# Restricted Earth-Fault Protection in REF 542*plus*

## Application and Setting Guide


ABB

## Contents:

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# 1. Scope

This document introduces the application of restricted earth-fault protection in REF 542*plus*. Restricted earth-fault protection is designed to detect power transformer earth faults. The operation principle is primarily based on the biased differential protection scheme with threefold tripping characteristic. The earth-fault current can be calculated from the three phase currents or separately measured by a ring-type-CT. Suitable relay settings and the selection of current transformers are illustrated with examples. A recommendation for the specification of a suitable nominal power of the current transformers is also given.

KEYWORDS: *restricted earth-fault protection*, *biased differential protection*, *transformer protection*.

# 2. Introduction

The restricted earth-fault protection in REF 542*plus* is designed to detect high-resistance earth faults within the protection zone of power transformers. There are two operation principles available, i.e. the biased differential scheme and the phase comparison scheme. The biased differential scheme can be used, if the actual accuracy limit factor of the CT is sufficient for the application. In the case of heavy CT saturation, the phase comparison scheme is recommended to be used instead, to avoid unwanted tripping.

The protection function block used for this application is called restricted differential protection.

## 2.1. Biased differential protection scheme

The basic principle of the biased differential protection is shown in Fig. 2.1.-1.

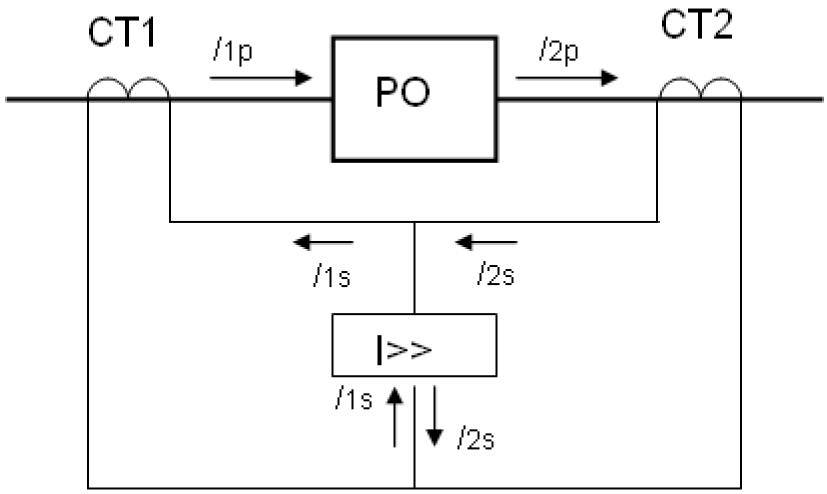


*Fig. 2.1.-1 Operation principle of biased differential protection*

PO is the protected object, CT1 and CT2 the current transformers in the boundary zones, $I_{1p}$ and $I_{2p}$ the current on the primary side of the current transformer and $I_{1s}$ and $I_{2s}$ the transmitted current on the secondary side of the related current transformer. The secondary sides of the current transformer circuits are commonly connected through the differential protection (DP). Assuming that the current transformers have no error, as shown in Fig. 2.1.-1, during normal load conditions or during through-fault condition, no current will flow through the differential protection Only in the event of an internal fault between the two current transformers a trip can be initiated, because the transmitted currents on the secondary side, $I_{1s}$ and $I_{2s}$, no longer are the same. Consequently, the difference between the two current values, the differential current $I_d$, is no longer zero.

$$\bar{I}_d = \bar{I}_{1s} - \bar{I}_{2s}$$

In fact, the simplest version of differential protection can be an overcurrent protection relay, which is placed in the differential current path of the two current transformer circuits.

Fig. 2.1.-2 shows one of the possible connection schemes for restricted earth-fault protection.

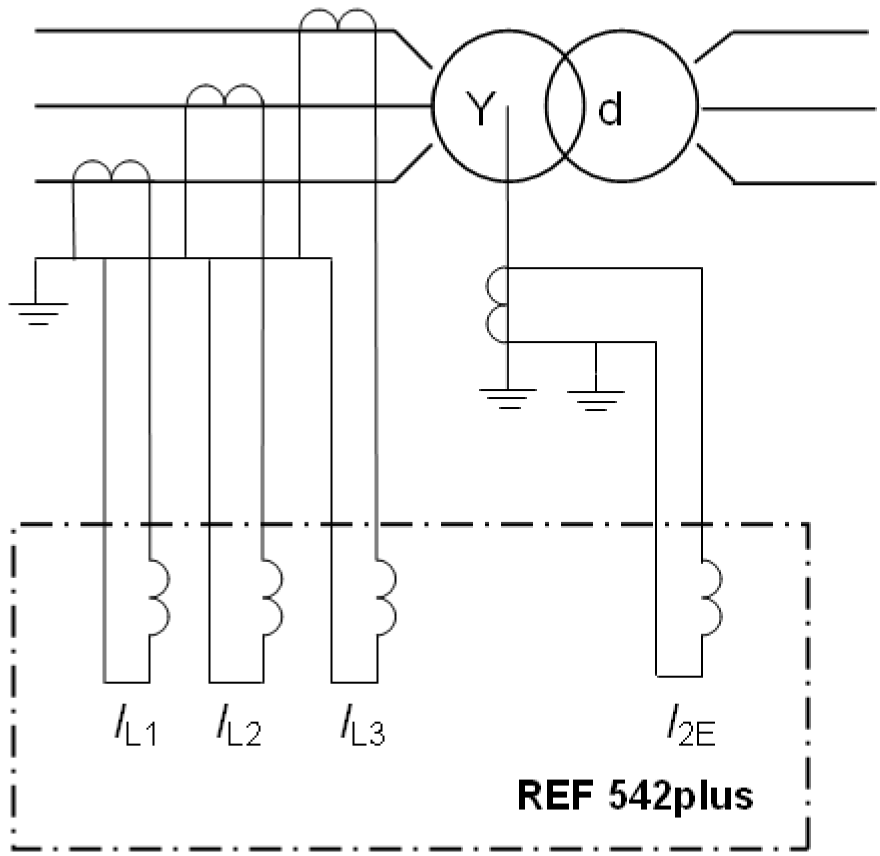


*Fig. 2.1.-2 Connection scheme for restricted earth-fault protection*

The current quantities to be applied in restricted earth-fault protection are the residual current $I_{1E}$, calculated from the sum of the three phase currents

$$\overline{I}_{1E} = \overline{I}_{L1} + \overline{I}_{L2} + \overline{I}_{L3}$$

and the neutral current $I_{2E}$ measured by a CT placed in the grounding path of the power transformer. Another method to measure the residual current $I_{1E}$ is to use a ring-type CT.

Due to the fact that current transformers always have a certain error, the differential current always differs from zero as soon as there is a load current flowing. Especially during a through-fault condition with high short circuit current , the differential current too may be very high due to the error of the current transformers. Depending on the sensitivity of the setting value of the overcurrent protection relay, when it is used as a simple differential protection relay, unwanted tripping may occur.

For this reason, it is necessary to stabilize the differential protection by means of a so called bias current. For the restricted earth-fault protection using the biased differential protection principle, the following measurement quantities are used:

Operating quantity: $\overline{I}_d = (\overline{I}_{1E} - \overline{I}_{2E})$

Biasing quantity: $\overline{I}_b = MAX(|\overline{I}_{1E}| - |\overline{I}_{2E}|)$

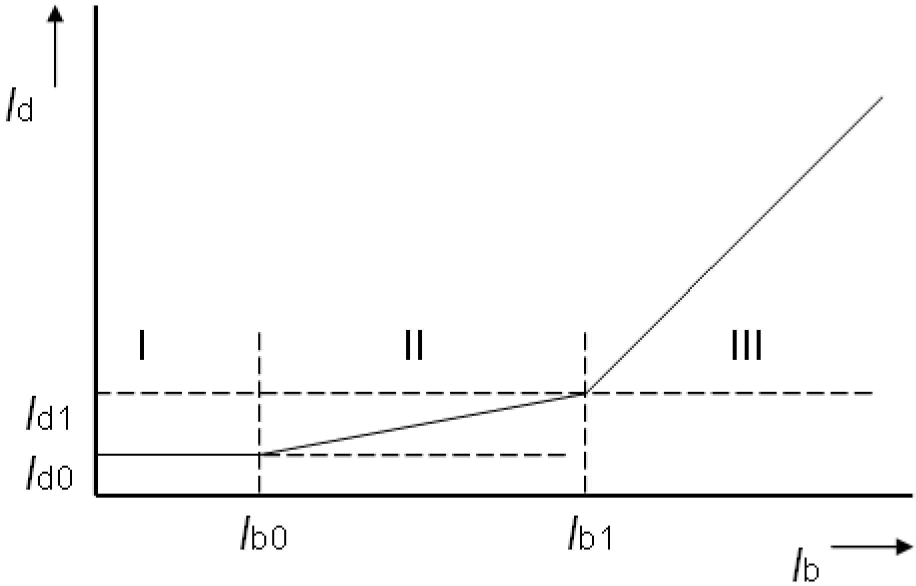


*Fig. 2.1.-3 Tripping characteristic of biased differential protection scheme*

In this case the biasing quantity is the maximum value of the transmitted earth-fault current on the secondary side of the CT, i.e. either $I_{1E}$ or $I_{2E}$. Consequently, the stabilization impact is always optimized, e.g. in the event of a three-phase through-fault with severe CT saturation on the transformer terminals.

By using this biasing quantity it is possible to define the dependence between the tripping of the differential protection and the through current. The higher the through-fault current is, the higher the level of the differential current for tripping must be. Beside, to increase the operational reliability, a trip signal is generated only if a neutral current $I_{2E}$ of a magnitude exceeding 50% of the setting value $I_{d0}$ is detected.

The tripping characteristic is divided into three ranges. The first one, range I, is dedicated for low fault current conditions, the second one, range II, for normal fault current conditions and the third one, range III, for heavy fault currents.

## 2.2. Phase comparison scheme

In systems with a high time constant of the decaying DC component of the short-circuit current, the phase current CTs can be severely saturated. If unwanted tripping cannot be excluded when the biased differential scheme is used, the phase comparison scheme should be applied instead.

In the phase comparison scheme, the magnitude of the residual current $I_{1E}$ and the neutral current $I_{2E}$ are no longer decisive. The operation of the protection is based on the phase shift between these two currents. Provided the related CTs are not saturated, the residual current $I_{1E}$ and the neutral current $I_{2E}$ shall theoretically have opposite directions when a fault occurs inside the protection zone. Therefore, the phase shift between these two current quantities is 180° at an internal fault. Consequently, the phase shift in an external or a through-fault situation is 0°. On the basis of the phase shift between these two currents, it is possible to differentiate an internal fault from an external one. As shown in Fig. 2.2.-1 a specific operation area, therefore, can be defined for the restricted earth-fault protection.

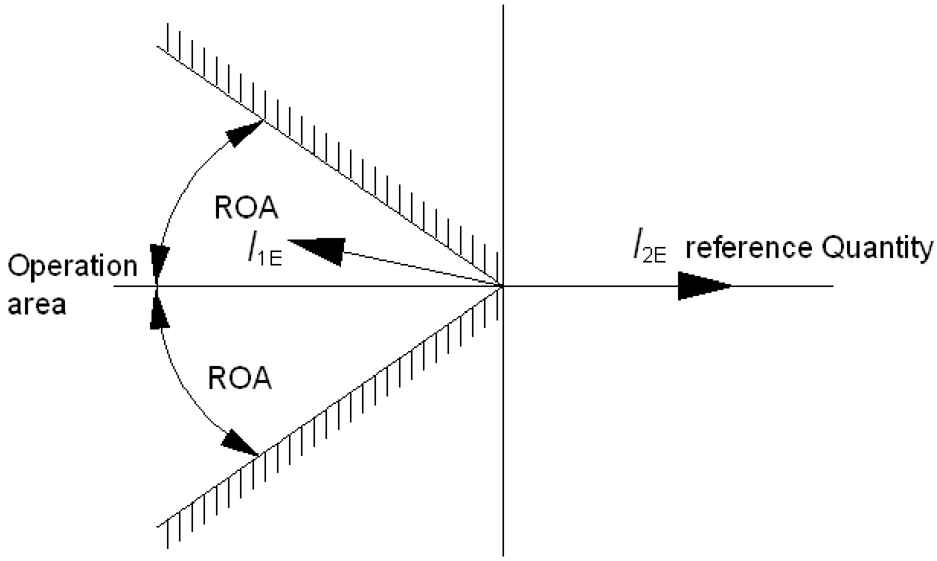


*Fig. 2.2.-1 Tripping characteristic of the phase comparison scheme*

The operation area can be defined by the so called relay operation angle ROA. Then the neutral current $I_{2E}$ is used as the reference quantity. The phase shift cannot be determined if the magnitude of the neutral current is under 3% of the rated current value Ir, which is a setting parameter in the function block of the restricted earth-fault protection. The operation area can be increased or decreased according to the setting value of ROA. The setting value shall be so selected that an external fault with a heavily saturated CT will not cause tripping by the restricted earth-fault protection. If there is no need to use the phase comparison scheme, it is disabled by giving the ROA a setting value equal to 180°. Then the restricted earth-fault protection will operate according to the biased differential protection scheme.

# 3. Technical implementation

## 3.1. Connection scheme

The flexibility of REF 542*plus* allows the relay to be connected to the current transformers in different ways. Below one way of connecting the terminal:

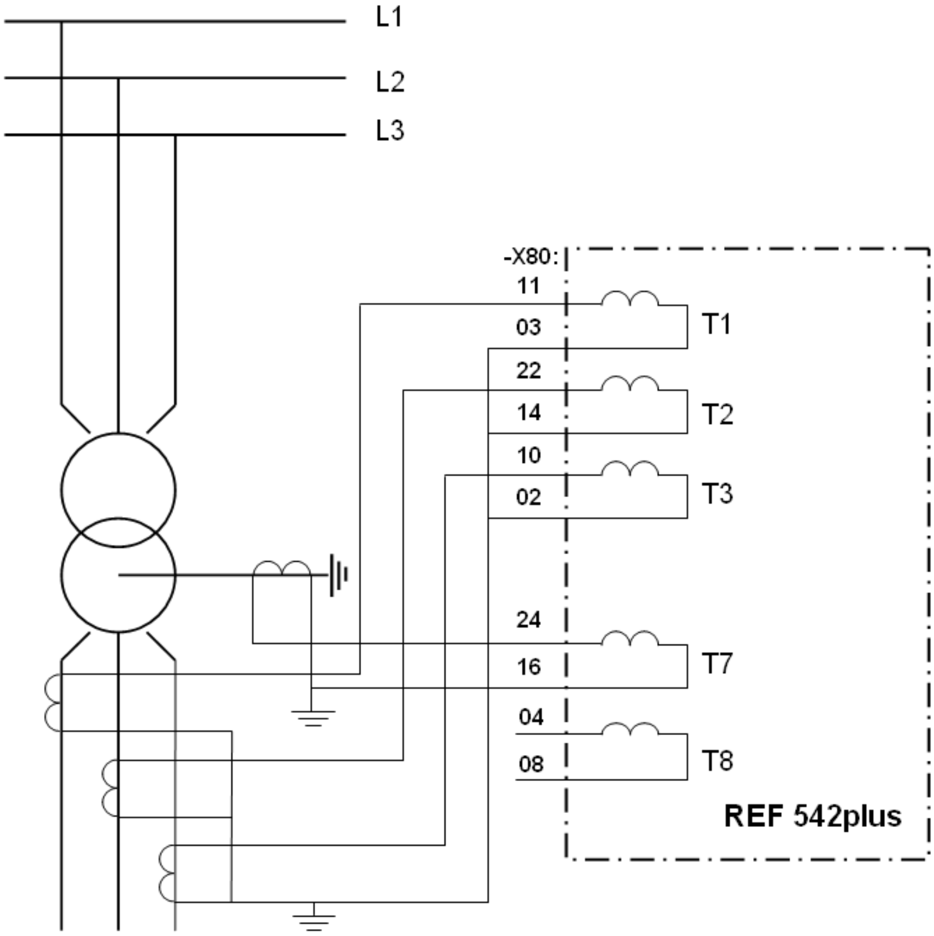


*Fig. 3.1.-1 Connection diagram for REF 542plus using four CTs*

For the restricted earth-fault protection to operate properly, the REF 542*plus* shall be connected to residual and neutral current. If the residual current is calculated, the first group T1/T2/T3 shall be specified for the inputs of the three-phase current transformer on the transformer side, where the protection zone of the restricted earth-fault protection is defined. Then the neutral current can be connected to either input T7 or input T8. In the above connection diagram the neutral current is wired to input T7.

Should an additional ring-type CT be applied to measure the residual current directly, the ring-type CT may, for example, be connected to the current input transformer T8, the neutral current being connected to T7, as already shown in the above connection diagram.

## 3.2. Setting example for restricted earth-fault protection

An example of setting the REF 542*plus* for restricted earth-fault protection will be described in the following section. The power transformer is assumed to have the following technical data:

| | |
|---|---|
| Transformer rated voltage | 3.3 kV / 0.433 kV |
| Rated power | 1.6 MVA |
| Vector group: | Dyn 11 |
| Transformer impedance | 8.6 % |
| The transformer neutral is solidly earthed on the low voltage side | 0.433 kV |
| CT for phase currents | 3000 A / 1 A |
| CT for neutral current | 1250 A / 1 A |

The CTs are connected and grounded as shown in Fig. 3.1.-1.

### 3.2.1. Calculation

The rated current of the power transformer on the low-voltage side is:

0.433 kV side: $I_{2r} = 1.60\ \text{MVA} / (0.433\ \text{kV} \times \sqrt{3})$

In this example, the power transformer is assumed to be fed from the 3.3 kV side and a fault to have occurred near the transformer terminals on the 0.433 kV side. Further, it is assumed that the short-circuit power of the sourcing power system is infinitely high. So, in the event of a three-phase fault under rated conditions and without considering the load tap changer, the short-circuit current will be:

0.433 kV side: $I_{2sc} = (2133\ \text{A} \times 100\% / 8.6\%) = 24.8\ \text{kA}$

In a solidly earthed system, the earth-fault current can be assumed to be of the same magnitude as the three-phase short-circuit current.

Depending on the fault current condition, the fault current range can be defined as follows:

| | |
|---|---|
| Low fault current condition: | current range 0 to 2 $I_r$ |
| Normal fault current condition: | current range 1 to 6 $I_r$ |
| Heavy fault current condition: | current range 4 $I_r$ and higher |

### 3.2.2. Adaptation of the connection scheme

Based on the connection scheme shown in Fig. 3.1.-1, the analog inputs of the REF 542*plus* shall be set as shown in Fig. 3.2.2.-1.

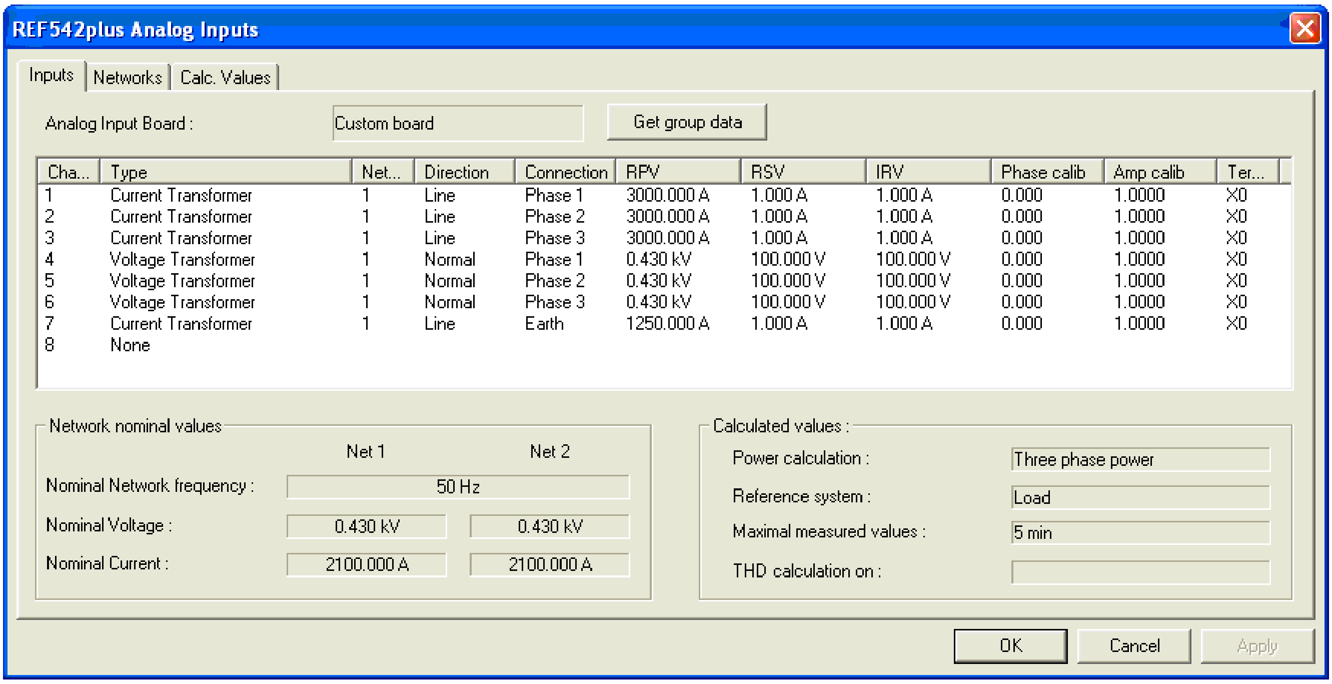


*Fig. 3.2.2.-1 Setting of analog inputs*

The CTs on each phase of the low-voltage side are connected to the analog inputs AI 01, AI 02 and AI 03, which are defined as NET 1. Due to the connection of the CT secondary side according to Fig. 3.1.-1, the LINE direction has to be selected. The rated value of the input transformer used is 1 A. The parameters of the neutral CT have to be set accordingly. If necessary, additional phase and amplitude calibration on each input transformer can be performed.

The correctness of the setting can be checked on the measurement page of the HMI. The magnitude of the current on the 0.43 kV side and the resulting differential current are shown accordingly on the display.

Fig. 3.2.2.-2 shows the adaptation of the connection to the selected example.

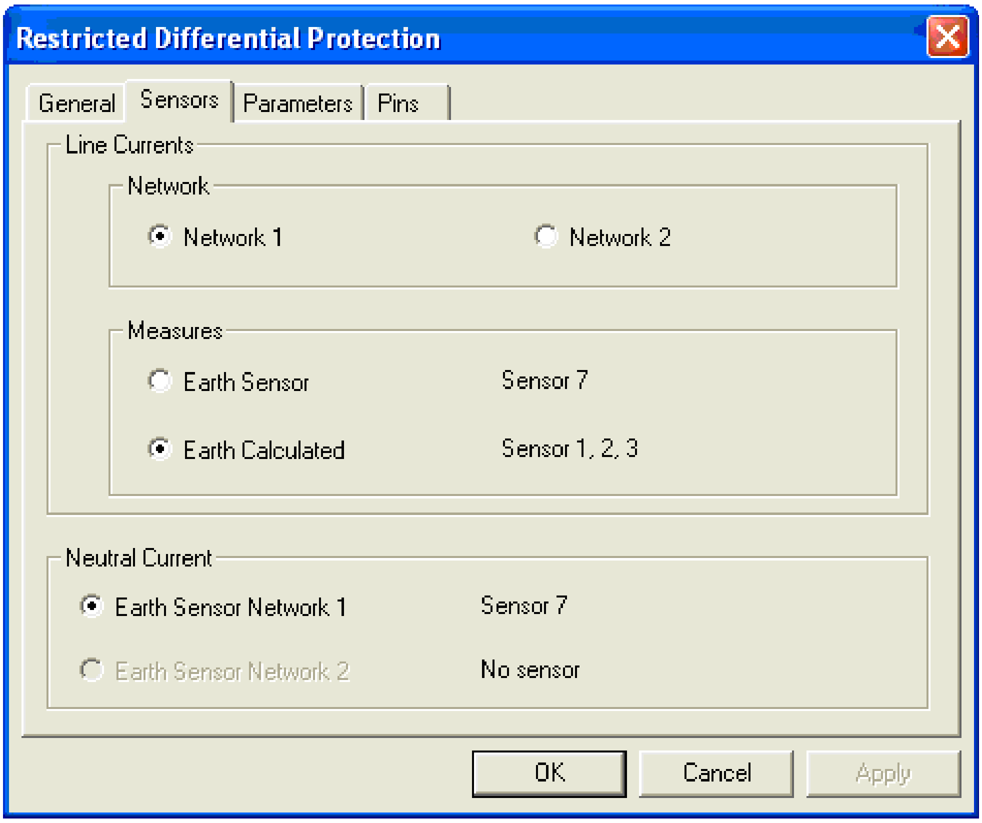


*Fig. 3.2.2.-2 Adaptation of analog inputs*

In this setting the residual current is calculated from the phase current connected to the current input transformers T1, T2 and T3. The neutral current is connected to the current input transformer T7.

## 3.2.3. Setting the tripping characteristic for the biased scheme

The result of the calculation above is used to define the tripping characteristic. Due to the different rated values of the phase CTs and the neutral CT a rated current value must be established to define a reference value for the internal calculation of the differential current in of the event of an earth fault. In this example, the lower rated value of the neutral CT is used in order increase the sensitivity. Therefore the rated current $I_r$ is set to be 1250 A.

The limit value (1st turning point of the operating curve) of the low fault current condition of the setting shall be set to 1 $I_r$. Because 1250 A is used as the reference value, the phase CTs will carry a current that is less than half their rated current. If we assume that the error of the phase CTs is in the range of ± 2 … 3% in this low-current range, the threshold value of the differential current can be set as follows:

$$(0.03 + 0.03) I_r = 0.06\ I_r$$

Here it is assumed that the normal fault current range is 2 $I_r$. In this current range the CT error can be assumed to be at its minimum, i.e. ± 1%. So the slope of the slightly biased range can be defined as follows:

$$(0.01 + 0.01) I_r / (2 - 1) I_r = 0.02$$

If no CT saturation is to be assumed, a very sensitive setting may be considered for the heavily biased slope. When CTs of protection class 5P are used, the setting may be defined as below, under the assumption that the maximum error in the high fault current range is always less than ± 5%:

$$(0.05 + 0.05) I_r / I_r = 0.1$$

If CT saturation cannot be avoided, a higher value can be selected. For a safe margin, the highest value for the heavily biased slope, i.e. 1, can be selected too. Fig. 3.2.3.-1 shows the setting of the tripping characteristic:

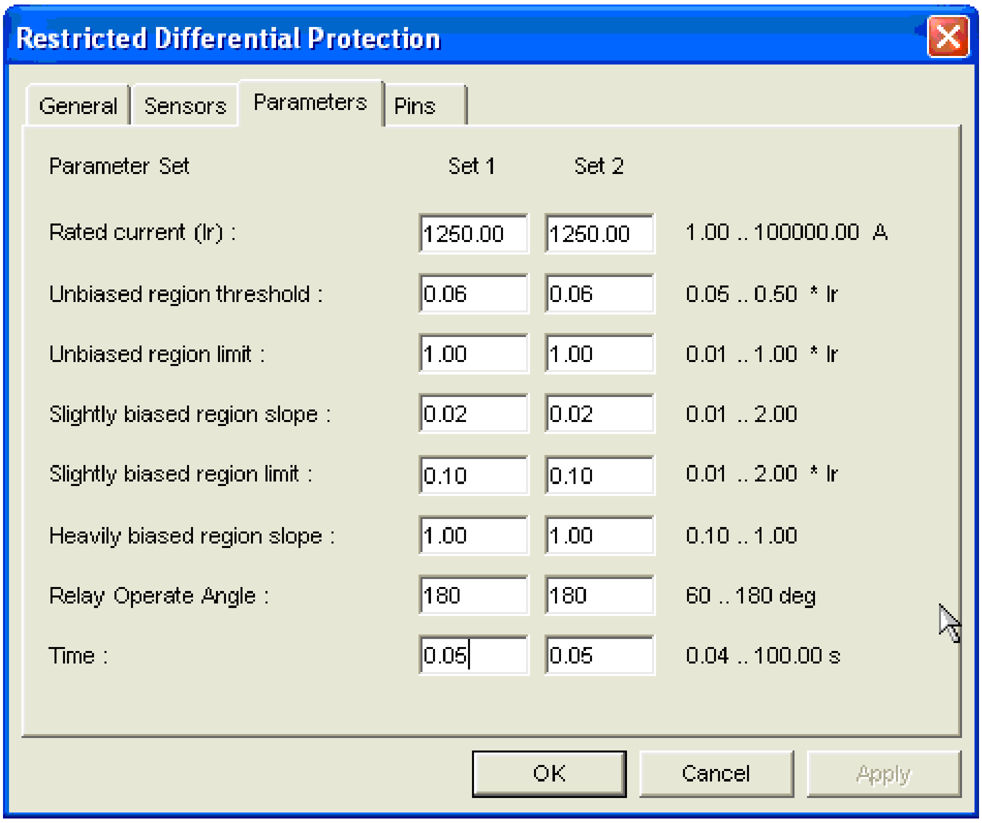


*Fig. 3.2.3.-1 Setting parameters for tripping characteristic*

Because the restricted earth-fault protection is to operate according to the stabilized biased characteristic, the phase comparison scheme is disabled. Consequently, the ROA (relay operating angle) must be set to 180°.

### 3.2.4. Use of phase comparison scheme (ROA < 180°)

If the phase current CTs are liable to heavy saturation, the biased differential characteristic is not to be recommended. Instead, the phase comparison scheme should be applied. By selecting a ROA value less than 180°, the stabilized bias characteristic will not be operative anymore. The generation of a trip signal will only depend on the phase shift angle between the residual voltage and the neutral current. A ROA setting of 90° is recommended. This setting value is derived from experience. To achieve a reliable operation behavior, the trip signal will be generated only if a neutral current of at least 3% of the rated current Ir is detected. As shown in Fig. 3.2.3.-1, the value of the rated current Ir is set to be 1250 A in this example.

### 3.2.5. CT Requirement

The CT has a significant influence on the correct behavior of the transformer differential protection. To guarantee selectivity and fast tripping, the CT has to fulfill certain requirement. The through-fault current must be reproduced with no saturation of CTs due to earth faults and two-phase faults with earth connection.

In this setting example, the phase CTs must be able to transfer the short circuit current without saturation. In general, it can be assumed that the possible maximum short-circuit current will not exceed the three-phase fault current. So the maximum short-circuit current will be less than 24.8 kA. The required accuracy limit factor for the CTs can be determined as following [1]:

$$F_a \geq 24.8 \text{ kA} / 3000 \text{ A} = 8.26$$

The value mentioned above is only valid for a symmetrical fault current. If the short-circuit current includes a decaying DC component, the accuracy limit factor has to be increased. The factor depends on the value of the time constant of the DC component, which can be in the range from 5 to 10. If the highest value of the heavily biased slope, i.e. 1, is selected, a value between 5 and 6 will be sufficient.

# 4. Summary

This application note describes the application of the restricted earth-fault protection in the REF 542*plus*. The operation principle of the restricted earth-fault protection is to compare the residual current with the neutral current flowing through the neutral earthing of the power transformer. The setting of the protection is illustrated by a corresponding example. Should the CTs be heavily saturated due to a high short-circuit current, the application of the phase comparison scheme is recommended to be used instead of the stabilized biased differential current scheme.

# 5. References

[1] 1MRS755481 Calculation of the Current Transformer, Accuracy Limit Factor, ABB Application Note

1MRS755860 Protection Functions, Configuration and Settings

# 6. List of symbols

| | |
|---|---|
| $I_{L1,2,3}$ | Current in phase 1, 2 or 3 |
| $I_{E1}$ | Residual current (to be calculated or measured) |
| $I_{E2}$ | Neutral current |
| $I_d$ | Differential current |
| $I_b$ | Bias current |
| ROA | Relay operate angle |
| $I_r$ | Setting value for rated current in function block |

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