# MiCOM 30 Series
# Restricted Earth Fault Protection

## Application Guide

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ALSTOM

# Contents

## Symbols and Subscripts

### Symbols

| | |
|---|---|
| $\underline{I}$ | Current phasor |
| V | Voltage |
| S | Power |
| k | Matching factor |
| N | Number of turns |
| f | Fault location factor |
| K | Dimensioning factor |
| n | Number |
| C | Constant |

### Subscripts

| | |
|---|---|
| prim | Primary |
| sec | Secondary |
| nom | Nominal |
| ref | Reference |
| P | Phase |
| G | Ground (en: earth) |
| Y | Star point |
| L | Lead |
| sc | Short circuit |
| ext | External |
| int | Internal |
| max | Maximum value |
| CT | Main current transformer (set) |
| A, B, C | Phase A, B, or C |
| x | Dummy variable for phase A, B, or C |
| amp | Amplitude-matched |
| 1, 2, 3 | Measuring system 1, 2, or 3 |
| a, b | End or winding a or b of the protected object |
| d | Differential |
| R | Restraining |
| stab | Stability, stabilizing |
| knee | Knee point |
| operating | Operating |
| m | Magnetizing |

# 1 Introduction

Protection devices in the MiCOM 30 series are described in detail in the respective operating manuals as regards technical properties, functional characteristics, and proper handling during installation, connection, commissioning, and operation. However, the operating manuals do not provide any information regarding the philosophy behind each specific product or the way in which the functional possibilities of a particular protection device can be used to handle special applications.

The present application guide is intended to close this gap. For the restricted earth fault protection function group of MiCOM P63x devices, the purpose is to give the reader a better understanding of the design of the individual function blocks and then to provide related instructions for settings, commissioning, and testing.

Note: Although MiCOM P63x devices provide this function group under the name „Ground Differential Protection" the present application guide uses the more common name „Restricted Earth Fault Protection".

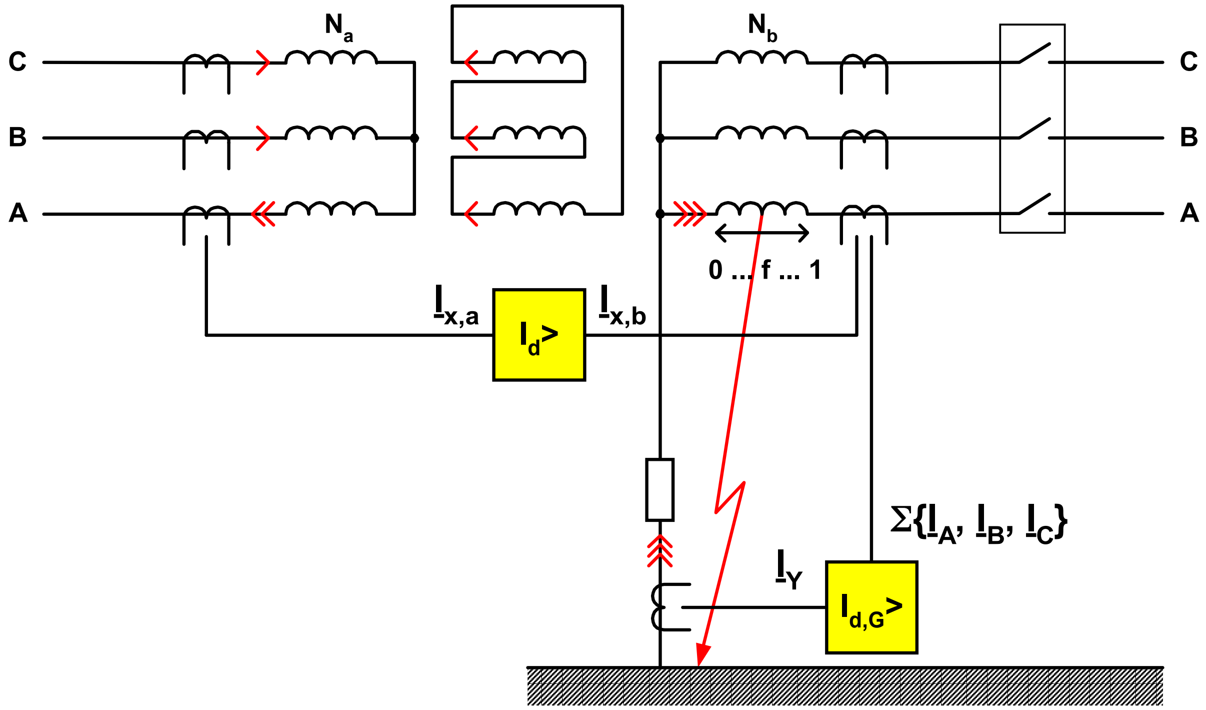
# 2 Basic Mode of Operation

Restricted earth fault protection is applied on transformers in order to detect ground-faults on a given winding more sensitively than overall transformer differential protection is able to do. Restricted earth fault protection – as well as transformer differential protection – is based on the principle of comparison of measured variables by comparing the residual current of the phase current transformers of the given winding with the current of the associated grounded star point. Since residual current may occur due to transient saturation during high through-fault currents restraining is required for restricted earth fault protection. For this purpose two different measuring principles are available:

- Biased restricted earth fault protection
- High impedance restricted earth fault protection

As mentioned above restricted earth fault protection provides higher sensitivity for the detection of ground-faults than overall transformer differential protection.

In the following a ground-fault is considered within low-voltage winding (winding b) of a transformer Yyn(d). Fault location is given by the fault location factor f. In case of open circuit breaker at low-voltage side the ground-fault is fed from high-voltage side (winding a) only and the phase currents at low-voltage side are zero. The grounding resistance mainly limits the ground-fault current which is given for a fault location at connection side (f = 1) as $I_{G,max}$.



Assuming equal induced voltage per turn of the faulty winding b the ground-fault current will be of linear dependency on the fault location f:

$$I_Y = f \cdot I_{G,max}$$

Due to ampere turns balance the fault current is induced by two thirds only from the high-voltage winding being on the same leg. The missing third comes from the compensating delta winding. The induction is given in accordance with the ratio of the number of turns $f \cdot N_b$ of the partial winding to $N_a$. Since the phase current transformers at low-voltage side are at zero current the differential currents of the measuring systems of the transformer differential protection are given by the respective phase currents at high-voltage side and the differential current of the restricted earth fault protection is given by the star point current:

$$\begin{aligned} I_{d,1} &= \left|\underline{I}_{A,a}\right| = \frac{2}{3} \cdot \frac{f \cdot N_b}{N_a} \cdot f \cdot I_{G,max} \\ I_{d,2} &= \left|\underline{I}_{B,a}\right| = \frac{1}{3} \cdot \frac{f \cdot N_b}{N_a} \cdot f \cdot I_{G,max} \qquad \Leftrightarrow \qquad I_{d,G} = \left|\underline{I}_{Y}\right| = f \cdot I_{G,max} \\ I_{d,3} &= \left|\underline{I}_{C,a}\right| = \frac{1}{3} \cdot \frac{f \cdot N_b}{N_a} \cdot f \cdot I_{G,max} \end{aligned}$$

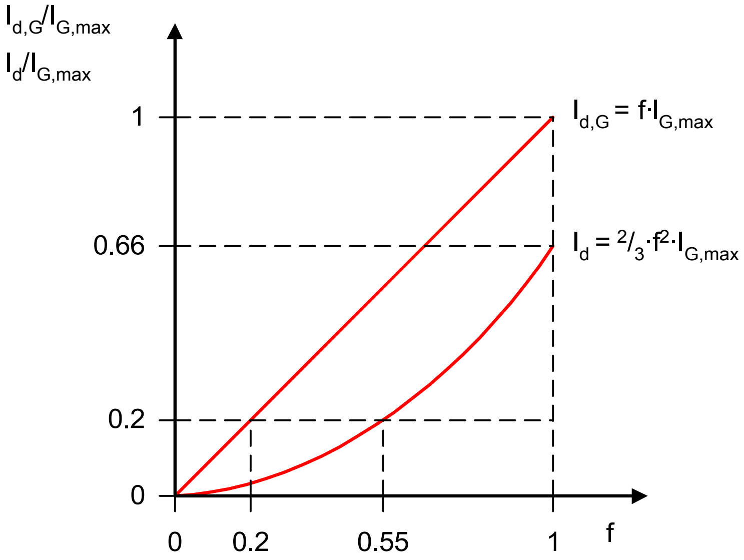
The measuring system of transformer differential protection carrying the highest differential current is used for the comparison of the sensitivity of restricted earth fault protection and transformer differential protection. For simplification the rated transformation ratio of the power transformer is considered first to be 1:

$$\frac{V_{nom,a}}{V_{nom,b}} = 1 \quad \text{and} \quad \frac{\frac{V_{nom,a}}{\sqrt{3}}}{\frac{V_{nom,b}}{\sqrt{3}}} = \frac{N_a}{N_b} \quad \Rightarrow \quad \frac{N_a}{N_b} = 1$$

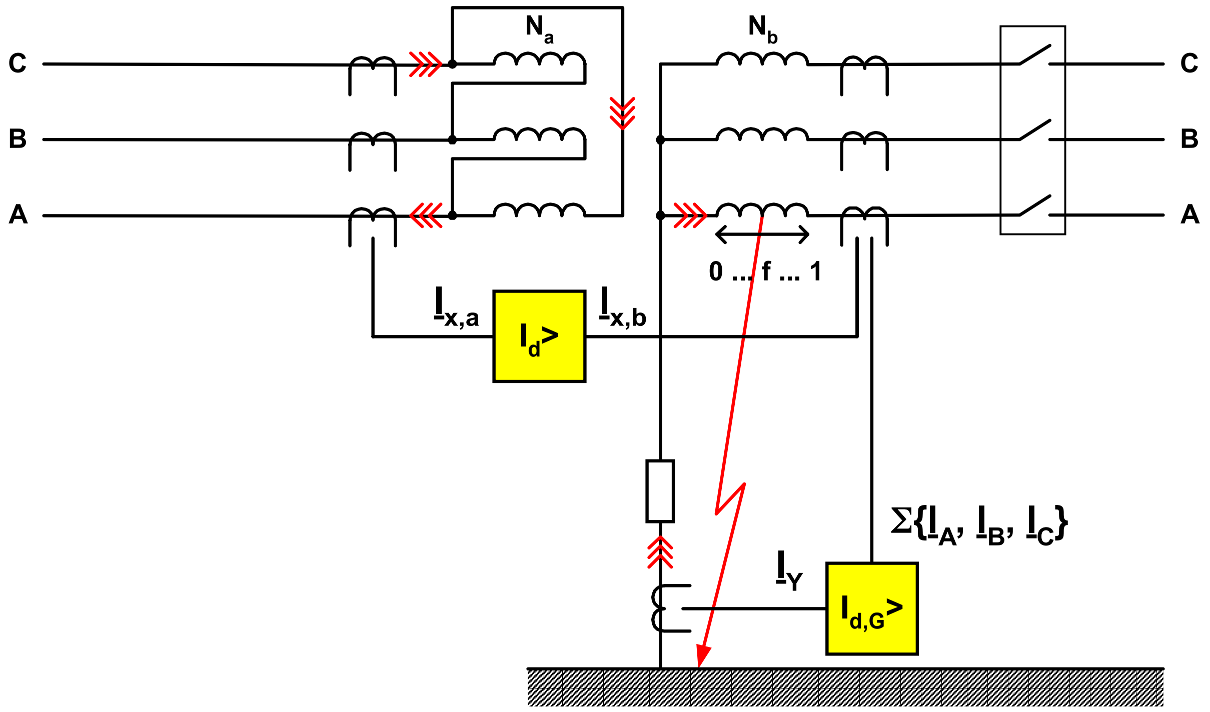
The differential currents of transformer differential protection and restricted earth fault protection are then as follows:

$$I_d = \frac{2}{3} \cdot f^2 \cdot I_{G,max} \quad \Leftrightarrow \quad I_{d,G} = f \cdot I_{G,max}$$

The fundamental advantage of restricted earth fault protection resides in the linear dependency of the differential current on fault location factor f whereas this dependency is given in proportion of the square for transformer differential protection. The graph below presents the much larger protected zone of restricted earth fault protection in comparison with transformer differential protection:



A further example deals with a transformer Dyn where ground-fault is considered likewise in the zone of the low-voltage winding (winding b). The single-phase-to-ground fault is transformed to the high-voltage side (winding a) as double-phase fault clear of ground.



The differential currents of transformer differential protection and restricted earth fault protection are calculated as follows:

$$
\begin{aligned}
I_{d,1} &= \left|\underline{I}_{A,a}\right| = \frac{f \cdot N_b}{N_a} \cdot f \cdot I_{G,max} \\
I_{d,2} &= \left|\underline{I}_{B,a}\right| = 0 \qquad\qquad \Leftrightarrow \qquad\qquad I_{d,G} = \left|\underline{I}_{Y}\right| = f \cdot I_{G,max} \\
I_{d,3} &= \left|\underline{I}_{C,a}\right| = \frac{f \cdot N_b}{N_a} \cdot f \cdot I_{G,max}
\end{aligned}
$$

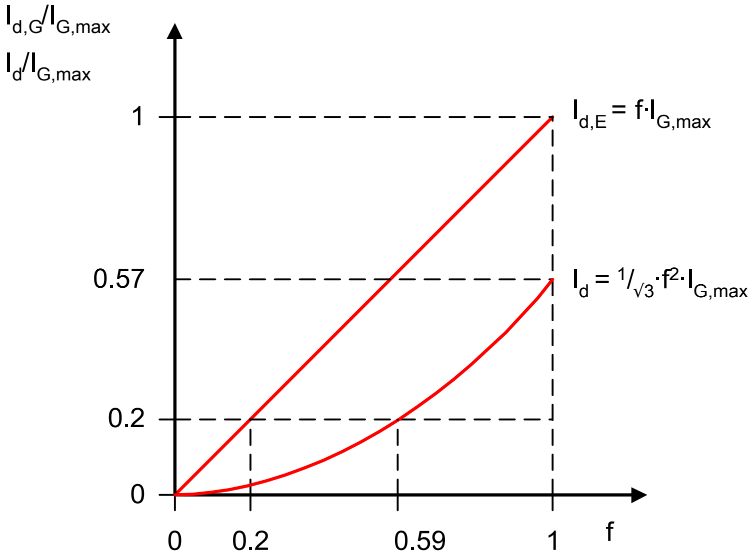
The measuring system of transformer differential protection carrying the highest differential current is used again for the comparison of the sensitivity of restricted earth fault protection and transformer differential protection. For simplification the rated transformation ratio of the power transformer is considered first to be 1. In this case factor √3 has to be taken into consideration due to delta connection of the windings at high-voltage side:

$$
\frac{V_{nom,a}}{V_{nom,b}} = 1 \quad \text{and} \quad \frac{V_{nom,a}}{\frac{V_{nom,b}}{\sqrt{3}}} = \frac{N_a}{N_b} \quad \Rightarrow \quad \frac{N_a}{N_b} = \sqrt{3} \quad \text{or} \quad \frac{N_b}{N_a} = \frac{1}{\sqrt{3}}
$$

The differential currents of the transformer differential protection and of the restricted earth fault protection are then as follows:

$$I_d = \frac{1}{\sqrt{3}} \cdot f^2 \cdot I_{G,max} \qquad \Leftrightarrow \qquad I_{d,G} = f \cdot I_{G,max}$$

The graph below illustrates that the protected zone of transformer differential protection is even less than in the first example:



For the quantitative comparison of the protected zone of transformer differential protection and restricted earth fault protection the rated transformation ratio of the power transformer was considered first to be 1. While the sensitivity of restricted earth fault protection is independent of the power transformer ratio the sensitivity of transformer differential protection gets worse with $N_a > N_b$.

# 3 Biased Restricted Earth Fault Protection

Biased restricted earth fault protection is based on differential protection principle by defining a suitable restraining quantity in combination with a suitable tripping characteristic to it. Two different operating modes with different properties are available by choice.

Restricted earth fault protection provides amplitude matching. Hence the primary nominal currents of phase current transformers and star point current transformer may be different. The secondary nominal currents are settable to 1 A oder 5 A via software parameter each.

## 3.1 Amplitude Matching

Amplitude matching is implemented on the same method as used with transformer differential protection (please refer to Application Guide „Transformer Differential Protection“). Amplitude matching factors are assigned to the phase currents and to the star point current. The definition of the two amplitude-matching factors is given based on the set nominal data as follows:

$$k_{amp,P} = \frac{I_{nom,CT,P}^{(prim)}}{I_{ref,P}^{(prim)}} = \frac{I_{nom,CT,P}^{(prim)}}{\dfrac{S_{ref}^{(prim)}}{\sqrt{3} \cdot V_{nom}^{(prim)}}} \quad \text{and} \quad k_{amp,Y} = \frac{I_{nom,CT,Y}^{(prim)}}{I_{ref,Y}^{(prim)}} = \frac{I_{nom,CT,Y}^{(prim)}}{\dfrac{S_{ref}^{(prim)}}{\sqrt{3} \cdot V_{nom}^{(prim)}}}$$

The common reference power shall be set equal to the nominal power of the given winding. Doing so the amplitude-matched currents are scaled to the nominal current of this winding. The amplitude-matched currents are formed by scalar multiplication, whereby the individual currents are multiplied by the corresponding amplitude-matching factor.

The amplitude-matching factors are calculated automatically by the protection device. The device also checks automatically whether the resulting amplitude-matching factors are within the limits specified by requirements of numerical processing:

- None of the amplitude-matching factors $k_{amp,P}$ and $k_{amp,Y}$ must exceed a value of 16:

$$k_{amp,P} \le 16 \quad \text{and} \quad k_{amp,Y} \le 16$$

- None of the amplitude-matching factors $k_{amp,P}$ and $k_{amp,Y}$ must fall below a value of 0.5 :

$$k_{amp,P} \ge 0.5 \quad \text{and} \quad k_{amp,Y} \ge 0.5$$

Note: Software versions -601 and -602 of P631/632/633/634 series require more severe restrictions (please refer to the corresponding Technical Manual).

## 3.2 Biasing by Residual Current

In case of operating mode for biasing by residual current differential current and restraining current are defined as follows:

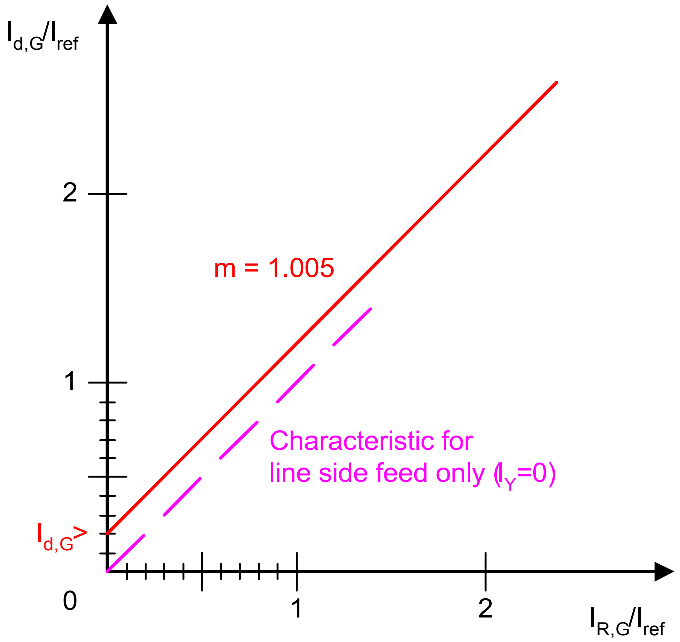
$$I_{d,G} = \left| k_{amp,P} \cdot \Sigma\{I_A, I_B, I_C\} + k_{amp,Y} \cdot I_Y \right|$$
$$I_{R,G} = \left| k_{amp,P} \cdot \Sigma\{I_A, I_B, I_C\} \right|$$

According to Kirchhoff's first law the differential current is always defined as the phasor sum of the currents being involved in the given current node. As restraining quantity the residual current is taken.

The tripping characteristic forms a straight line fixed by a slope being a little bit larger than 1:

$$I_{d,G}(I_{R,G}) = I_{d,G>} + m \cdot I_{R,G} \qquad \text{where} \qquad m = 1.005$$

Following the graphical representation it's clear that tripping requires star point current. Residual currents e.g. due to transient saturation of the phase current transformers arise in the differential current and in the restraining current equally and hence are given by the bisetrix below the tripping characteristic:



This property gives this biasing method an exceptional behaviour in terms of restraining quality. As a detrimental effect an on-load test is not possible, i.e. the secondary short-circuiting of one of the phase currents under sufficient load current does not result in tripping.

## 3.3 Biasing by Maximum Phase Current

In case of operating mode for biasing by maximum phase current differential current and restraining current are defined as follows:

$$I_{d,G} = \left| k_{amp,P} \cdot \Sigma\left\{ \underline{I}_A, \underline{I}_B, \underline{I}_C \right\} + k_{amp,Y} \cdot \underline{I}_Y \right|$$

$$I_{R,G} = \frac{1}{2} \cdot \left( k_{amp,P} \cdot \max\left\{ \left|\underline{I}_A\right|, \left|\underline{I}_B\right|, \left|\underline{I}_C\right| \right\} + k_{amp,Y} \cdot \left|\underline{I}_Y\right| \right)$$

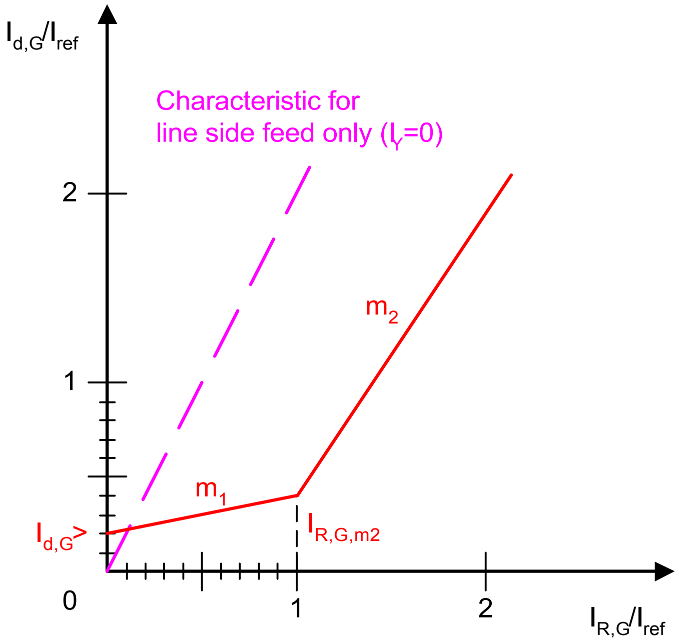
According to Kirchhoff's first law the differential current is always defined as the phasor sum of the currents being involved in the given current node. As restraining quantity the sum of the absolute values of maximum phase current and star point current is taken.

The tripping characteristic is of dual slope design. The two sections of the tripping curve are defined by the following characteristic equations:

$$I_{d,G}(I_{R,G}) = I_{d,G} > \; + m_1 \cdot I_{R,G} \qquad \text{for} \quad 0 \ldots I_{R,G} \ldots I_{R,G,m2}$$

$$I_{d,G}(I_{R,G}) = I_{d,G} > \; + I_{R,G,m2} \cdot (m_1 - m_2) + m_2 \cdot I_{R,G} \quad \text{for} \quad I_{R,G,m2} \ldots I_{R,G} \ldots$$

Following the graphical representation it's clear that the above described on-load test can be carried out:

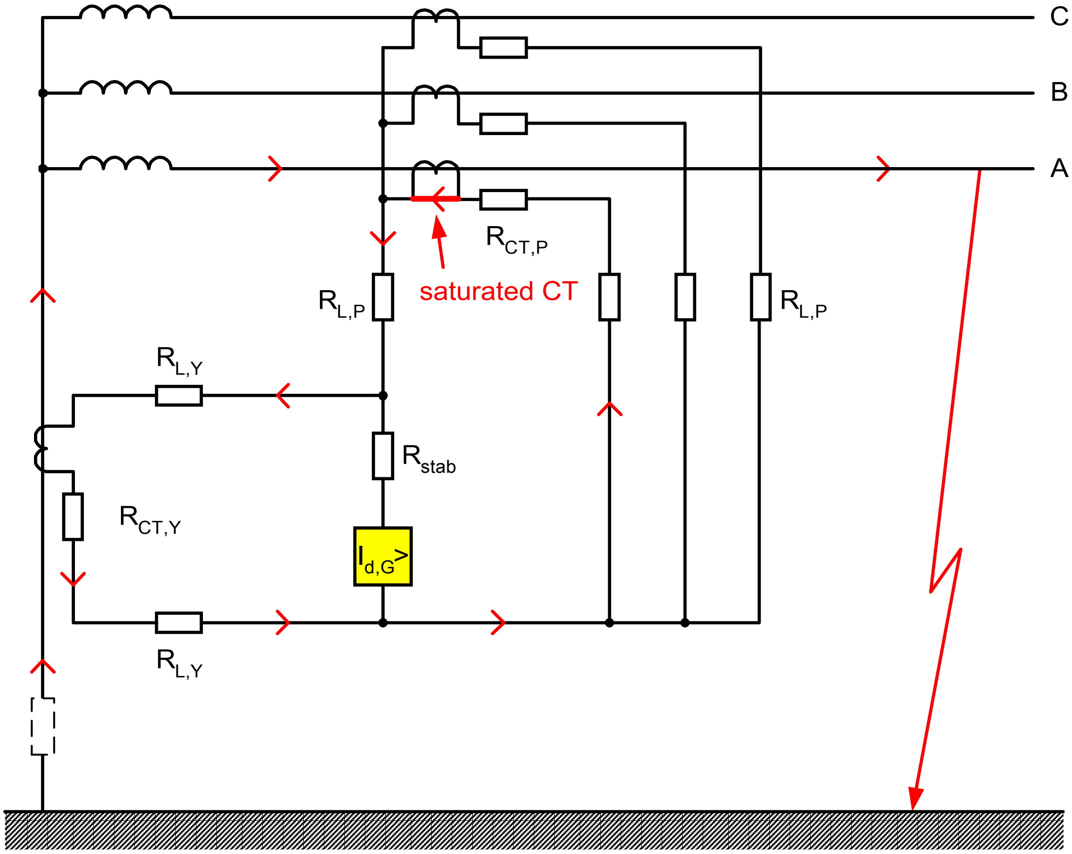


# 4 High Impedance Restricted Earth Fault Protection

For high impedance restricted earth fault protection the differential quantity is formed externally of the protection device by connecting the secondary current transformer circuits in parallel. A likely rated resistance (so-called high impedance) is inserted in the differential path in order to achieve the required restraining level. Instead of star point current the differential current is fed to the restricted earth fault protection that operates as an overcurrent element. The rated transformation ratios of all current transformers being involved must be identical.

## 4.1 High Impedance Principle

If any current transformer experiences saturation its normally high magnetizing inductance breaks down to a low value determined by the permeability of air. The relatively high ohmic resistance in the differential path results in the effect that differential current caused by current transformer saturation does not flow completely through the differential path but flows through the low magnetizing inductance of the saturated current transformer. Thus the insertion of the so-called high impedance has a restraining effect:



By neglecting the residual magnetizing inductance and the burden of the protection device within the differential path as well the voltage across the stabilizing resistor at maximum through-fault current is given by:

$$V_{sc,ext,max} = I_{sc,ext,max} \cdot (R_{CT,P} + 2 \cdot R_{L,P})$$

The restraining limitation of restricted earth fault protection is given by the set current pickup value in conjunction with the rated value of the stabilizing resistor. Furthermore the set secondary nominal current and the amplitude matching factor which is automatically calculated by the protection device on the basis of the set nominal data have to be taken into consideration:

$$V_{stab} = I_{stab} \cdot R_{stab}$$

where

$$I_{stab} = \frac{I_{d,G} > \cdot I_{nom}}{k_{amp,Y}}$$

Stability of restricted earth fault protection can be achieved by choosing a sufficient high value of the stabilizing resistor so that the current flowing through the protection device caused by $V_{sc,max}$ does not exceed the set pickup value.

## 4.2 Stability Requirement

Whereas the quantity $V_{stab}$ is based on pure sinusoidal current the voltage $V_{sc,max}$ being caused by spill current will be highly non-sinusoidal. The wave form of this voltage is governed particularly by the fact that transient saturation of the main current transformers occurs only during parts of each current wave form cycle. The behaviour of the restricted earth fault protection element under those non-sinusoidal quantities is inherent to the relay design and therefore has to be determined by investigations as part of type testing. The result of these investigations is expressed in terms of a required dimensioning factor K. Stability requirement is described by the following equation:

$$\begin{aligned} V_{stab} &> K \cdot V_{sc,ext,max} \\ &> K \cdot I_{sc,ext,max} \cdot (R_{CT,P} + 2 \cdot R_{L,P}) \end{aligned}$$

For P631/632/633/634 series the dimensioning factor has been determined as

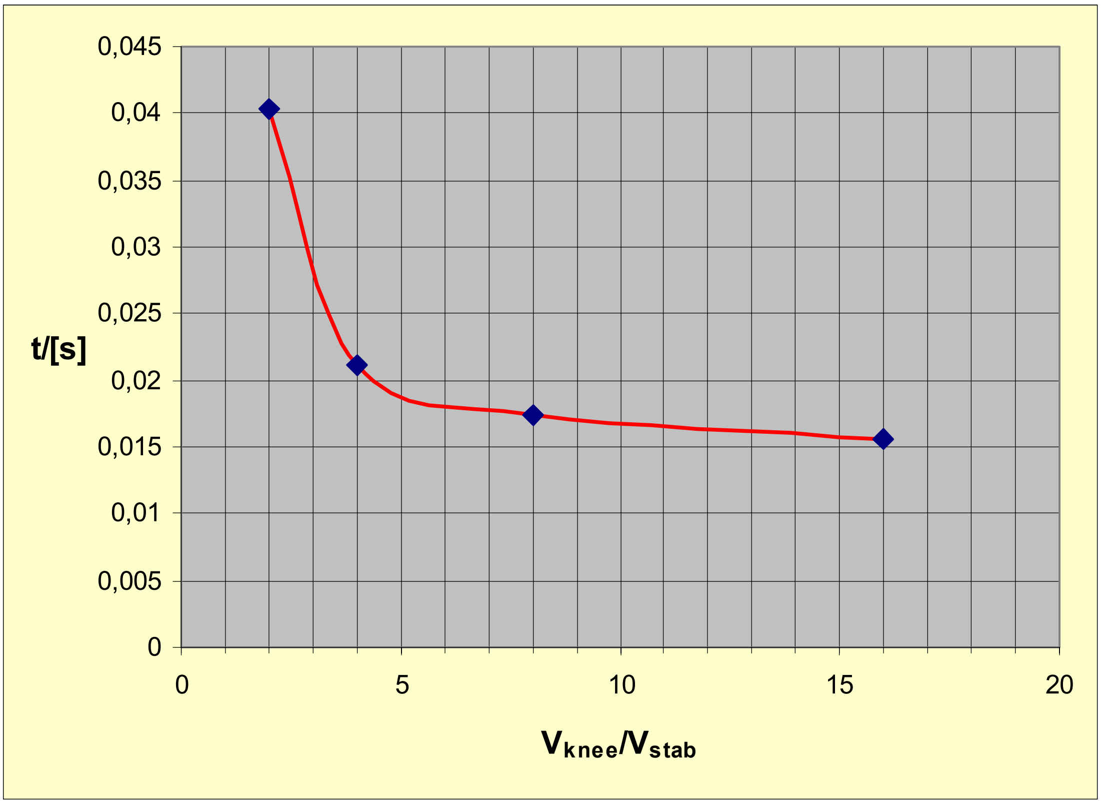
$$K = 1.1$$

## 4.3 Operating Time

In case of an internal fault the differential current is going up to the knee point of the main current transformers being involved in restricted earth fault protection. The ratio of knee point voltage $V_{knee}$ to stability voltage $V_{stab}$ determines the tripping time of the restricted earth fault protection. This ratio shall be chosen higher than 2 in order to ensure tripping times of less than 2 cycles at nominal frequency of 50 Hz:

$$V_{knee} > 2 \cdot V_{stab}$$

Typical tripping times as a function of the ratio of knee point voltage $V_{knee}$ to stability voltage $V_{stab}$ for the P631/632/633/634 series can be taken from the following diagram:



The diagram is the result of investigations which were carried out for impedance ratios in the range of 5 to 120 and for fault currents in the range of 0.5 to $40 \cdot I_{nom}$

## 4.4 CT Requirements

From the required minimum stability voltage $V_{stab}$ according to chapter 4.2 and the required ratio $V_{knee}/V_{stab}$ according to chapter 4.3 we obtain the required minimum knee point voltage $V_{knee}$ as follows:

$$V_{knee} > 2 \cdot K \cdot I_{sc,ext,max} \cdot \left(R_{CT,P} + 2 \cdot R_{L,P}\right)$$

Of course as mentioned above the transformation ratios of all main current transformers being involved in restricted earth fault protection must be identical.

## 4.5 Sensitivty

The sensitivity in terms of primary fault current is obtained from the set pickup value $I_{d,G}>$. If a high number of main current transformers is connected in parallel, e.g. when using as busbar protection, their magnetizing currents cannot be neglected anymore. In this case the sum of the magnetizing currents $n \cdot I_m$ at stability voltage $V_{stab}$ has to be taken into consideration:

$$I^{(prim)}_{operation} = \frac{I^{(prim)}_{nom,CT}}{I_{nom}} \cdot \left(I_{stab} + n \cdot I_m\right)$$

where

$$I_{stab} = \frac{I_{d,G} > \cdot I_{nom}}{k_{amp,Y}}$$

The magnetizing currents of all main current transformers being involved in restricted earth fault protection reduce the current through the stabilizing resistor. Therefore the actual pickup value will be adequately higher. For the required setting value $I_{d,G}>$ we obtain:

$$I_{d,G} > \ \le k_{amp,Y} \cdot \left( \frac{I^{(prim)}_{operation}}{I^{(prim)}_{nom,CT}} - \frac{n \cdot I_m}{I_{nom}} \right)$$

## 4.6 Stabilizing Resistor

Once the pickup value for restricted earth fault protection has been determined according to chapter 4.5 the required value for the stabilizing resistor is obtained from the stability requirement according to chapter 4.2 and from the definitions according to chapter 4.1 as follows:

$$R_{stab} > K \cdot \frac{I_{sc,ext,max} \cdot \left(R_{CT,P} + 2 \cdot R_{L,P}\right)}{\dfrac{I_{d,G} > \cdot I_{nom}}{k_{amp,Y}}}$$

## 4.7 Use of Metrosil Non-linear Resistors

Metrosil non-linear resistors are used to limit the peak voltage developed by the current transformers under internal fault conditions, to a value below the insulation level of the current transformers, relay and interconnecting leads, which are normally able to withstand 3000 V peak.

The following formulae should be used to estimate the peak transient voltage that could be produced for an internal fault. The peak voltage produced during an internal fault will be a function of the current transformer kneepoint voltage and the prospective voltage that would be produced for an internal fault if current transformer saturation did not occur:

$$\hat{V} = 2 \cdot \sqrt{2} \cdot \sqrt{V_{knee} \cdot (V_{sc,int,max} - V_{knee})}$$

where

$$V_{sc,int,max} = I_{sc,int,max} \cdot (R_{CT} + 2 \cdot R_L + R_{stab})$$

When the value given by the formulae is greater than 3000 V peak, Metrosil non-linear resistors should be applied. They are connected across the relay circuit (relay and stabilizing resistor) and serve the purpose of shunting the secondary current output of the current transformer from the relay in order to prevent very high secondary voltages.

Metrosil non-linear resistors are externally mounted and take the form of annular discs. Their operating characteristic for d.c. or instantaneous values follow the expression:

$$V = C \cdot I^{0.25}$$

With a sinusoidal voltage applied across the Metrosil non-linear resistor, the r.m.s. current would be approximately 0.52 times the peak current. This is due to the fact that the current waveform through the Metrosil non-linear resistor is not sinusoidal but appreciably distorted. This r.m.s. current value can be calculated as follows:

$$I = 0.52 \cdot \left( \frac{\sqrt{2} \cdot V}{C} \right)^4$$

Metrosil Units with 1 A CTs

For satisfactory application the Metrosil units with 1 A CTs have been designed to comply with the following restrictions:

1. At stability voltage, the Metrosil current should be less than 30 mA rms.
2. At the maximum secondary internal fault current the Metrosil unit should limit the voltage to 1500 V rms if possible.

The Metrosil units normally recommended for use with 1 A CTs are as shown in the following table:

| Stability Voltage | Nominal Characteristic | Recommended Metrosil Type | |
|---|---|---|---|
| | | Single Pole Relay | Triple Pole Relay |
| Up to 125 V rms | C = 450 | 600A/S1/S256 | 600A/S3/1/S802 |
| 125 to 300 V rms | C = 900 | 600A/S1/S1088 | 600A/S3/1/S1195 |

Note: Single pole Metrosil units are normally supplied without mounting brackets unless otherwise specified by the customer

Metrosil Units with 5 A CTs

For satisfactory application the Metrosil units with 5 A CTs have been designed to comply with the following requirements:

1. At stability voltage, the Metrosil unit current should be less than 100 mA rms (the actual maximum currents passed by the units shown below their type description).
2. At the maximum secondary internal fault current the Metrosil unit should limit the voltage to 1500 V rms for 0.25 s. At the higher relay settings, it is not possible to limit the fault voltage to 1500 V rms hence higher fault voltages have to be tolerated (indicated by *, **, ***).

The Metrosil units normally recommended for use with 5 A CTs and single pole relays are as shown in the following table:

| Secondary Internal Fault Current | Recommended Metrosil Type | | | |
|---|---|---|---|---|
| | Stability Voltage | | | |
| | Up to 200 V rms | 250 V rms | 275 V rms | 300 V rms |
| 50 A rms | 600A/S1/S1213<br>C = 540/640<br>35 mA rms | 600A/S1/S1214<br>C = 670/800<br>40 mA rms | 600A/S1/S1214<br>C = 670/800<br>50 mA rms | 600A/S1/S1223<br>C = 740/870*<br>50 mA rms |
| 100 A rms | 600A/S2/P/S1217<br>C = 470/540<br>70 mA rms | 600A/S2/P/S1215<br>C = 570/670<br>75 mA rms | 600A/S2/P/S1215<br>C = 570/670<br>100 mA rms | 600A/S2/P/S1196<br>C = 620/740*<br>100 mA rms |
| 150 A rms | 600A/S3/P/S1219<br>C = 430/500<br>100 mA rms | 600A/S3/P/S1220<br>C = 520/620<br>100 mA rms | 600A/S3/P/S1221<br>C = 570/670**<br>100 mA rms | 600A/S3/P/S1222<br>C = 620/740***<br>100 mA rms |

*2400 V peak
**2200 V peak
***2600 V peak

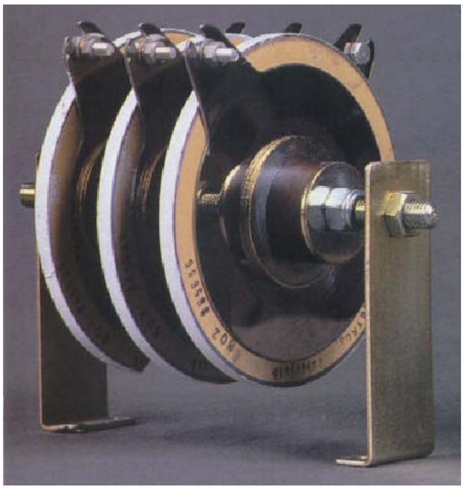
In some situations single disc assemblies may be acceptable, contact ALSTOM for detailed applications.

Note:

1. The Metrosil units recommended for use with 5 A CTs can also be applied for use with triple pole relays and consist of three single pole units mounted on the same central stud but electrically insulated for each other. To order these units please specify "Triple pole Metrosil type", followed by the single pole type reference.
2. Metrosil units for higher stability voltage and fault currents can be supplied if required.

Single pole Metrosil unit without brackets:

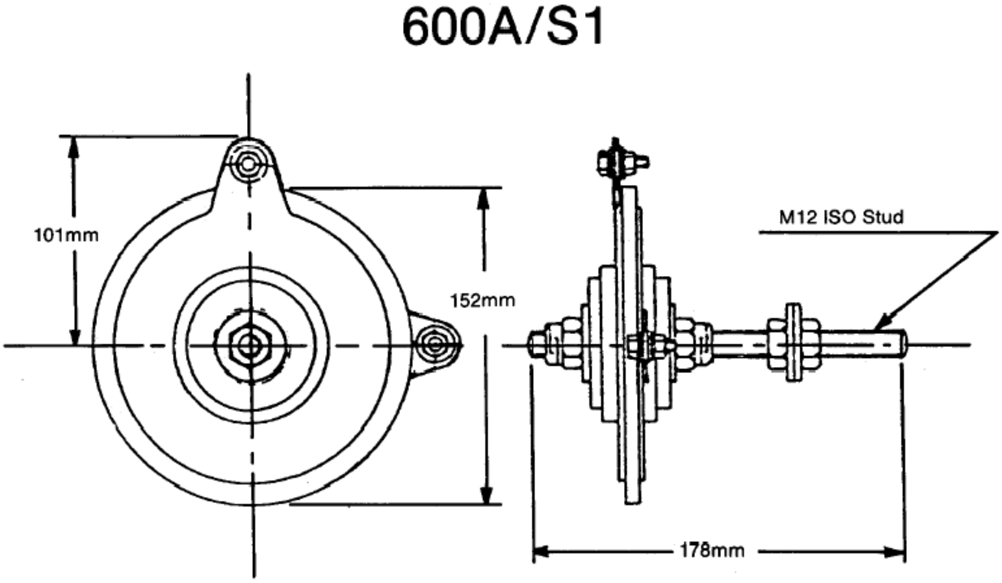
Triple pole Metrosil unit with brackets:



Dimensions and weights of Metrosil units:

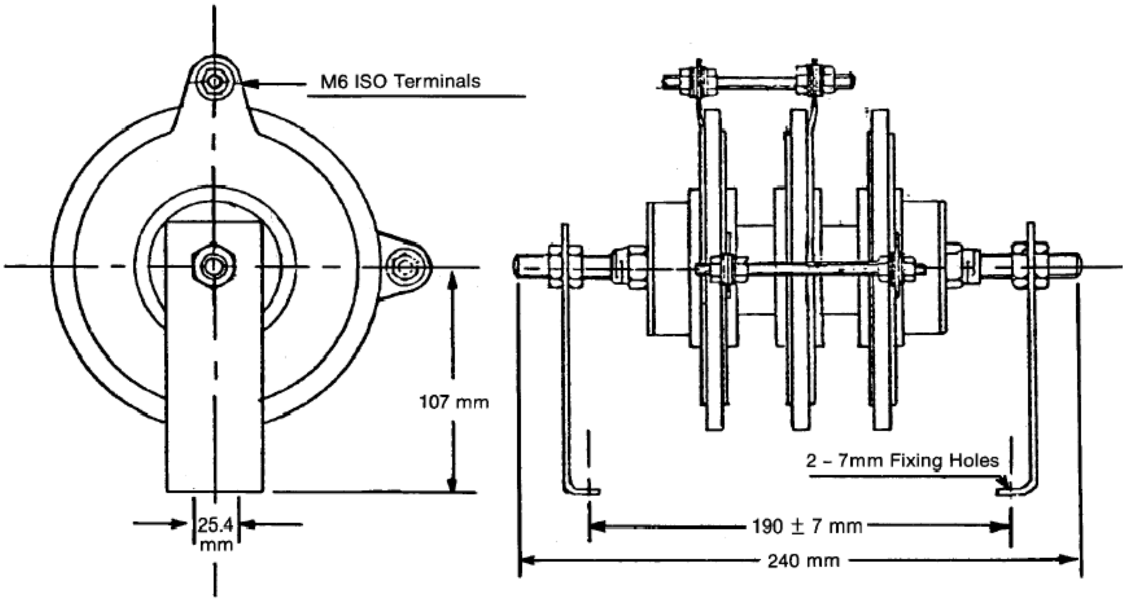
| Metrosil Unit Type | Stud Length | Fixing Centers | Unit Weight |
|---|---|---|---|
| 600A/S1 without mounting brackets<br>600A/S1 with mounting brackets | 178 mm<br>178 mm | –<br>100 ± 25 mm | 1.2 kg<br>1.2 kg |
| 600A/S2/P | 240 mm | 170 ± 25 mm | 2.3 kg |
| 600A/S3/P<br>600A/S3/I | 240 mm | 190 ± 7 mm | 3.1 kg |
| Triple Pole 600A/S2/P | 406 mm | 340 ± 20 mm | 5.8 kg |
| Triple Pole 600A/S3/P | 508 mm | 457 ± 7 mm | 8.5 kg |

Outline sketch of single pole Metrosil unit without mounting brackets:



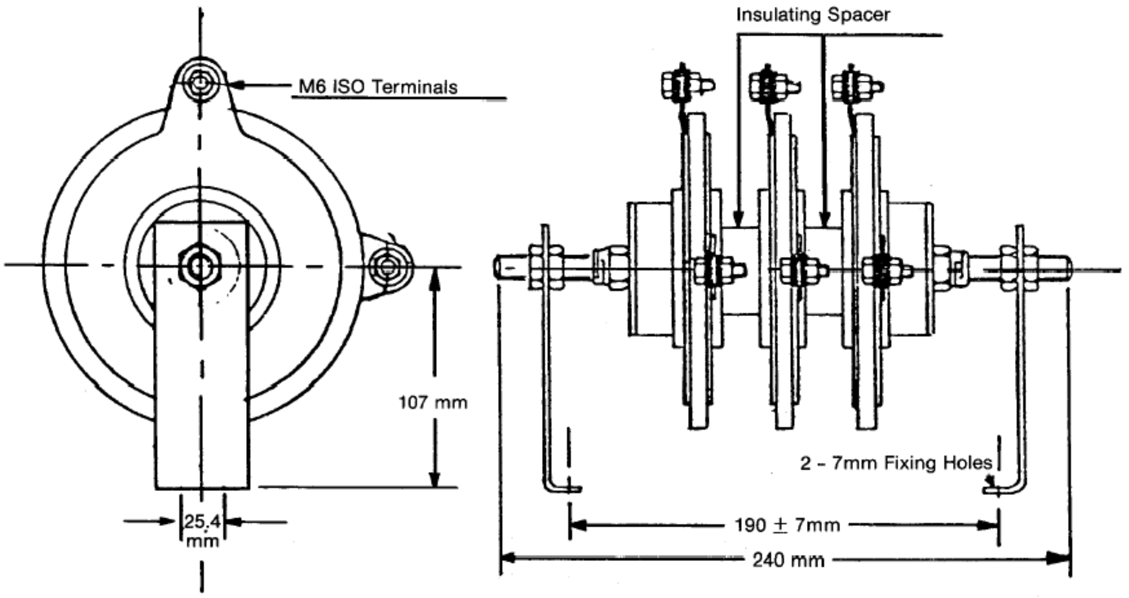
Outline sketch of single pole Metrosil unit comprising three disks in parallel:

600A/S3/P



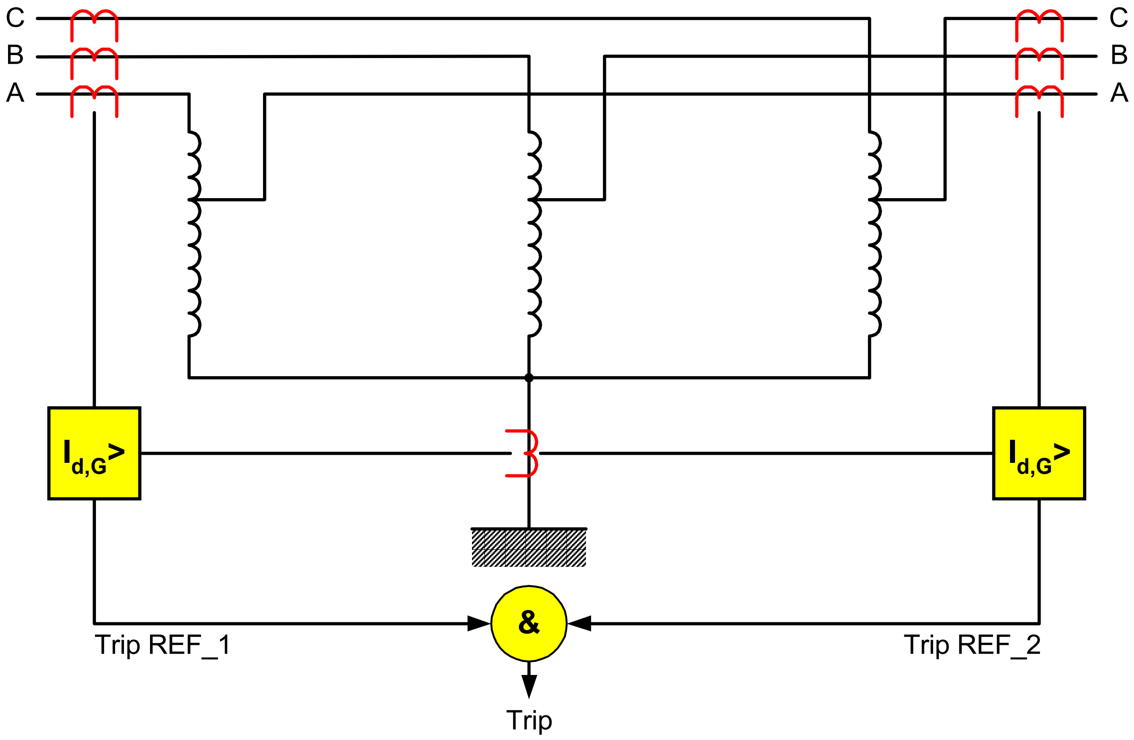
Outline sketch of triple pole Metrosil unit comprising one single disk each:

600A/S3/I



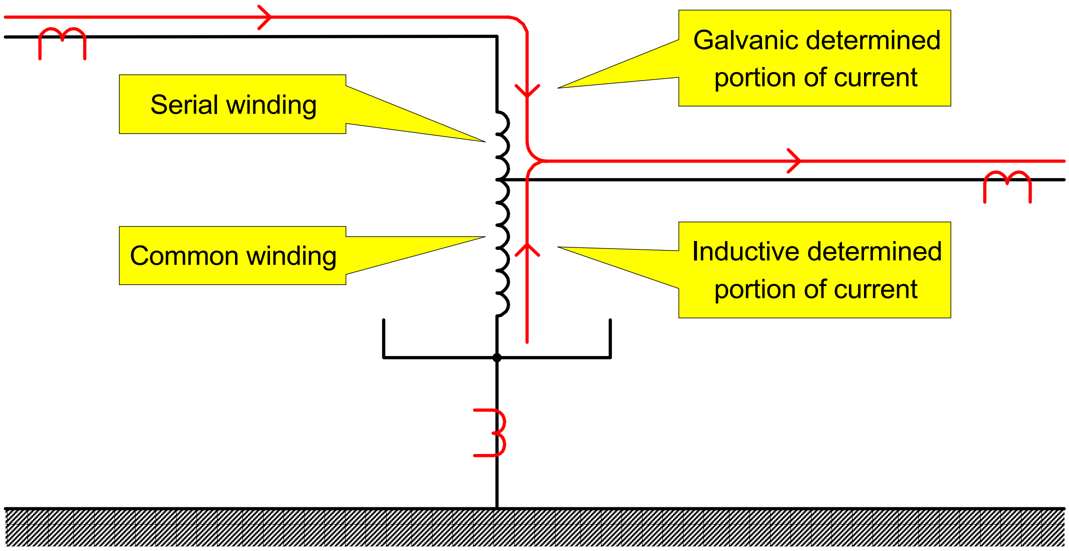
# 5 Application on Autotransformers

Aside from high impedance principle biased restricted earth fault protection may also be applied with autotransformers. For this an independent operating restricted earth fault protection element is used for each end. The trip decision is obtained by the Boolean AND operation on both trip signals:

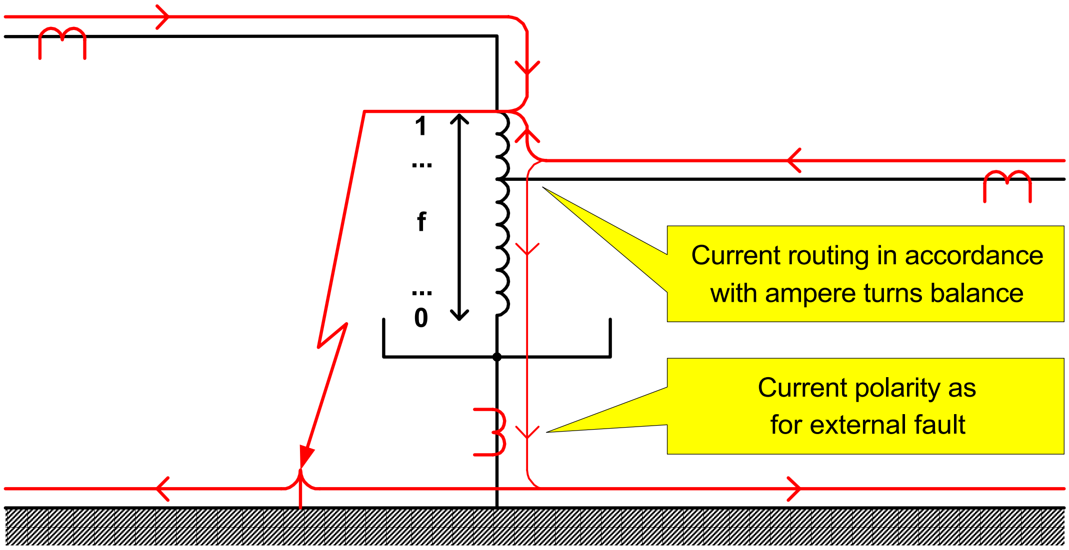


Since SW version -603 MiCOM P63x devices provide this Boolean AND operation of the two trip signals as fixed logic. Hence the use of the programmable scheme logic is not required.

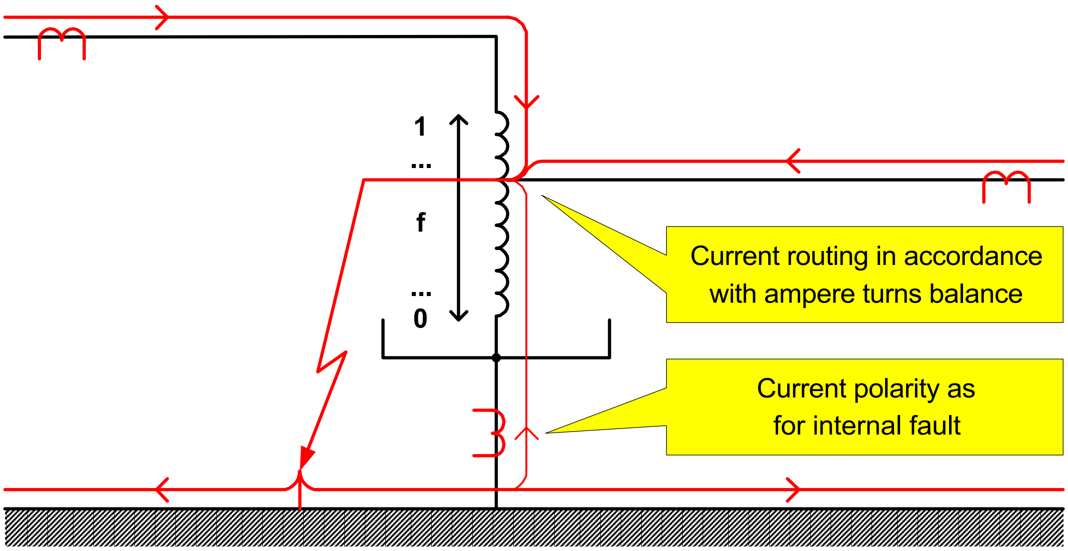
Please note that the sensitivity of restricted earth fault protection with autotransformers is different to the sensitivity of restricted earth fault protection with separate-winding transformers. A current through the serial winding of an autotransformer induces a current through the common winding that is determined by the rule of ampere turns balance in terms of amplitude and polarity. In case of symmetrical load an inductively generated portion of current flows always from star point through the common winding which is neutralized in star point by the other two phase currents. The current from star point to common grounding is zero:



In case of a ground-fault being considered in the zone of the serial winding of an autotransformer, infeed from low-voltage side results in paradoxical polarity of the current flowing through star-point grounding. Due to the rule of ampere turns balance a current is induced in the common winding of which the polarity is such as for an external fault:



By moving the fault location in the direction of the common winding, a polarity reversal of the star-point current is achieved – depending on infeed condition and based on the rule of ampere turns balance – at least at low-voltage connection point:



Current routing in accordance with ampere turns balance

Current polarity as for internal fault

The insensitivity of restricted earth fault protection for fault loactions within the serial winding of an autotransformer is not critical in practice since those ground-faults result in high phase currents which can be detected by transformer differential protection without any problem.

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