typically 30 ms*	<10 ms
Reset time, restrained	Typically <35 ms	

\*Bias current is above  $0.2 I_n$

### 2.3.1 Notes for testing

Normally in the EuroProt+ devices the trip contacts are assigned to the Trip Logic function block, and not to the protection function blocks. Because of this the testing personnel must make sure that the Trip Logic is switched on ('Operation' parameter is set to other than 'Off') before starting the testing, otherwise there will be no physical trip on the relay.

#### Notes for testing the operation characteristics:

- Direction settings in the CT4 module function are 'Line' and 'Bus'. However, in case of differential protection 'Line' means 'Towards protected object'. So if the two CTs' starpoints are towards protected object, their settings should be 'Line' for both.
- Reference winding is the primary side (see Chapter 1.2). Reference current is the nominal current of the transformer (see Chapter 1.3.1).
- The adaptive characteristics to external faults might cause different test results, as the characteristics will be different under certain circumstances (see Chapter 1.8.3). To avoid this, the pre-fault currents should not exceed  $1 \cdot I_n$ .

If the pre-fault currents cannot be adjusted, then setting the *pre-fault time to zero* also solves the issue.

#### Notes for testing the harmonic restraint characteristic:

- When testing the 2<sup>nd</sup> harmonic restraint, keep in mind that either of the two conditions (inrush or external fault, see Chapter 1.5) must be fulfilled to activate the restraint along with the condition of the differential current to be at least  $0.1 I_n$ .
- The 5<sup>th</sup> harmonic restraint can be tested freely the condition of the differential current to be at least  $0.1 I_n$ .

#### Notes for analyzing better the disturbance records:

- The following calculated analogue signals must be added to the Disturbance Recorder of the device (defined in the .epcs configuration file in EuroCAP):
  - Differential currents for each phase (CAn\_IdL1/2/3)
  - Shifted currents of each side (can be added by Protecta personnel only, but can be copied by the user from other .epcs files)
- Using the current channels above, the measured  $I_{diff}$  and  $I_{bias}$  valued can be obtained for every point in the record:
  - $I_{diff}$ : just check the RMS value of the fundamental Fourier component
  - $I_{bias}$ : check the RMS value of the fundamental Fourier component of each phase, then calculate according to the Bias Current's equation

### 2.3.2 CT sizing requirements

The CT sizing guidelines for internal and external faults (according to the IEC60255-187-1 standard) can be acquired on request from Protecta personnel on [application@protecta.hu](mailto:application@protecta.hu)

### 2.3.3 Transformer and primary CT rated current ratios

When ordering a device with differential protection, it must be taken into consideration that the function's characteristics are based on the *transformer's rated current*. This means that the rated currents of the primary CTs shall be selected in a way that their secondary currents are reasonably high to be measured accurately on the protection device's CT modules.

The desirable value for the primary CTs' rated current would be close to that of the transformer's rated currents, so that their measurements stay accurate for the differential protection.

For example, let's take a transformer with the following data:

$$\begin{aligned} S_n &= 50 \text{ MVA} \\ U_{n1} &= 230 \text{ kV} \\ U_{n2} &= 22 \text{ kV} \end{aligned}$$

The reference currents (transformer rated currents) on the primary and secondary sides in this case are:

$$\begin{aligned} I_{reference_1} &= \frac{S_n}{\sqrt{3} U_{n1}} \rightarrow I_{reference_1} = 125.5 \text{ A} \\ I_{reference_2} &= \frac{S_n}{\sqrt{3} U_{n2}} \rightarrow I_{reference_2} = 2624.4 \text{ A} \end{aligned}$$

Staying at the example, if a CT with a rated current of 2000A is installed on the *primary (1)* side, and another CT with 3000A on the *secondary (2)* side, the matching ratios between the transformer's and the CT's rated currents would be the following:

$$\begin{aligned} TR_1 &= \frac{I_{TRn1}}{I_{CTn1}} \rightarrow TR_1 = \frac{125.5 \text{ A}}{2000 \text{ A}} = 0.06275 = 6.275\% \\ TR_2 &= \frac{I_{TRn2}}{I_{CTn2}} \rightarrow TR_2 = \frac{2624.4 \text{ A}}{3000 \text{ A}} = 0.8748 = 87.48\% \end{aligned}$$

The issue is on the primary side, where a rated current (100%) flowing on the transformer would represent only **6.275%** on the CT. In other words, if 6.275% current (62.75 mA on 1A rated secondary) is flowing on the primary side and no current on the secondary side, the differential protection function will show 100% differential current on its on-line data. With a base sensitivity setting of 20%, 12.55 mA current (1.255%) could already cause the function to operate.

#### 2.3.3.1 Recommended CT/TR nominal current matching ratios

Because of the issue above, applying the function to different matching ratios might provide different accuracy results (the lower the ratio, the better the accuracy); this also depends on the function block settings, see the table below.

Table 2-9 Characteristic accuracy depending on the CT/TR matching ratio

CHARACTERISTICS' PARAMETERS		MATCHING RATIO (PRIMARY SIDE)*		
BASE SENSITIVITY	1ST SLOPE	7 (14.29%)	12 (8.33%)	16 (6.25%)
10% (minimum)	10% (minimum)	3%	6%	10%
20% (default)	20% (default)	3%	4%	7%
20% (default)	30%	3%	3%	5%

\*CT/TR ratio on the secondary side is constant (87.48%, see the example above))

The 3% accuracy shown in Table 2-8 with the base sensitivity of 20% can be expected with a matching ratio of **7 or lower** (or higher than 14.29% if shown in TR/CT ratio instead).

If the 1<sup>st</sup> slope is at least 20% as well (default setting), the same accuracy can be reached until the ratio of **12**.

## 3 Appendix

### 3.1 Transformation matrices

The algorithm of differential protection function in version 5 and above is adaptive. This means that the target of the matrix transformation is always the primary side of the transformer. For example, if the vector group is Yd1, then the algorithm transforms to the Y side, and in case of vector group Dy1, the target is the D side.

Protecta applies in transformer differential protection function the vector shift compensation according to parameter Pri-Sec Vector Group (and Pri-Ter Vector Group in case of three winding transformer).

The numerical differential protection function applies numerical matrix transformation for modeling the connection of the transformer's coils. In the transformer, the magnitude of the current is transformed according to the turn's ratio and the vector group of the transformers. This transformation is implemented with help of matrix equations.

In the following chapters these calculations will be explained.

#### 3.1.1 The matrix equations

In the Vector group compensation software module, the transformation matrices of Table 3-1 are applied. The Matrix ID can start with character

- U for **U**nit matrix;
- P for **P**hase shifting matrix;
- Z for **Z**ero sequence eliminating matrix.

The number in the Matrix ID indicates the phase shift in clock notation. (e.g. P11 matrix is a phase shifting matrix to 11 o'clock from 0 o'clock, i.e. 30 degrees anti-clockwise.)

Table 3-1 Vector shift compensation matrices

Matrix ID	Matrix
U0	$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$
U6	$\begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{bmatrix}$
P11	$\frac{1}{\sqrt{3}} * \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix}$
P5	$\frac{1}{\sqrt{3}} * \begin{bmatrix} -1 & 1 & 0 \\ 0 & -1 & 1 \\ 1 & 0 & -1 \end{bmatrix}$
P1	$\frac{1}{\sqrt{3}} * \begin{bmatrix} 1 & 0 & -1 \\ -1 & 1 & 0 \\ 0 & -1 & 1 \end{bmatrix}$
P7	$\frac{1}{\sqrt{3}} * \begin{bmatrix} -1 & 0 & 1 \\ 1 & -1 & 0 \\ 0 & 1 & -1 \end{bmatrix}$
Z0	$\frac{1}{3} * \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix}$
Z6	$\frac{1}{3} * \begin{bmatrix} -2 & 1 & 1 \\ 1 & -2 & 1 \\ 1 & 1 & -2 \end{bmatrix}$
Z4	$\frac{1}{3} * \begin{bmatrix} -1 & 2 & -1 \\ -1 & -1 & 2 \\ 2 & -1 & -1 \end{bmatrix}$
Z10	$\frac{1}{3} * \begin{bmatrix} 1 & -2 & 1 \\ 1 & 1 & -2 \\ -2 & 1 & -1 \end{bmatrix}$
Z8	$\frac{1}{3} * \begin{bmatrix} -1 & -1 & 2 \\ 2 & -1 & -1 \\ -1 & 2 & -1 \end{bmatrix}$
Z2	$\frac{1}{3} * \begin{bmatrix} 1 & 1 & -2 \\ -2 & 1 & 1 \\ 1 & -2 & 1 \end{bmatrix}$
U4	$\begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix}$
U10	$\begin{bmatrix} 0 & -1 & 0 \\ 0 & 0 & -1 \\ -1 & 0 & 0 \end{bmatrix}$

### 3.1.2 Transformation to the D side

The algorithm uses the transformation to D side, if the primary coil of transformer is D connected, and in case of zig-zag connected tertiary coil.



If there is a neutral grounding transformer in the protected zone, the setting of “Neutral grounding transf.” parameter could be necessary. There are more details about this case in Chapter 1.3.4.

#### 3.1.2.1 Application for two winding transformers

If the primary is “D” connected then the secondary can be configured to “y”, “d” or “z”. The possible combinations are shown in Table 3-2.

Table 3-2 Vector shift compensation matrices for transformers of primary “D” connection

Primary	D
Secondary	Transformation
y1	U0 P11
y5	U0 P7
y7	U0 P5
y11	U0 P1
d0	U0 U0
d6	U0 U6
z0	U0 Z0
z2	U0 Z10
z4	U0 Z8
z6	U0 Z6
z8	U0 Z4
z10	U0 Z2

### 3.1.2.2 Application for three winding transformers

If the primary is “D” connected then the secondary and/or the tertiary can be configured to “y”, “d” or “z”. The possible combinations are shown in

Table 3-3.

Table 3-3 Vector shift compensation matrices for three winding transformers of primary “D” connection

		Primary D					
		Tertiary					
		y1	y5	y7	y11	d0	d6
Secondary	y1	U0 P11 P11	U0 P11 P7	U0 P11 P5	U0 P11 P1	U0 P11 U0	U0 P11 U6
	y5	U0 P7 P11	U0 P7 P7	U0 P7 P5	U0 P7 P1	U0 P7 U0	U0 P7 U6
	y7	U0 P5 P11	U0 P5 P7	U0 P5 P5	U0 P5 P1	U0 P5 U0	U0 P5 U6
	y11	U0 P1 P11	U0 P1 P7	U0 P1 P5	U0 P1 P1	U0 P1 U0	U0 P1 U6
	d0	U0 U0 P11	U0 U0 P7	U0 U0 P5	U0 U0 P1	U0 U0 U0	U0 U0 U6
	d6	U0 U6 P11	U0 U6 P7	U0 U6 P5	U0 U6 P1	U0 U6 U0	U0 U6 U6
	z0	U0 Z0 P11	U0 Z0 P7	U0 Z0 P5	U0 Z0 P1	U0 Z0 U0	U0 Z0 U6
	z2	U0 Z10 P11	U0 Z10 P7	U0 Z10 P5	U0 Z10 P1	U0 Z10 U0	U0 Z10 U6
	z4	U0 Z8 P11	U0 Z8 P7	U0 Z8 P5	U0 Z8 P1	U0 Z8 U0	U0 Z8 U6
	z6	U0 Z6 P11	U0 Z6 P7	U0 Z6 P5	U0 Z6 P1	U0 Z6 U0	U0 Z6 U6
	z8	U0 Z4 P11	U0 Z4 P7	U0 Z4 P5	U0 Z4 P1	U0 Z4 U0	U0 Z4 U6
z10	U0 Z2 P11	U0 Z2 P7	U0 Z2 P5	U0 Z2 P1	U0 Z2 U0	U0 Z2 U6	

		Primary D					
		Tertiary					
		z0	z2	z4	z6	z8	z10
Secondary	y1	U0 P11 Z0	U0 P11 Z10	U0 P11 Z8	U0 P11 Z6	U0 P11 Z4	U0 P11 Z2
	y5	U0 P7 Z0	U0 P7 Z10	U0 P7 Z8	U0 P7 Z6	U0 P7 Z4	U0 P7 Z2
	y7	U0 P5 Z0	U0 P5 Z10	U0 P5 Z8	U0 P5 Z6	U0 P5 Z4	U0 P5 Z2
	y11	U0 P1 Z0	U0 P1 Z10	U0 P1 Z8	U0 P1 Z6	U0 P1 Z4	U0 P1 Z2
	d0	U0 U0 Z0	U0 U0 Z10	U0 U0 Z8	U0 U0 Z6	U0 U0 Z4	U0 U0 Z2
	d6	U0 U6 Z0	U0 U6 Z10	U0 U6 Z8	U0 U6 Z6	U0 U6 Z4	U0 U6 Z2
	z0	U0 Z0 Z0	U0 Z0 Z10	U0 Z0 Z8	U0 Z0 Z6	U0 Z0 Z4	U0 Z0 Z2
	z2	U0 Z10 Z0	U0 Z10 Z10	U0 Z10 Z8	U0 Z10 Z6	U0 Z10 Z4	U0 Z10 Z2
	z4	U0 Z8 Z0	U0 Z8 Z10	U0 Z8 Z8	U0 Z8 Z6	U0 Z8 Z4	U0 Z8 Z2
	z6	U0 Z6 Z0	U0 Z6 Z10	U0 Z6 Z8	U0 Z6 Z6	U0 Z6 Z4	U0 Z6 Z2
	z8	U0 Z4 Z0	U0 Z4 Z10	U0 Z4 Z8	U0 Z4 Z6	U0 Z4 Z4	U0 Z4 Z2
z10	U0 Z2 Z0	U0 Z2 Z10	U0 Z2 Z8	U0 Z2 Z6	U0 Z2 Z4	U0 Z2 Z2	

In case of vector groups Yyz and Ydz too, the target of transformation is the D side. These cases are shown in Table 3-4.

Table 3-4 Vector shift compensation matrices for three winding transformers of primary “Y” and tertiary “z” connection

		Primary Y			
		Tertiary			
		z1	z5	z7	z11
Secondary	y0	P1 P1 Z0	P11 P11 Z6	P1 P1 Z6	P11 P11 Z0
	y6	P1 P7 Z0	P11 P5 Z6	P1 P7 Z6	P11 P5 Z0
	d1	P1 U0 Z0	P11 U10 Z6	P1 U0Z 6	P11 U10 Z0
	d5	P11 U6 Z10	P11 U6 Z6	P11 U6 Z4	P11 U6 Z0
	d7	P1 U6 Z0	P11 U4 Z6	P1U6 Z6	P11 U4 Z0
	d11	P11 U0 Z10	P11 U0 Z6	P11 U0 Z4	P11 U0 Z0

### 3.1.3 Transformation to the Y side

If the primary coil of the transformer is Y connected, the target of the transformation is Y side, and the algorithm may subtract zero sequence current depending on the Primary, Secondary and Tertiary starpoint parameters.

#### 3.1.3.1 Application for two winding transformers

If the primary is “Y” or “Yg” connected then the secondary can be configured to “y”, “yg”, or “d”. The possible combinations are shown in Table 3-5.

Table 3-5 Vector shift compensation matrices for two winding transformers of primary “Y” connection

Primary	Y	Yg
Secondary	Transformation	
y0	U0 U0	Z0 U0
yg0	U0 Z0	Z0 Z0
y6	U0 U6	Z0 U6
yg6	U0 Z6	Z0 Z6
d1	U0 P11	Z0 P11
d5	U0 P7	Z6 P7
d7	U0 P5	Z0 P5
d11	U0 P1	Z0 P1

#### 3.1.3.2 Application for three winding transformers

If the primary is “Y” or “Yg” connected then the secondary and/or the tertiary can be configured to “y”, “yg”, “d” or “z”. The possible combinations are shown in Table 3-6 and Table 3-7.

Table 3-6 Vector shift compensation matrices for three winding transformers of primary “Y” connection

		Primary Y			
		Tertiary			
		y0	yg0	y6	yg6
Secondary	y0	U0 U0 U0	U0 U0 Z0	U0 U0 U6	U0 U0 Z6
	yg0	U0 Z0 U0	U0 Z0 Z0	U0 Z0 U6	U0 Z0 Z6
	y6	U0 U6 U0	U0 U6 Z0	U0 U6 U6	U0 U6 Z6
	yg6	U0 Z6 U0	U0 Z6 Z0	U0 Z6 U6	U0 Z6 Z6
	d1	U0 P11 U0	U0 P11 Z0	U0 P11 U6	U0 P11 Z6
	d5	U0 P7 U0	U0 P7 Z0	U0 P7 U6	U0 P7 Z6
	d7	U0 P5 U0	U0 P5 Z0	U0 P5 U6	U0 P5 Z6
	d11	U0 P1 U0	U0 P1 Z0	U0 P1 U6	U0 P1 Z6

		Primary Y			
		Tertiary			
		d1	d5	d7	d11
Secondary	y0	U0 U0 P11	U0 U0 P7	U0 U0 P5	U0 U0 P1
	yg0	U0 Z0 P11	U0 Z0 P7	U0 Z0 P5	U0 Z0 P1
	y6	U0 U6 P11	U0 U6 P7	U0 U6 P5	U0 U6 P1
	yg6	U0 Z6 P11	U0 Z6 P7	U0 Z6 P5	U0 Z6 P1
	d1	U0 P11 P11	U0 P11 P7	U0 P11 P5	U0 P11 P1
	d5	U0 P7 P11	U0 P7 P7	U0 P7 P5	U0 P7 P1
	d7	U0 P5 P11	U0 P5 P7	U0 P5 P5	U0 P5 P1
	d11	U0 P1 P11	U0 P1 P7	U0 P1 P5	U0 P1 P1

Table 3-7 Vector shift compensation matrices for three winding transformers of primary “Yg” connection

		Primary Yg			
		Tertiary			
		y0	yg0	y6	yg6
Secondary	y0	Z0 U0 U0	Z0 U0 Z0	Z0 U0 U6	Z0 U0 Z6
	yg0	Z0 Z0 U0	Z0 Z0 Z0	Z0 Z0 U6	Z0 Z0 Z6
	y6	Z0 U6 U0	Z0 U6 Z0	Z0 U6 U6	Z0 U6 Z6
	yg6	Z0 Z6 U0	Z0 Z6 Z0	Z0 Z6 U6	Z0 Z6 Z6
	d1	Z0 P11 U0	Z0 P11 Z0	Z0 P11 U6	Z0 P11 Z6
	d5	Z0 P7 U0	Z0 P7 Z0	Z0 P7 U6	Z0 P7 Z6
	d7	Z0 P5 U0	Z0 P5 Z0	Z0 P5 U6	Z0 P5 Z6
d11	Z0 P1 U0	Z0 P1 Z0	Z0 P1 U6	Z0 P1 Z6	

		Primary Yg			
		Tertiary			
		d1	d5	d7	d11
Secondary	y0	Z0 U0 P11	Z0 U0 P7	Z0 U0 P5	Z0 U0 P1
	yg0	Z0 Z0 P11	Z0 Z0 P7	Z0 Z0 P5	Z0 Z0 P1
	y6	Z0 U6 P11	Z0 U6 P7	Z0 U6 P5	Z0 U6 P1
	yg6	Z0 Z6 P11	Z0 Z6 P7	Z0 Z6 P5	Z0 Z6 P1
	d1	Z0 P11 P11	Z0 P11 P7	Z0 P11 P5	Z0 P11 P1
	d5	Z0 P7 P11	Z0 P7 P7	Z0 P7 P5	Z0 P7 P1
	d7	Z0 P5 P11	Z0 P5 P7	Z0 P5 P5	Z0 P5 P1
	d11	Z0 P1 P11	Z0 P1 P7	Z0 P1 P5	Z0 P1 P1

## 3.2 Handling previous function block versions

### 3.2.1 Summary of function block versions

The differential protection function block has been updated several times during the years. In this table, a quick overview is shown about the main differences with regards to **Version 10** which this manual is about.

Table 3-8 Differential protection function versions

VERSION	TRANSFORMATION TYPE	MAIN DIFFERENCES TO VER. 10
1	Delta	<ul style="list-style-type: none"> <li>• 2<sup>nd</sup> slope is fixed to 200%, not settable</li> <li>• Harmonic cross blocking is always enabled, not settable</li> <li>• Instead of <math>S_n</math> and <math>U_n</math> parameters, the ratio of the transformer and CT nominal current (TR/CT ratio) is given directly by parameter for each side (i.e. it is to be calculated by the user). The parameters are: <i>TR Primary Comp; TR Secondary Comp</i></li> <li>• Transformation type is always Delta</li> <li>• Because of the delta-transformation, there are no parameters about the starpoint grounding</li> <li>• Fixed (non-graphical) analogue assignments (2.8 firmware system)</li> </ul>
2	Delta	<ul style="list-style-type: none"> <li>• Instead of <math>S_n</math> and <math>U_n</math> parameters, the ratio of the transformer and CT nominal current (TR/CT ratio) is given directly by parameter for each side (i.e. it is to be calculated by the user). The parameters are: <i>TR Primary Comp; TR Secondary Comp</i></li> <li>• Transformation type is always Delta</li> <li>• Because of the delta-transformation, there are no parameters about the starpoint grounding</li> <li>• Fixed (non-graphical) analogue assignments (2.8 firmware system)</li> </ul>
3	Delta	<ul style="list-style-type: none"> <li>• Transformation type is always Delta</li> <li>• Because of the delta-transformation, there are no parameters about the starpoint grounding</li> <li>• Fixed (non-graphical) analogue assignments (2.8 firmware system)</li> </ul>
5	Automatic (Y or Delta, depending on the primary winding)	<ul style="list-style-type: none"> <li>• Fixed (non-graphical) analogue assignments (2.8 firmware system)</li> </ul>
10	Automatic (Y or Delta, depending on the primary winding)	n/a (current version)

For the 2.10 system, all functions with graphical analogue inputs received the initial version number 10, hence the lack of other intermediate versions.

### 3.2.2 Analyzing function versions 3 and below

The manual for the previous versions is available on the Protecta website, however this manual is valid for earlier versions as well, keeping in mind the following differences:

- a) These functions always transform to the delta (D) side, not to the primary side. When using these functions, disregard Chapter 1.3.3 of this manual, and use the transformation matrices listed in Chapter 3.1.2 instead.
- b) Very early versions (i.e. lower than 2) don't have the  $U_n$ ,  $S_n$  parameters, but rather compensation parameters between the CT and TR rated currents. The principle is the same, but the user must calculate these values based on the transformer's  $U_n$ ,  $S_n$  parameters and the CT's rated current.

If there is need of assistance in handling these functions, feel free to contact Protecta Support.

Note that there is an XRIO setting file available for these functions (ver. 3). With that, only the parameters of the CT modules and the differential protection function should be entered along the type of the fault to be generated. By using this file, testing the operation characteristic will not need any further setting.

### 3.2.3 After updating to function block version 5 or 10

In case of updating the function block from an older version to version 5, only the new parameters (Primary, Secondary and Tertiary starpoint) must be set.

As for the other parameters, there are no changes necessary to maintain the correct functionality.