MiCOM 30 Series
Transformer Differential Protection

Application Guide

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ALSTOM

Contents

Appendix

A Vector Groups and Transformer Configurations

Symbols and Subscripts

Symbols

$\underline{I}$	Current phasor
$\underline{a}$	Operator for phase rotation of +120°
V	Voltage
φ	Angle
S	Power
k	Matching factor

Subscripts

prim	Primary quantity
sec	Secondary quantity
rel	Variable within relay
nom	Nominal quantity
ref	Reference quantity
max	Maximum value
max-1	Second largest value
mid	Mean value
min	Minimum value
CT	Main current transformer (set)
A, B, C	Phase A, B, or C
x	Dummy variable for phase A, B, or C
x+1	Dummy variable for the lagging phase in the cycle with respect to phase A, B, or C
x-1	Dummy variable for the leading phase in the cycle with respect to phase A, B, or C
amp	Amplitude-matched
vec	Amplitude-matched and vector-group-matched (including zero-sequence current filtering)
zero	Zero-sequence component
pos	Positive-sequence component
neg	Negative-sequence component
1, 2, 3	Measuring system 1, 2, or 3
y	Dummy variable for measuring system 1, 2, or 3
a, b, c, d	End or winding a, b, c, or d of the protected object
z	Dummy variable for end or winding a, b, c, or d of the protected object
d	Differential variable
R	Restraining variable

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.

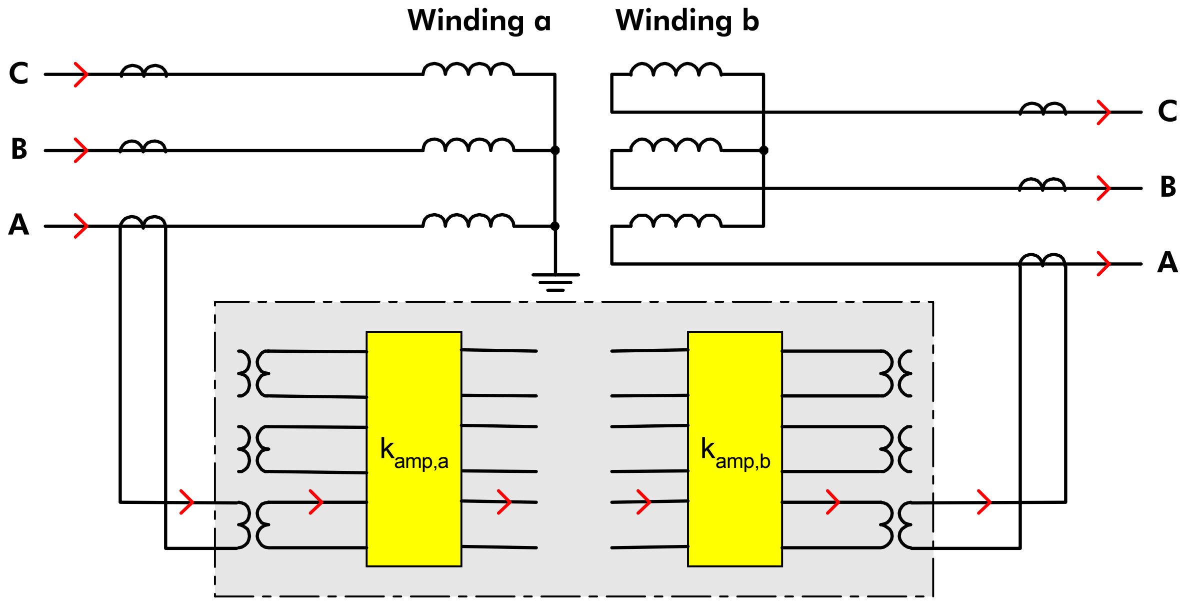
The present application guide is intended to close this gap. For the transformer differential protection function group of MiCOM P63x devices, the purpose is to give the reader a better understanding of the design of the individual function blocks and then to provide related instructions for settings,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

2 Mode of Operation and Basic Setting Instructions

Transformer differential protection is based on the principle of comparison of measured variables, i.e., the instantaneous values of the phase currents of all ends are compared with one another. Both the absolute value and the phase of the measured variables in question are included in the current comparison.

2.1 Amplitude Matching

Before the phase currents of the individual windings or ends can be compared, they must first be matched with respect to the absolute value transformations resulting from the rated transformation ratios of the transformer and the main current transformer.



$$I_{x,a}^{(prim)} \Rightarrow I_{x,a}^{(sec)} \Rightarrow I_{x,a}^{(rel)} \Rightarrow I_{amp,x,a} \qquad I_{amp,x,b} \Leftarrow I_{x,b}^{(rel)} \Leftarrow I_{x,b}^{(sec)} \Leftarrow I_{x,b}^{(prim)}$$

The goal of amplitude matching is that in fault-free operation under idealized conditions the corresponding phase currents of the individual ends will be scaled so that they are equivalent in absolute value. Phase currents that have been matched so as to be equal in absolute value are referred to as amplitude-matched phase currents:

$$I_{amp,x,a} = I_{amp,x,b}$$

Scaling to produce identical absolute values is achieved by means of one amplitude-matching factor k_{amp} for each end:

$$k_{amp,a} \cdot I_{x,a}^{(rel)} = k_{amp,b} \cdot I_{x,b}^{(rel)}$$

The phase current in the relays can be expressed as primary phase current for each end by means of the individual rated transformation ratios, i.e., via the nominal current of the relay and the secondary and primary nominal current of the main current transformer:

$$k_{amp,a} \cdot I_{x,a}^{(rel)} = k_{amp,b} \cdot I_{x,b}^{(rel)}$$

$$k_{amp,a} \cdot \frac{I_{x,a}^{(sec)}}{I_{nom,rel,a}} = k_{amp,b} \cdot \frac{I_{x,b}^{(sec)}}{I_{nom,rel,b}}$$

$$k_{amp,a} \cdot \frac{I_{x,a}^{(prim)}}{\frac{I_{nom,CT,a}^{(prim)}}{I_{nom,CT,a}^{(sec)}} \cdot I_{nom,rel,a}} = k_{amp,b} \cdot \frac{I_{x,b}^{(prim)}}{\frac{I_{nom,CT,b}^{(prim)}}{I_{nom,CT,b}^{(sec)}} \cdot I_{nom,rel,b}}$$

Under the condition that for each end the nominal current of the relay and the secondary nominal current of the main current transformer agree, we obtain:

$$k_{amp,a} \cdot \frac{I_{x,a}^{(prim)}}{I_{nom,CT,a}^{(prim)}} = k_{amp,b} \cdot \frac{I_{x,b}^{(prim)}}{I_{nom,CT,b}^{(prim)}}$$

The ratio of the primary currents is obtained from the ratio of the nominal transformer voltages as follows:

$$\frac{I_{x,a}^{(prim)}}{I_{x,b}^{(prim)}} = \frac{k_{amp,b} \cdot I_{nom,CT,a}^{(prim)}}{k_{amp,a} \cdot I_{nom,CT,b}^{(prim)}} = \frac{V_{nom,b}^{(prim)}}{V_{nom,a}^{(prim)}}$$

As one can see, the equation does not determine the absolute values of the individual amplitude-matching factors but rather the ratio of these factors:

$$\frac{k_{amp,a}}{k_{amp,b}} = \frac{V_{nom,a}^{(prim)} \cdot I_{nom,CT,a}^{(prim)}}{V_{nom,b}^{(prim)} \cdot I_{nom,CT,b}^{(prim)}}$$

The absolute value of the amplitude-matching factors in each case is now defined advantageously so that matching results in scaling to the nominal transformer currents. This is done by introducing reference power S_{ref} as a common reference quantity for all ends:

$$\frac{k_{amp,a}}{k_{amp,b}} = \frac{V_{nom,a}^{(prim)} \cdot I_{nom,CT,a}^{(prim)}}{V_{nom,b}^{(prim)} \cdot I_{nom,CT,b}^{(prim)}} = \frac{\frac{I_{nom,CT,a}^{(prim)}}{\frac{1}{V_{nom,a}^{(prim)}}}}{\frac{I_{nom,CT,b}^{(prim)}}{\frac{1}{V_{nom,b}^{(prim)}}}} = \frac{\frac{I_{nom,CT,a}^{(prim)}}{\frac{S_{ref}^{(prim)}}{\sqrt{3} \cdot V_{nom,a}^{(prim)}}}}{\frac{I_{nom,CT,b}^{(prim)}}{\frac{S_{ref}^{(prim)}}{\sqrt{3} \cdot V_{nom,b}^{(prim)}}}} = \frac{\frac{I_{nom,CT,a}^{(prim)}}{I_{ref,a}^{(prim)}}}{\frac{I_{nom,CT,b}^{(prim)}}{I_{ref,b}^{(prim)}}}$$

Scaling to the nominal transformer currents is thus only possible in cases in which the nominal powers of the individual windings of all ends are equal and can thus be set to be the common reference power S_{ref}. In three-winding transformers, the nominal powers of the individual windings generally differ. In such cases it is recommended that the nominal power of the highest-power winding be set as the reference power S_{ref}.

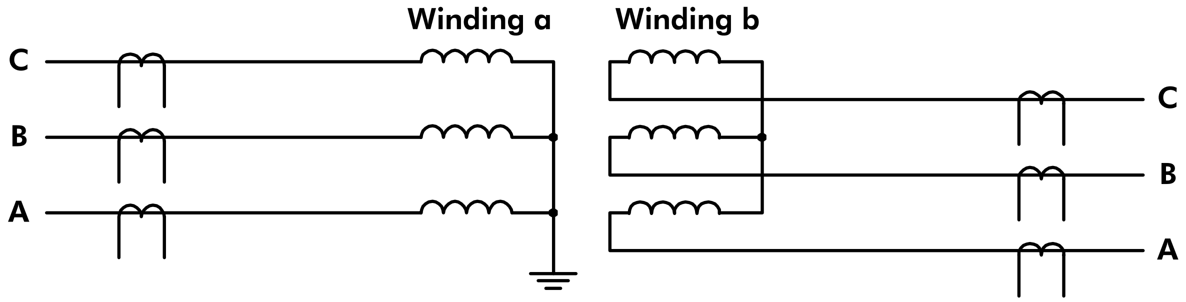
In each case, a *common* reference power S_{ref} must be set for *all* ends. The amplitude-matching factors are obtained in each case as follows:

$$k_{amp,z} = \frac{I_{nom,CT,z}^{(prim)}}{I_{ref,z}^{(prim)}} = \frac{I_{nom,CT,z}^{(prim)}}{\dfrac{S_{ref}^{(prim)}}{\sqrt{3} \cdot V_{nom,z}^{(prim)}}}$$

The amplitude-matched phase currents are formed by scalar multiplication, whereby the individual phase currents are multiplied by the corresponding amplitude-matching factor:

$$\underline{I}_{amp,x,z} = k_{amp,z} \cdot \underline{I}_{x,z} = \frac{I_{nom,CT,z}^{(prim)}}{I_{ref,z}^{(prim)}} \cdot \underline{I}_{x,z} = \frac{I_{nom,CT,z}^{(prim)}}{\dfrac{S_{ref}^{(prim)}}{\sqrt{3} \cdot V_{nom,z}^{(prim)}}} \cdot \underline{I}_{x,z}$$

Setting the amplitude-matching function is very simple and does not require any calculations. Only the following primary nominal values need to be set:



$$I_{nom,CT,a}^{(prim)} \qquad V_{nom,a}^{(prim)} \qquad V_{nom,b}^{(prim)} \qquad I_{nom,CT,b}^{(prim)}$$

$$S_{ref}^{(prim)} = S_{nom,max}^{(prim)}$$

The amplitude-matching factors are calculated automatically by the protection device. The device also checks automatically to see whether the resulting amplitude-matching factors $k_{amp,z}$ are within the limits specified by requirements of numerical processing:

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

$$k_{amp,z} \le 16$$

- The second-largest amplitude-matching factor $k_{amp,max-1}$ must not fall below a value of 0.5:

$$k_{amp,max-1} \ge 0.5$$

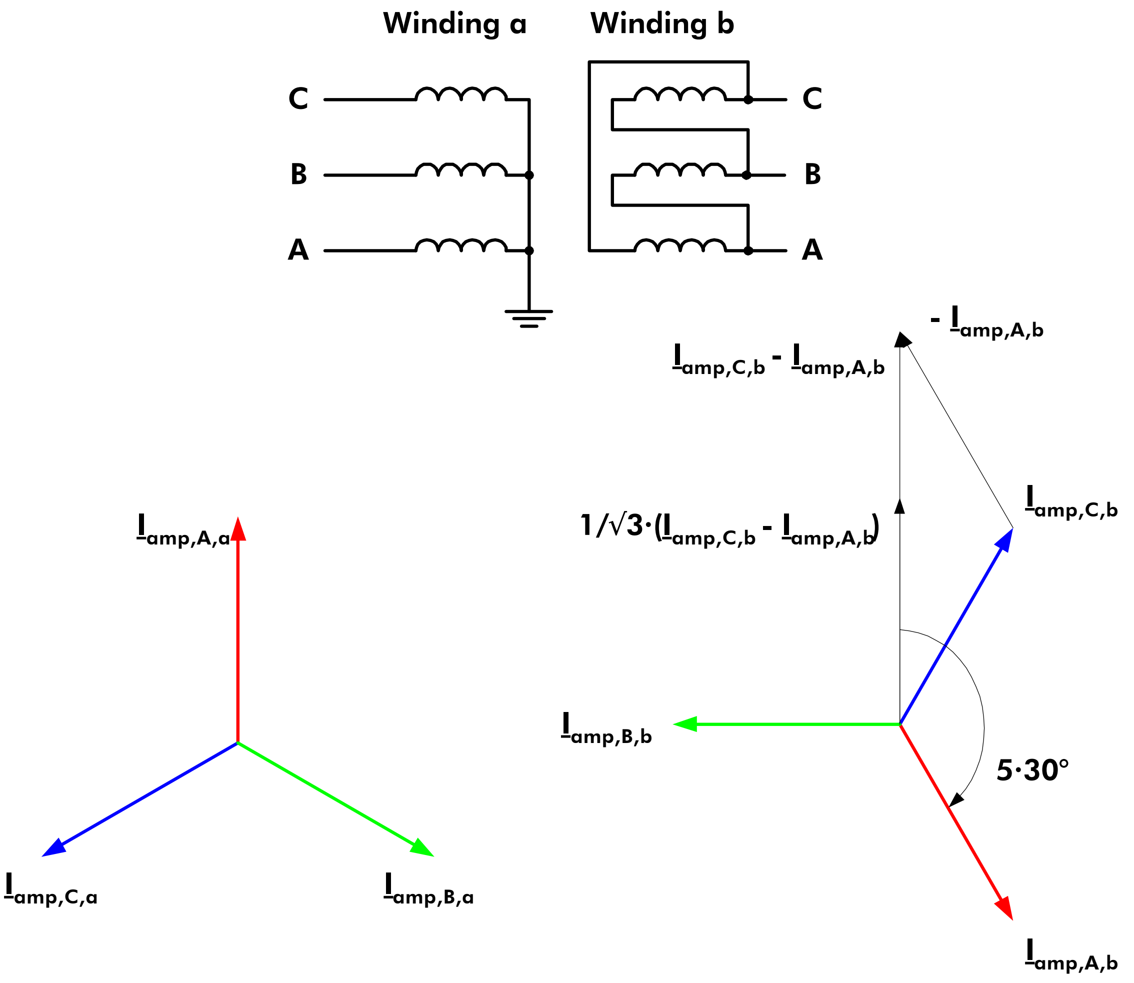
<u>Note</u>:
For the devices P631/632/633/634 the following harder restrictions are valid for SW versions -601 and -602:

$$k_{amp,z} \le 5 \qquad \frac{k_{amp,max}}{k_{amp,max-1}} \le 3 \qquad k_{amp,max-1} \ge 0.7$$

2.2 Vector Group Matching and Zero-Sequence Current Filtering

Since the phase of the measured variables is also included in the current comparison, the phase relations of the amplitude-matched phase currents of the ends in question must also be matched in accordance with the respective vector group. Basically, this matching operation can be carried out regardless of the phase winding connections, since the phase relation is described unambiguously by the characteristic vector group number.

Vector group matching is therefore performed solely by mathematical phasor operations on the amplitude-matched phase currents *of the low-voltage side* in accordance with the characteristic vector group number. This is shown in the following figure for vector group characteristic number 5, where vector group Yd5 is used as the example:



No operation is carried out on the high-voltage side in connection with vector group matching. However, one should note that the phase windings are connected in a wye configuration, the neutral of which is operationally grounded. In the event of system faults to ground, the circuit for the zero-sequence component of the fault current would close via the grounded neutral that lies within the transformer differential protection zone and would thus appear in the measuring systems as differential current. The consequence would be undesirable tripping.

For this reason the zero-sequence component of the three-phase system must be eliminated from the phase currents on the high-voltage side. In accordance with its definition, the zero-sequence current is determined as follows from the amplitude-matched phase currents:

$$\underline{I}_{amp,zero,z} = \frac{1}{3} \cdot \left(\underline{I}_{amp,A,z} + \underline{I}_{amp,B,z} + \underline{I}_{amp,C,z} \right)$$

On the low-voltage side, the zero-sequence current in the example shown above is automatically filtered out based on the mathematical phasor operations. This is not always necessary and also not always desired, but is basically the result of any subtraction of two phase current phasors:

$$\begin{aligned}
\underline{I}_{amp,A,z} &= \underline{I}_{amp,zero,z} + \underline{I}_{amp,pos,z} + \underline{I}_{amp,neg,z} \\
\underline{I}_{amp,B,z} &= \underline{I}_{amp,zero,z} + \underline{a}^2 \cdot \underline{I}_{amp,pos,z} + \underline{a} \cdot \underline{I}_{amp,neg,z} \\
\underline{I}_{amp,C,z} &= \underline{I}_{amp,zero,z} + \underline{a} \cdot \underline{I}_{amp,pos,z} + \underline{a}^2 \cdot \underline{I}_{amp,neg,z}
\end{aligned}$$

$$\begin{aligned}
\underline{I}_{amp,A,z} - \underline{I}_{amp,B,z} &= \left(1 - \underline{a}^2\right) \cdot \underline{I}_{amp,pos,z} + \left(1 - \underline{a}\right) \cdot \underline{I}_{amp,neg,z} \\
\underline{I}_{amp,B,z} - \underline{I}_{amp,C,z} &= \left(\underline{a}^2 - \underline{a}\right) \cdot \underline{I}_{amp,pos,z} + \left(\underline{a} - \underline{a}^2\right) \cdot \underline{I}_{amp,neg,z} \\
\underline{I}_{amp,C,z} - \underline{I}_{amp,A,z} &= \left(\underline{a} - 1\right) \cdot \underline{I}_{amp,pos,z} + \left(\underline{a}^2 - 1\right) \cdot \underline{I}_{amp,neg,z}
\end{aligned}$$

The following tables show that for all odd-numbered vector group characteristics the zero-sequence current on the low-voltage side is basically always filtered out, whereas for even-numbered vector group characteristics the zero-sequence current on the low-voltage side is basically never filtered out automatically. The latter is also true for the high-voltage side since in that case, as explained above, no mathematical phasor operations are performed.

Vector group matching and zero-sequence current filtering must therefore always be viewed in combination. The following tables list all the mathematical phasor operations.

Mathematical operations on the high-voltage side:

	With $\underline{I}_{zero}$ filtering	Without $\underline{I}_{zero}$ filtering
	$\underline{I}_{vec,y,z} = \underline{I}_{amp,x,z} - \underline{I}_{amp,zero,z}$	$\underline{I}_{vec,y,z} = \underline{I}_{amp,x,z}$

Mathematical operations on the low-voltage side for an even-numbered vector group characteristic:

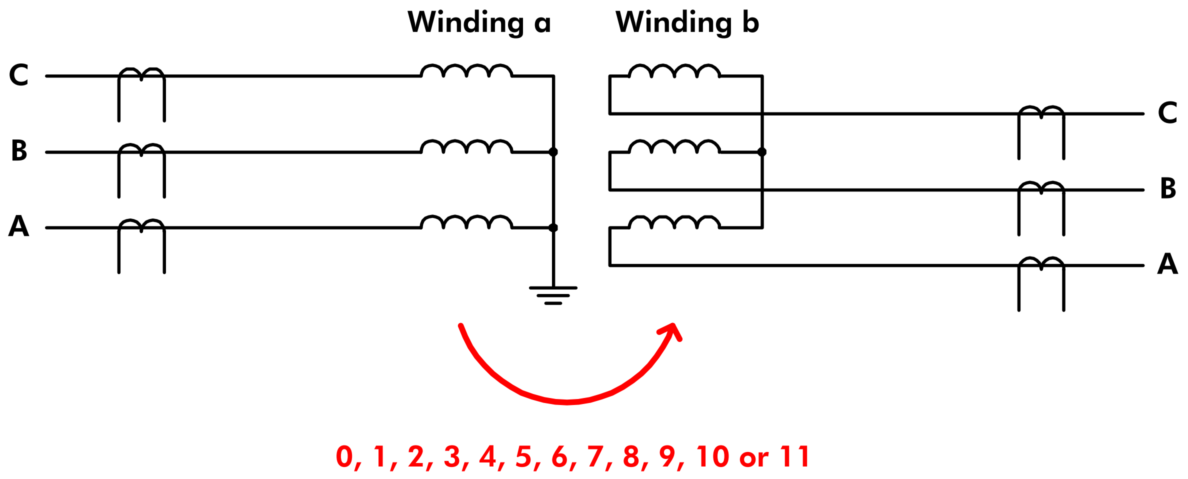
VG	With $\underline{I}_{\text{zero}}$ filtering	Without $\underline{I}_{\text{zero}}$ filtering
0	$\underline{I}_{\text{vec},y,z} = \underline{I}_{\text{amp},x,z} - \underline{I}_{\text{amp,zero},z}$	$\underline{I}_{\text{vec},y,z} = \underline{I}_{\text{amp},x,z}$
2	$\underline{I}_{\text{vec},y,z} = -\left(\underline{I}_{\text{amp},x+1,z} - \underline{I}_{\text{amp,zero},z}\right)$	$\underline{I}_{\text{vec},y,z} = -\underline{I}_{\text{amp},x+1,z}$
4	$\underline{I}_{\text{vec},y,z} = \underline{I}_{\text{amp},x-1,z} - \underline{I}_{\text{amp,zero},z}$	$\underline{I}_{\text{vec},y,z} = \underline{I}_{\text{amp},x-1,z}$
6	$\underline{I}_{\text{vec},y,z} = -\left(\underline{I}_{\text{amp},x,z} - \underline{I}_{\text{amp,zero},z}\right)$	$\underline{I}_{\text{vec},y,z} = -\underline{I}_{\text{amp},x,z}$
8	$\underline{I}_{\text{vec},y,z} = \underline{I}_{\text{amp},x+1,z} - \underline{I}_{\text{amp,zero},z}$	$\underline{I}_{\text{vec},y,z} = \underline{I}_{\text{amp},x+1,z}$
10	$\underline{I}_{\text{vec},y,z} = -\left(\underline{I}_{\text{amp},x-1,z} - \underline{I}_{\text{amp,zero},z}\right)$	$\underline{I}_{\text{vec},y,z} = -\underline{I}_{\text{amp},x-1,z}$

Mathematical operations on the low-voltage side for an odd-numbered vector group characteristic:

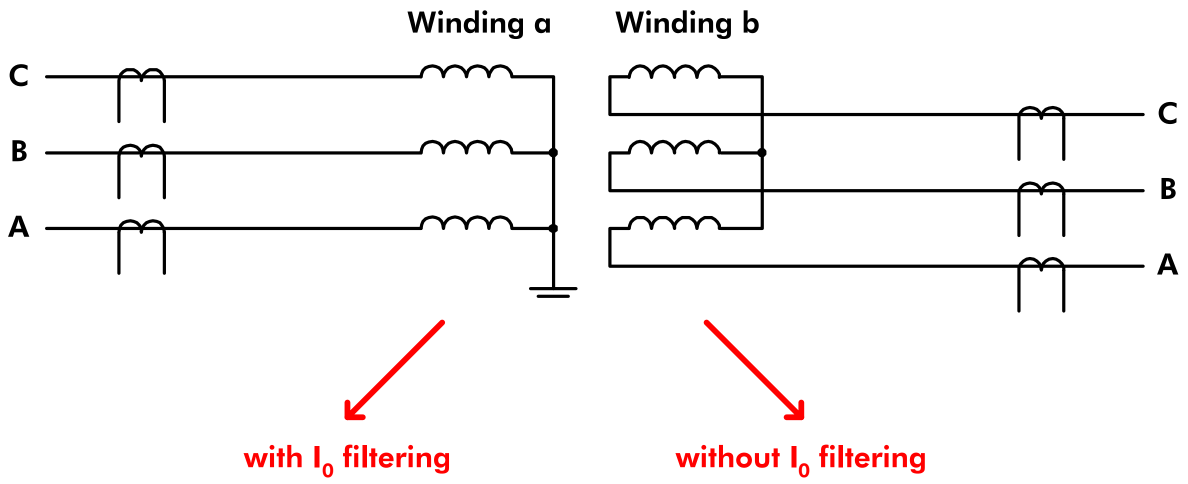
VG	With $\underline{I}_{\text{zero}}$ filtering	Without $\underline{I}_{\text{zero}}$ filtering
1	$\underline{I}_{\text{vec},y,z} = \frac{1}{\sqrt{3}} \cdot \left(\underline{I}_{\text{amp},x,z} - \underline{I}_{\text{amp},x+1,z}\right)$	$\underline{I}_{\text{vec},y,z} = \frac{1}{\sqrt{3}} \cdot \left(\underline{I}_{\text{amp},x,z} - \underline{I}_{\text{amp},x+1,z}\right) + \underline{I}_{\text{amp,zero},z}$
3	$\underline{I}_{\text{vec},y,z} = \frac{1}{\sqrt{3}} \cdot \left(\underline{I}_{\text{amp},x-1,z} - \underline{I}_{\text{amp},x+1,z}\right)$	$\underline{I}_{\text{vec},y,z} = \frac{1}{\sqrt{3}} \cdot \left(\underline{I}_{\text{amp},x-1,z} - \underline{I}_{\text{amp},x+1,z}\right) + \underline{I}_{\text{amp,zero},z}$
5	$\underline{I}_{\text{vec},y,z} = \frac{1}{\sqrt{3}} \cdot \left(\underline{I}_{\text{amp},x-1,z} - \underline{I}_{\text{amp},x,z}\right)$	$\underline{I}_{\text{vec},y,z} = \frac{1}{\sqrt{3}} \cdot \left(\underline{I}_{\text{amp},x-1,z} - \underline{I}_{\text{amp},x,z}\right) + \underline{I}_{\text{amp,zero},z}$
7	$\underline{I}_{\text{vec},y,z} = \frac{1}{\sqrt{3}} \cdot \left(\underline{I}_{\text{amp},x+1,z} - \underline{I}_{\text{amp},x,z}\right)$	$\underline{I}_{\text{vec},y,z} = \frac{1}{\sqrt{3}} \cdot \left(\underline{I}_{\text{amp},x+1,z} - \underline{I}_{\text{amp},x,z}\right) + \underline{I}_{\text{amp,zero},z}$
9	$\underline{I}_{\text{vec},y,z} = \frac{1}{\sqrt{3}} \cdot \left(\underline{I}_{\text{amp},x+1,z} - \underline{I}_{\text{amp},x-1,z}\right)$	$\underline{I}_{\text{vec},y,z} = \frac{1}{\sqrt{3}} \cdot \left(\underline{I}_{\text{amp},x+1,z} - \underline{I}_{\text{amp},x-1,z}\right) + \underline{I}_{\text{amp,zero},z}$
11	$\underline{I}_{\text{vec},y,z} = \frac{1}{\sqrt{3}} \cdot \left(\underline{I}_{\text{amp},x,z} - \underline{I}_{\text{amp},x-1,z}\right)$	$\underline{I}_{\text{vec},y,z} = \frac{1}{\sqrt{3}} \cdot \left(\underline{I}_{\text{amp},x,z} - \underline{I}_{\text{amp},x-1,z}\right) + \underline{I}_{\text{amp,zero},z}$

Note:
For the devices P631/632/633/634 the addition of zero-sequence current in case of odd numbered vector groups (column ‚Without $\underline{I}_{\text{zero}}$ filtering’) are not realized for SW versions -601 and -602.

Setting the vector group matching function is very simple and does not require any calculations. Only the characteristic vector group number needs to be set:



Setting the zero-sequence current filtering function is very simple and does not require any calculations. Zero-sequence current filtering should only be activated for those ends where there is operational grounding of a neutral point:



2.3 Tripping Characteristic

After the currents of the individual ends have been matched, the transformer being protected can be viewed as a current node as defined by the first Kirchhoff law. According to this law, the sum of the current phasors of all ends is equal to zero in fault-free operation under idealized conditions. Only an internal fault in the protection zone of differential protection will generate a phasor sum of end currents that differs from zero, namely the differential current I_d. The magnitude of the differential current I_d can therefore be used as the criterion for detecting an internal fault.

In practice, however, differential currents even occur in fault-free operation and can be attributed essentially to the following influencing factors:

- Magnetizing transformer current, which flows only from the infeed end and therefore appears as differential current
- Current-dependent transformation errors of the participating current transformer sets, which also result in a differential current

Whereas the magnetizing current is determined by the level of the system voltage and can therefore be viewed as constant, irrespective of load level, the transformation errors of the participating current transformer sets are a function of the respective current level. The threshold value of a transformer differential protection device is therefore not implemented as a constant differential current threshold but is formed as a function of the restraining current I_R. The restraining current corresponds to the current level in the transformer being protected. The function $I_d = f(I_R)$ is represented as the tripping characteristic in the I_d-I_R plane.

2.3.1 Definition of I_d and I_R

According to the first Kirchhoff law, the differential current I_d is always defined as the phasor sum of the end currents:

$$I_{d,y} = \left| \underline{I}_{vec,y,a} + \underline{I}_{vec,y,b} + \underline{I}_{vec,y,c} + \cdots \right|$$

The restraining current I_R represents the through-current of the transformer being protected, and for two-winding differential protection it is defined as the phasor difference, as follows:

$$I_{R,y} = \frac{1}{2} \cdot \left| \underline{I}_{vec,y,a} - \underline{I}_{vec,y,b} \right|$$

When the infeed to an internal fault from both ends is exactly equal as regards amplitude and angle, then both currents cancel one another out, i.e., the restraining current becomes zero and the restraining effect disappears. Disappearance of the restraining effect when there is an internal fault is a desirable result since in this case transformer differential protection attains maximum sensitivity.

In the case of transformer differential protection for more than two ends, we must work with a different definition of restraining current I_R since the phasor difference between more than two variables is not defined:

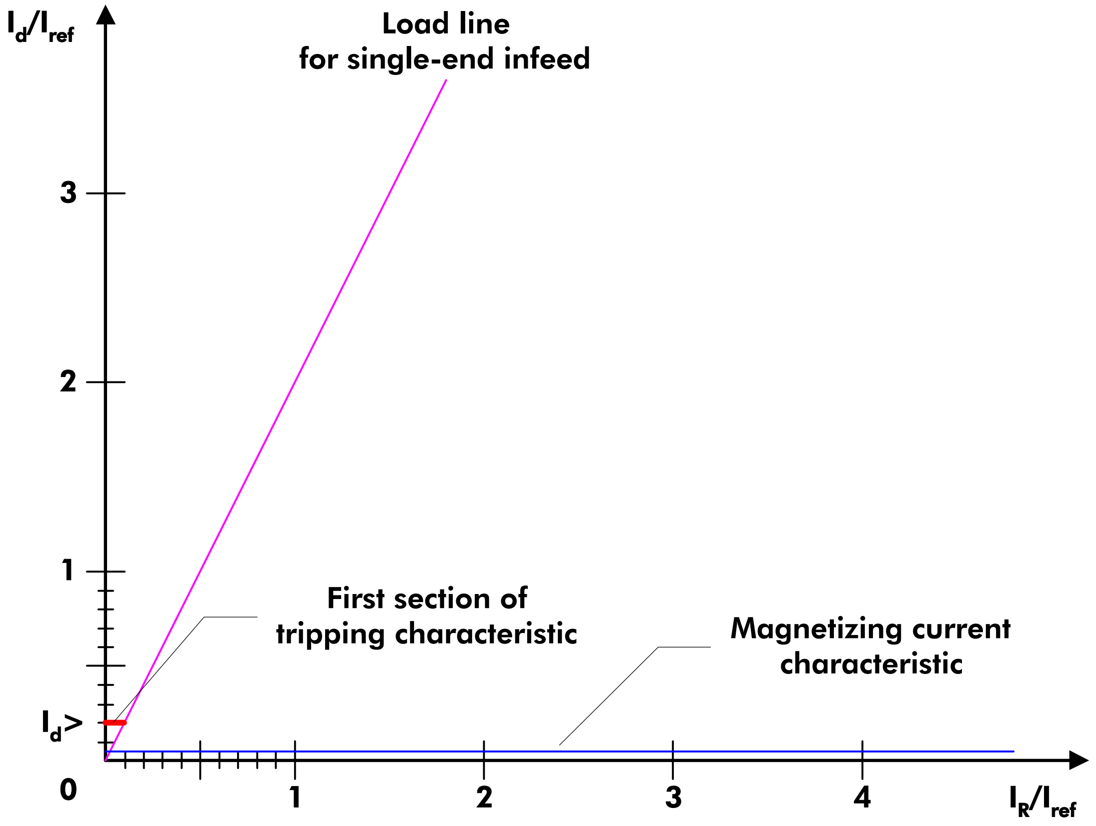
$$I_{R,y} = \frac{1}{2} \cdot \left(\left| \underline{I}_{vec,y,a} \right| + \left| \underline{I}_{vec,y,b} \right| + \left| \underline{I}_{vec,y,c} \right| + \cdots \right)$$

In this case the restraining effect never disappears when there is an internal fault; the restraining effect is even reinforced in the case of multi-end infeed. However, the restraining current factor ½ means that the differential current I_d has twice the value of the restraining current I_R so that safe and reliable tripping is also guaranteed in the case of multi-end infeed.

2.3.2 First Section of the Tripping Characteristic

The first section represents the most sensitive region of the tripping characteristic in the form of the settable basic threshold value $I_d>$. The default setting of 0.2 takes into account the magnetizing current of the transformer, which flows even in a no-load condition and is generally less than 5% of the nominal transformer current.

The first section of the tripping curve runs horizontally until it reaches the load line for single-end infeed. This is advantageous for commissioning and testing. In the case of single-end infeed, the desired characteristic value is always identical to the set basic threshold value $I_d>$ so that in this regard no special calculation of the characteristic threshold value is necessary.



The line of the first section of the tripping curve corresponds to the horizontal line of differential current, given the basic threshold value $I_d>$. The characteristic equation for the first section of the tripping characteristic is as follows:

$$I_{d,y}\left(I_{R,y}\right) = I_d >$$

The intersection of the first section of the tripping curve with the load line occurs at a restraining current $I_{R,m1}$, which is a function of the setting of the basic threshold value $I_d>$:

$$I_{R,m1} = 0.5 \cdot I_d >$$

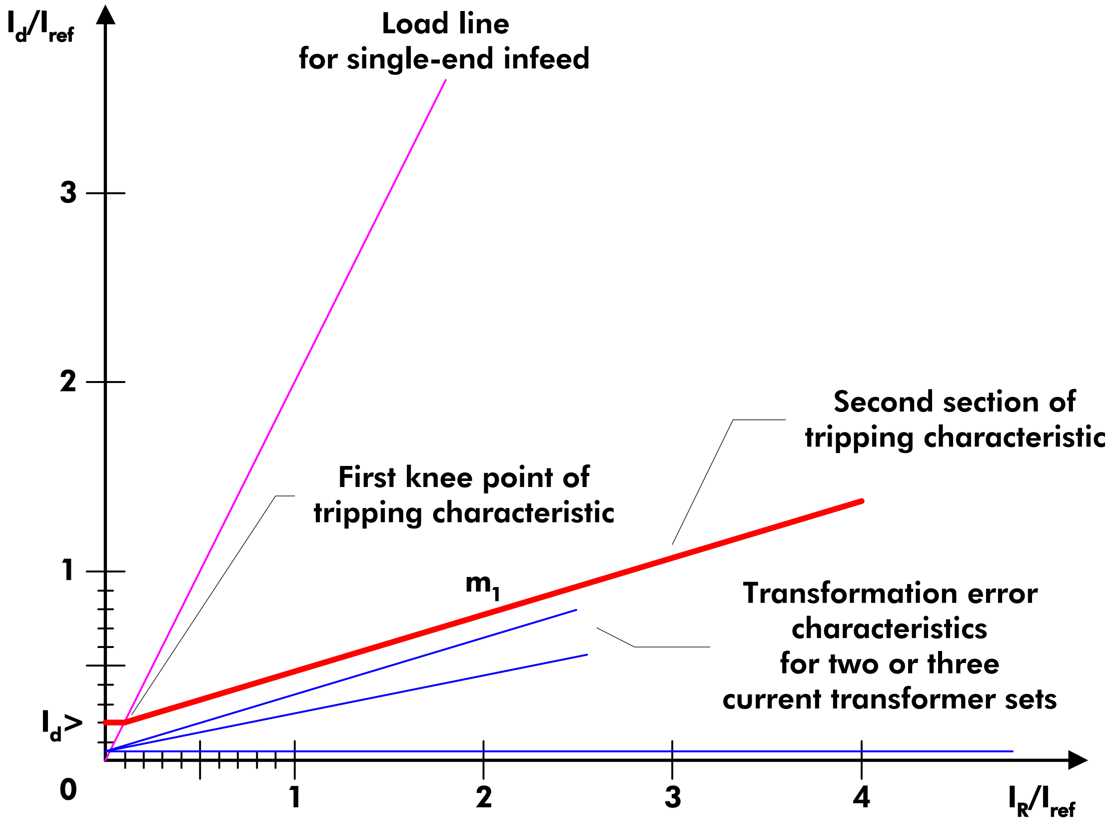
2.3.3 Second Section of the Tripping Characteristic

The second section of the tripping curve covers the load current range, so that in this section we must reckon not only with the transformer magnetizing current, which appears as differential current, but also with differential currents that can be attributed to the transformation errors of the current transformer sets.

If we calculate the "worst case" with Class 10P current transformers, then the maximum allowable amplitude error according to DIN EN 60044-1 is 3 % for nominal current. The phase-angle error can be assumed to be 2° for nominal current. The maximum allowable total error for nominal current is then obtained, in approximation, as (0.0-3 + sin 2°) ≈ 6.5 %. If the current is increased to the nominal accuracy limit current, then the total error for Class 10P current transformers can be 10 % maximum. Beyond the nominal accuracy limit current, the transformation error can be of any magnitude.

The dependence of the total error of a current transformer on current is therefore non-linear. In the operating current range, i.e., in the current range below the nominal accuracy limit current, we can expect a "worst case" total error of approximately 10 % per current transformer set.

The second section of the tripping characteristic forms a straight line, the slope of which should correspond to the cumulative total error of the participating current transformer sets. The curve slope m_1 can be set. The default setting for m_1 is defined as 0.3 with respect to protection of three-winding transformers.



The line of the second section of the tripping characteristic runs through the intersection of the load line for single-end infeed with the line of the first section of the tripping characteristic. The characteristic equation for the second section of the tripping characteristic is as follows:

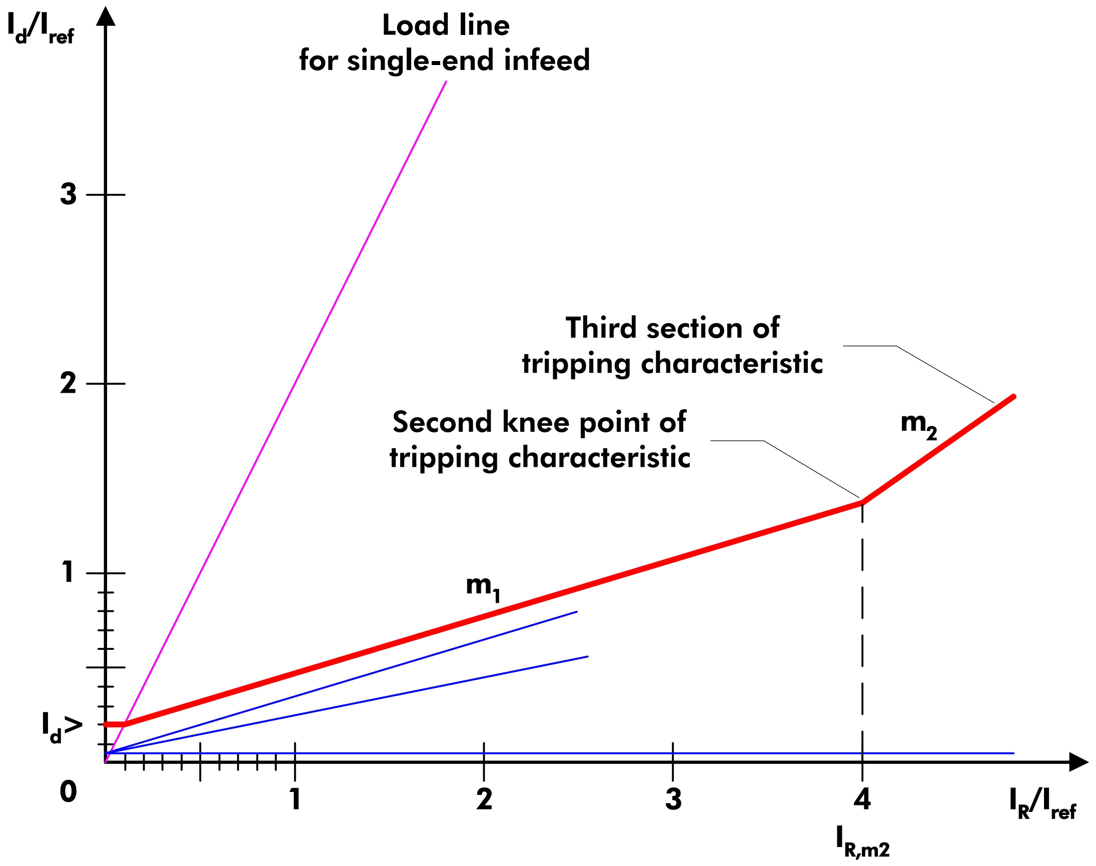
$$I_{d,y}\left(I_{R,y}\right) = m_1 \cdot I_{R,y} + I_d > \cdot\left(1 - 0{,}5 \cdot m_1\right)$$

A parallel shift of the first section of the tripping curve resulting from a change in the basic threshold value $I_d>$ also brings about a parallel shift of the second section of the tripping curve.

2.3.4 Third Section of the Tripping Characteristic

The second knee point of the tripping characteristic determines the end of the overcurrent zone in the direction of increasing restraining current in fault-free operation. It can be as high as four times the nominal current in certain operating cases – such as when a parallel transformer has failed.

Therefore, the second knee point can be set ($I_{R,m2}$) for a default setting of $4 \cdot I_{ref}$. $I_{R,m2}$ must be set in accordance with the maximum possible operating current.



Restraining currents that go beyond the set knee point are then evaluated as continuous fault currents. For truly *continuous* fault currents, the third section of the tripping characteristic could therefore be given an infinitely large slope. Since, however, we also need to take into account the possibility that a fault can occur in the transformer differential protection zone as the result of the system fault, a finite slope m_2 is provided for the third section of the tripping curve. The default setting for m_2 is 0.7.

The line of the third section of the tripping characteristic runs through the intersection of the vertical restraining current line at $I_{R,m2}$ with the line for the second section of the tripping characteristic. The characteristic equation for the third section of the tripping characteristic is as follows:

$$I_{d,y}(I_{R,y}) = m_2 \cdot I_{R,y} + I_d > \cdot (1 - 0{,}5 \cdot m_1) + I_{R,m2} \cdot (m_1 - m_2)$$

A parallel shift of the first section of the tripping characteristic resulting from a change in the basic threshold value $I_d>$ also brings about a parallel shift of the third section of the tripping characteristic.

2.3.5 Algorithmic Treatment of I_d and I_R

For evaluating differential current I_d and restraining current I_R in the I_d-I_R plane, the instantaneous values of the rectified quantities are not used since they do not guarantee stable tripping under all conditions.

Differential current I_d and restraining current I_R therefore undergo numerical smoothing. One purpose of this smoothing is to provide the lowest possible residual ripple; it should also be characterized by the shortest possible settling time (transient recovery time). Since the two requirements are contradictory in nature, a balance must be struck between the two. *Double* smoothing of differential current I_d and restraining current I_R is achieved as the result of complicated algorithmic analysis.

The rectified differential current I_d and the rectified restraining current I_R first undergo half-period, non-recursive smoothing, which has a very fast settling time. The starting quantities for this first smoothing operation are referred to as singly smoothed quantities.

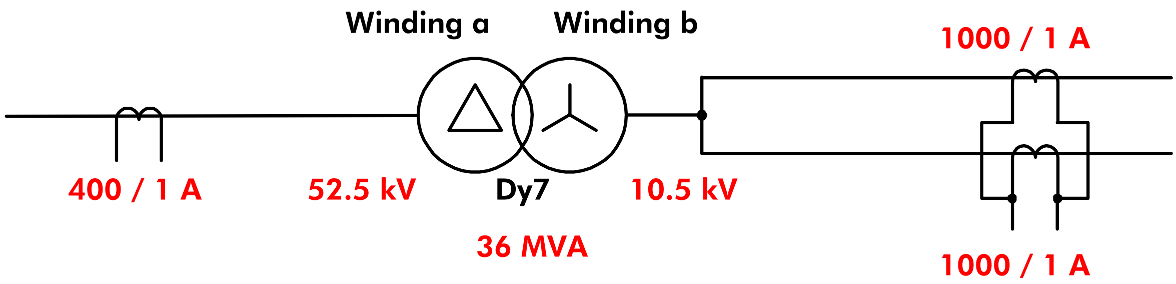
In a subsequent second smoothing operation, the singly smoothed quantities undergo an additional recursive smoothing process. The starting quantities for this second smoothing operation are referred to as doubly smoothed quantities.

3 Setting Instructions for Special Applications

3.1 Unfavorable Primary Nominal Transformer Current

➔ Amplitude Matching

In rare cases, there may be the problem that one of the conditions for the amplitude matching factors is no longer satisfied. The following example shows one such case:



~~$S_{ref,prim}$ = 36 MVA~~

~~$I_{ref,prim,a}$ = 396 A~~
~~$k_{amp,a}$ = 1.010~~

~~$k_{amp,a}$ / $k_{amp,b}$ = 2~~

~~$I_{ref,prim,b}$ = 1979 A~~
~~$k_{amp,b}$ = 0.505~~

$S_{ref,prim}$ = 25 MVA

$I_{ref,prim,a}$ = 275 A
$k_{amp,a}$ = 1.455

$k_{amp,a}$ / $k_{amp,b}$ = 2

$I_{ref,prim,b}$ = 1375 A
$k_{amp,b}$ = 0.727

If one selects the nominal power S_{nom} of the transformer as the reference power S_{ref}, as is recommended, then the condition $k_{amp} \geq 0.7$ is not satisfied on the low-voltage side. This is due to the unusually large difference between the primary nominal current of the main current transformer set, which is only 1000 A, and the nominal and reference current of the transformer low-voltage winding, which is 1979 A.
One solution is to vary the reference power. The ratio of the amplitude matching factor calculated above to the minimum required amplitude matching factor is 0.505 / 0.7 = 0.72. If we reduce the reference power that was set above by at least this factor to $0.72 \cdot 36$ MVA = 25.9 MVA ≈ 25 MVA, then amplitude matching is possible without any problem.

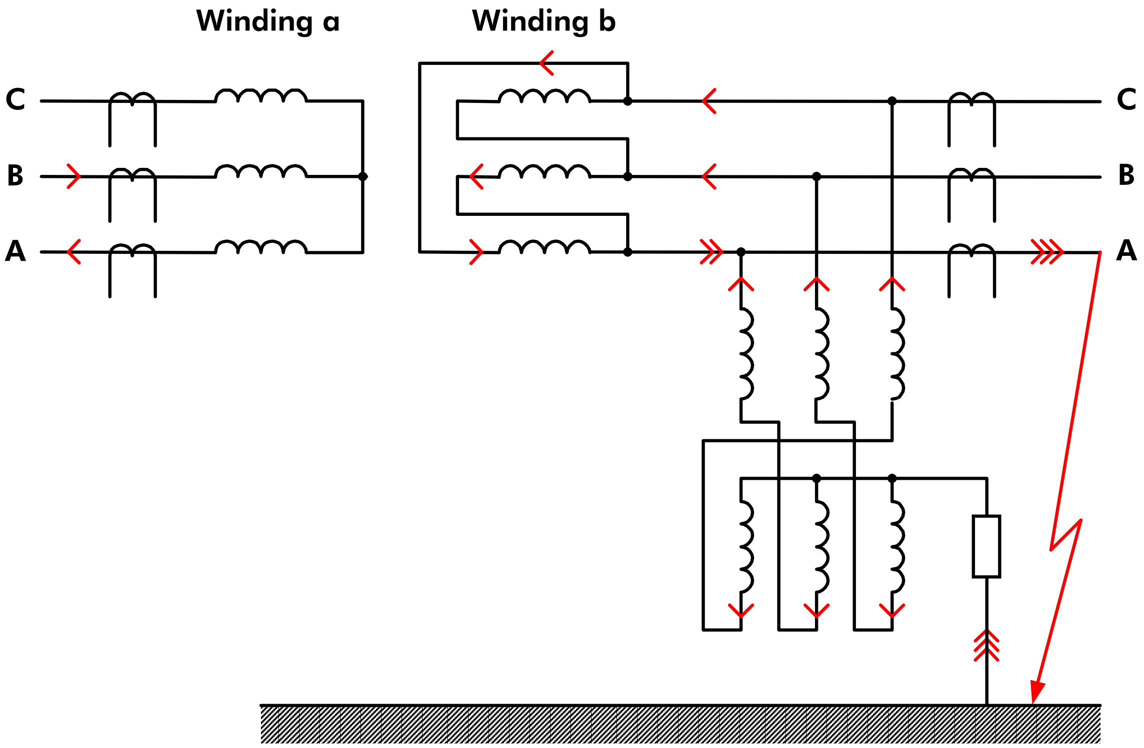
➔ Tripping Characteristic

One should note, however, that due to amplitude matching, which differs from the nominal transformer quantities, the phase currents are rated more highly by a factor of 1.455 / 1.010 = 1.44. For this reason, the basic threshold value Id> of the tripping characteristic should be increased by the same factor to $1.44 \cdot 0.2 = 0.288 \approx 0.3$.

3.2 In-Zone Grounding Transformer

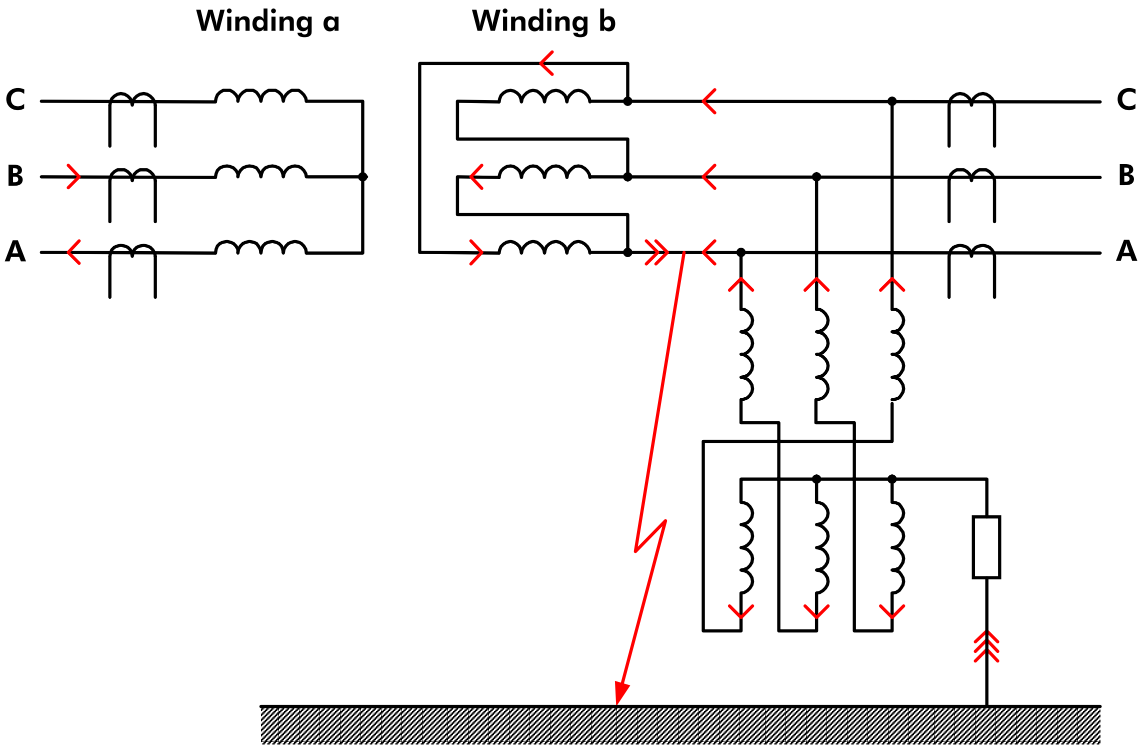
➔ Vector Group Matching and Zero-Sequence Current Filtering

If there is a grounding transformer on one end of the transformer within the zone of protection, then zero-sequence current filtering must always be activated on this end. This applies even if the phase windings on the grounding transformer end are delta-connected. Basically, zero-sequence current filtering must always be enabled if there is operational neutral grounding in the zone of protection on the end in question.
The following diagram shows the current distribution for such a configuration in the event of an external single-phase-to-ground fault:



On the high-voltage side, zero-sequence current filtering remains deactivated because the neutral point is not grounded, so that no current phasor operation is necessary for forming the vector-group-matched current variables.
Worthy of note on the low-voltage side are both zero-sequence current filtering and vector group matching for the characteristic vector group number 5, in connection with the fact that the phase currents of the low-voltage side must be set to be a factor of √3 smaller than the phase currents of the high-voltage side. This means that for the phase C measuring system the matched currents of both sides are zero and that for the phase A and B measuring systems the matched currents of the two sides cancel one another out.

In the case of an internal single-phase fault, on the other hand, transformer differential protection will be tripped. The following diagram shows the corresponding current distribution in the case of single-end infeed of the fault from the high-voltage side:

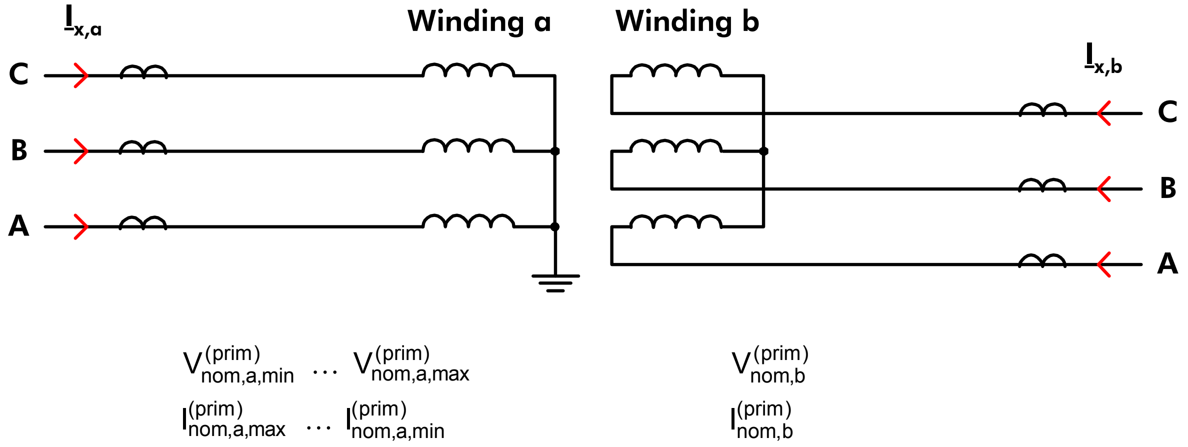


In the case of single-end infeed of the fault from the high-voltage side, the current transformer set on the low-voltage side remains at zero current. When the phase currents on the high-voltage side in Phases A and B are of sufficient intensity, they lead to tripping of transformer differential protection.

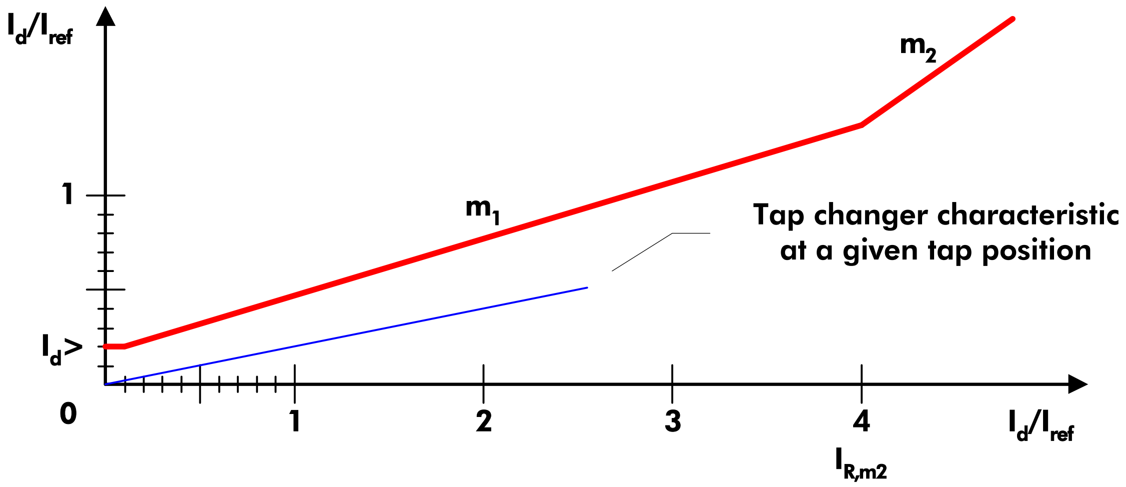
3.3 Tap-Changing Transformers

➔ Amplitude Matching

The infeed transformer is equipped with a tap changer on its high-voltage end for regulating the voltage of the input system. The rated transformation ratio of the transformer is changed by adjusting the tap changer, i.e., the nominal voltage on the high-voltage side and also the corresponding nominal current on the high-voltage side are not constant but are determined by a range which corresponds to the range of adjustment of the tap changer.



Amplitude matching can therefore only occur for a mean nominal voltage on the high-voltage side that still needs to be defined. Depending on the actual tap-change position, there appears a differential current I_d that is more or less large and increases linearly with the restraining current I_R. An adjustment of the tap changer brings about a change in the slope of this tap changer characteristic.



With regard to the tripping characteristic of differential protection, amplitude matching must be carried out by selecting a suitable mean value for the nominal voltage on the high-voltage side such that the slope of the tap changer curve is identical for the two outermost tapping positions:

$$\frac{\left|\underline{I}_{vec,y,a,max} + \underline{I}_{vec,y,b}\right|}{\frac{1}{2}\cdot\left|\underline{I}_{vec,y,a,max} - \underline{I}_{vec,y,b}\right|} = \frac{\left|\underline{I}_{vec,y,a,min} + \underline{I}_{vec,y,b}\right|}{\frac{1}{2}\cdot\left|\underline{I}_{vec,y,a,min} - \underline{I}_{vec,y,b}\right|}$$

For a load flow from the high-voltage side a in the direction of the low-voltage side b, $\underline{I}_{vec,y,a} = I_{vec,y,a}$ and $\underline{I}_{vec,y,b} = -I_{vec,y,b}$:

$$\frac{\left|I_{vec,y,a,max} - I_{vec,y,b}\right|}{\frac{1}{2}\cdot\left|I_{vec,y,a,max} + I_{vec,y,b}\right|} = \frac{\left|I_{vec,y,a,min} - I_{vec,y,b}\right|}{\frac{1}{2}\cdot\left|I_{vec,y,a,min} + I_{vec,y,b}\right|}$$

Furthermore, $I_{vec,y,a,max} > I_{vec,y,b}$ and $I_{vec,y,a,min} < I_{vec,y,b}$:

$$\frac{I_{vec,y,a,max} - I_{vec,y,b}}{I_{vec,y,a,max} + I_{vec,y,b}} = \frac{I_{vec,y,b} - I_{vec,y,a,min}}{I_{vec,y,a,min} + I_{vec,y,b}}$$

With the desired mean value $I_{vec,y,a,mid} = I_{vec,y,b}$, amplitude matching is complete:

$$\frac{I_{vec,y,a,max} - I_{vec,y,a,mid}}{I_{vec,y,a,max} + I_{vec,y,a,mid}} = \frac{I_{vec,y,a,mid} - I_{vec,y,a,min}}{I_{vec,y,a,min} + I_{vec,y,a,mid}}$$

$$\begin{aligned} &I_{vec,y,a,max}\cdot I_{vec,y,a,min} + I_{vec,y,a,max}\cdot I_{vec,y,a,mid} - I_{vec,y,a,mid}\cdot I_{vec,y,a,min} - I^2_{vec,y,a,mid} = \\ &= I_{vec,y,a,max}\cdot I_{vec,y,a,mid} - I_{vec,y,a,max}\cdot I_{vec,y,a,min} - I_{vec,y,a,mid}\cdot I_{vec,y,a,min} + I^2_{vec,y,a,mid} \end{aligned}$$

$$2\cdot I^2_{vec,y,a,mid} = 2\cdot I_{vec,y,a,max}\cdot I_{vec,y,a,min}$$

$$I_{vec,y,a,mid} = \sqrt{I_{vec,y,a,max}\cdot I_{vec,y,a,min}}$$

For amplitude matching, therefore, the geometric mean of the minimum and maximum nominal voltage must be set on the high-voltage side:

$$V^{(prim)}_{nom,a,mid} = \sqrt{V^{(prim)}_{nom,a,min}\cdot V^{(prim)}_{nom,a,max}}$$

➔ Tripping Characteristic

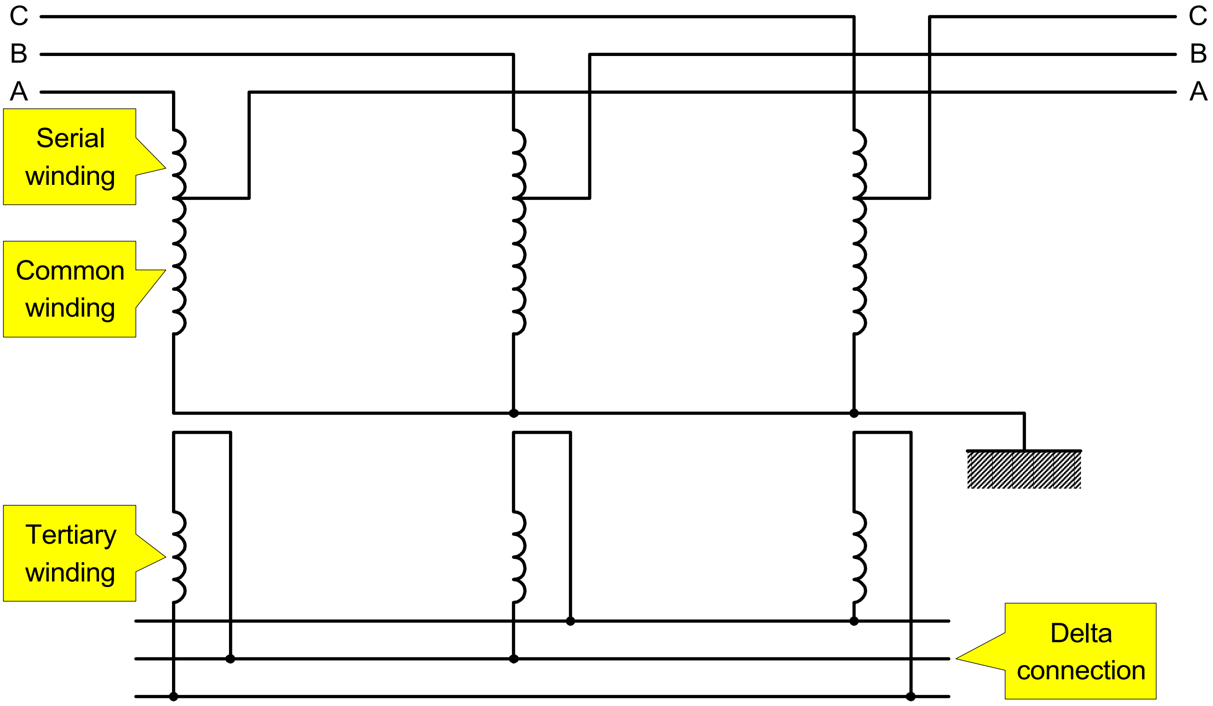
Slope m_1 of the second section of the tripping characteristic must be increased in accordance with the slope of the tap changer characteristic for the outermost tapping position, i.e., the setting for m_1 must be increased by the following value:

$$\frac{I^{(prim)}_{nom,a,max} - I^{(prim)}_{nom,a,mid}}{\frac{1}{2}\cdot\left(I^{(prim)}_{nom,a,max} + I^{(prim)}_{nom,a,mid}\right)} \quad \text{or} \quad \frac{I^{(prim)}_{nom,a,mid} - I^{(prim)}_{nom,a,min}}{\frac{1}{2}\cdot\left(I^{(prim)}_{nom,a,min} + I^{(prim)}_{nom,a,mid}\right)}$$

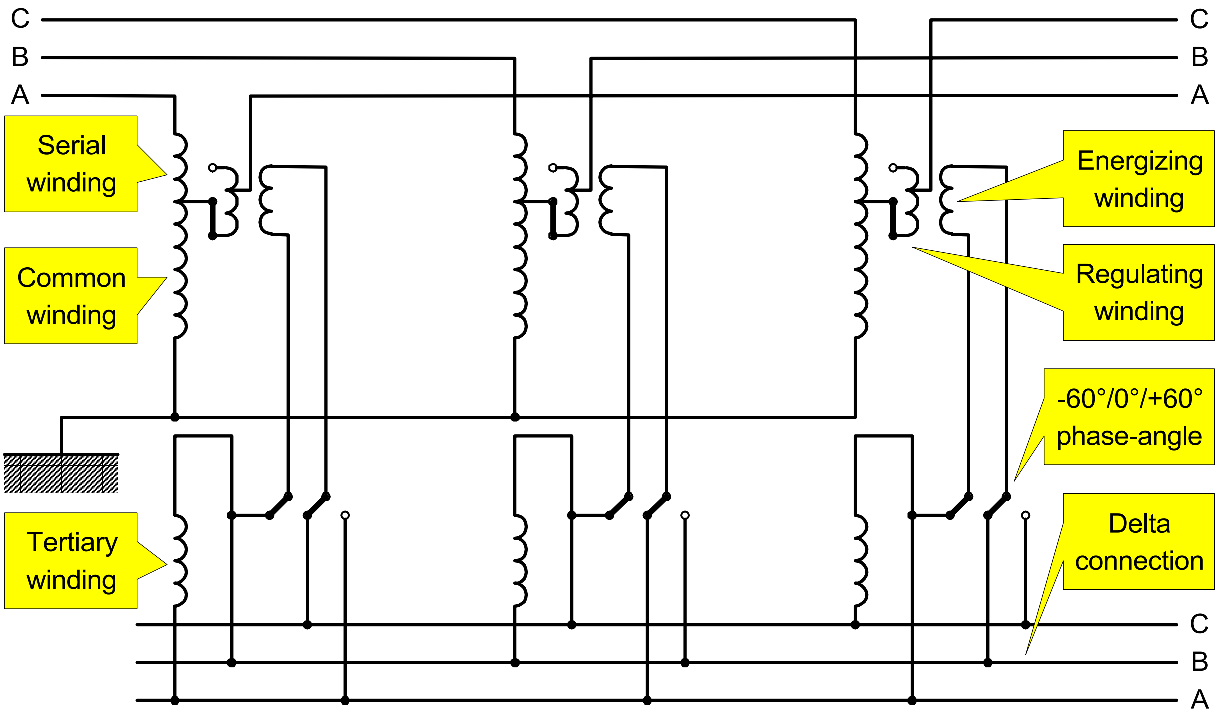
3.4 Autotransformers

Autotransformers are designed as three-phase units or consist of a group of three single-phase units. They are used for interconnection of solidly grounded EHV and HV networks if the rated voltages of both networks don't differ by more than factor 2 to 3. Material and weight as well as losses can be saved by autotransformers compared with separate-winding transformers.

Autotransformers with star connection of primary and secondary winding (serial and common winding) are usually equipped with a delta stabilizing winding (tertiary winding) rated about one third of the throughput rating.



Shunt reactors or capacitors for power factor correction can be connected to such a tertiary winding. A booster transformer consisting of energizing and regulating winding for voltage adjustment by in-phase or phase-angle regulation can be accommodated in the same tank.



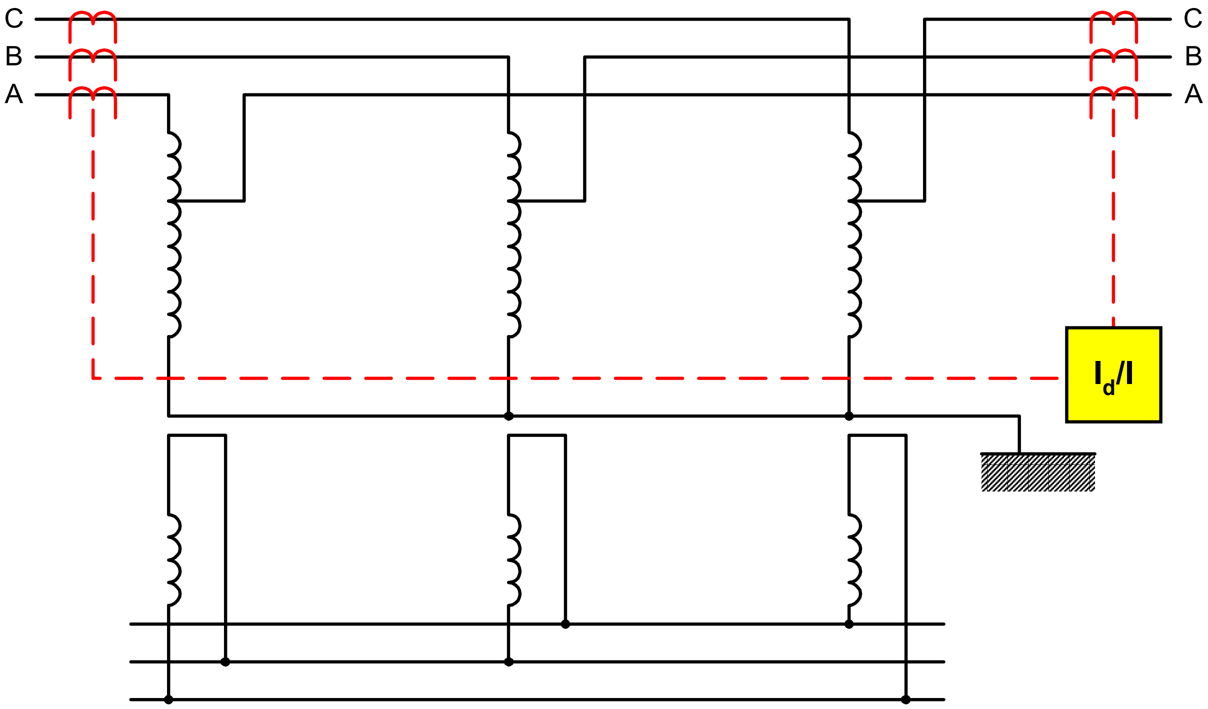
Depending on the application various possibilities with different features can be used for differential protection of autotransformers:

	Delta tertiary winding without feeders	Neutral grounding with phase-segregated CTs	CTs in series with delta tertiary winding	CTs outside delta tertiary winding
Differential protection	Two-end	Three-end	Three-end	Three-end
Amplitude matching	$V_{nom,a} \neq V_{nom,b}$ 1)	$V_{nom,a} = V_{nom,b}$ $= V_{nom,c}$ 1)	$\sqrt{3} \cdot V_{nom,c}$ 1)	$V_{nom,c}$ 1)
Vector group matching	$VG_{a-b} = 0$	$VG_{a-b} = 0$ $VG_{a-c} = 0$	$VG_{a-b} = 0$ $VG_{a-c} = 0$	$VG_{a-b} = 0$ $VG_{a-c} = odd$
Zero sequence current filt.	With	Without	Without	With
Inrush stabilization	With	Without	With	With
Phase-segregation	No	Yes	Yes	No
Affected by voltage adjustment	Yes	No	No	Yes
Sensitivity for ground faults	Low	High	High	Low
Protection against turn-to-turn faults	Yes	No	Yes	Yes
Protection of the delta tertiary winding	No	No	Yes	Yes

Each individual application is discussed below.

3.4.1 Delta Tertiary Winding without Feeders

A two-end differential protection may be applied in any case if the tertiary winding is used as delta stabilizing winding only i.e. if there is no additional feeding from the tertiary winding:



The setting of the differential protection corresponds to the setting of a separate-winding transformer with neutral grounding at both ends.

3.4.2 Neutral Grounding with Phase-Segregated CTs

In case of neutral grounding with phase-segregated CTs it's the ideal solution to apply a three-end differential protection. The protected zone corresponds to a galvanic connected electrical node.

➔ Amplitude Matching

Because of the galvanic connected electrical node the primary nominal voltages of all three ends have to be set to the same value (primary nominal voltage of the serial or of the common winding).

➔ Vector Group Matching

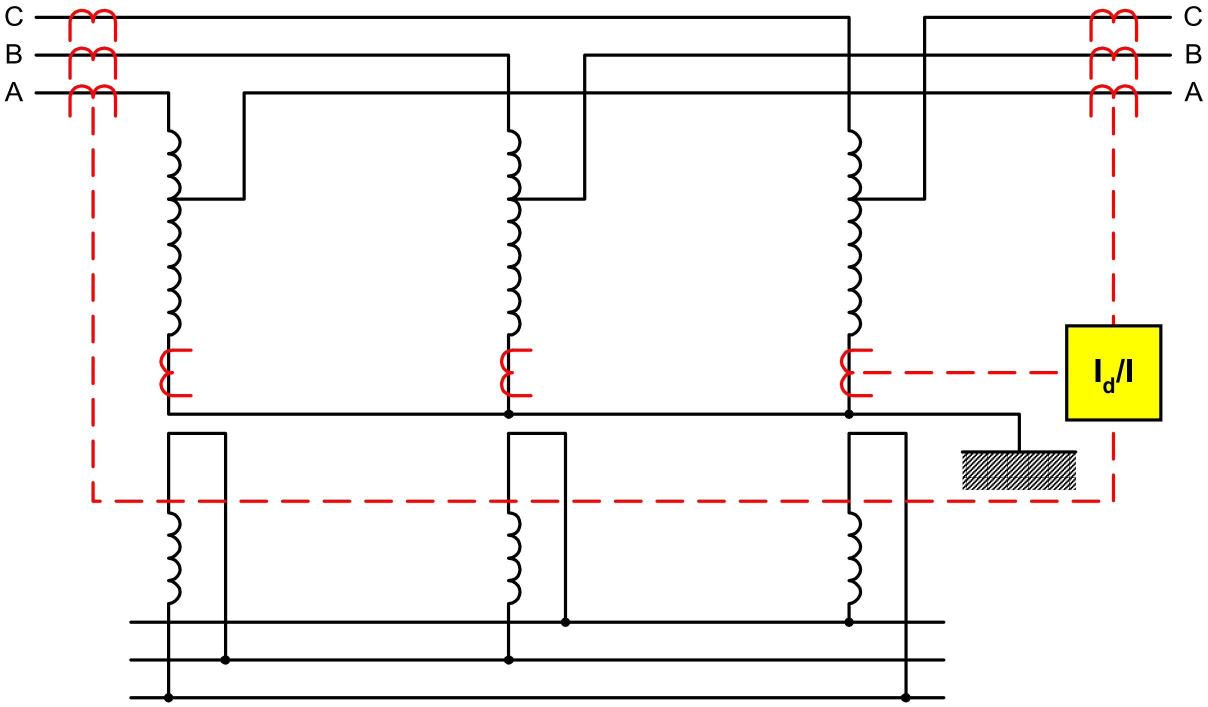
Because of the galvanic connected electrical node both vector group numbers have to be set to '0'.

➔ Zero-Sequence Current Filtering

Because of the inclusion of the neutral-to-ground current zero-sequence current filtering may be disabled for all three ends.

➔ Inrush Stabilization

Because of the galvanic connected electrical node there is no transformer coupling and therefore inrush stabilization may be disabled.



The differential protection described above operates strictly phase-segregated particularly due to the fact that inrush stabilization is not required. Sensitivity for ground fault detection is high. However turn-to-turn faults and faults on the tertiary winding cannot be detected on principle.

3.4.3 CTs in Series with Delta Tertiary Winding

If the corresponding current through the tertiary winding is measured instead of the neutral-to-ground current per phase a transformer coupling will be given.

➔ Amplitude Matching

Because of transformer coupling amplitude matching has to be based on the individual primary nominal voltages of the ends. Considering that the CTs of the third end are located in series with the delta tertiary winding √3 times of the corresponding primary nominal voltage has to be used for amplitude matching calculation.

➔ Vector Group Matching

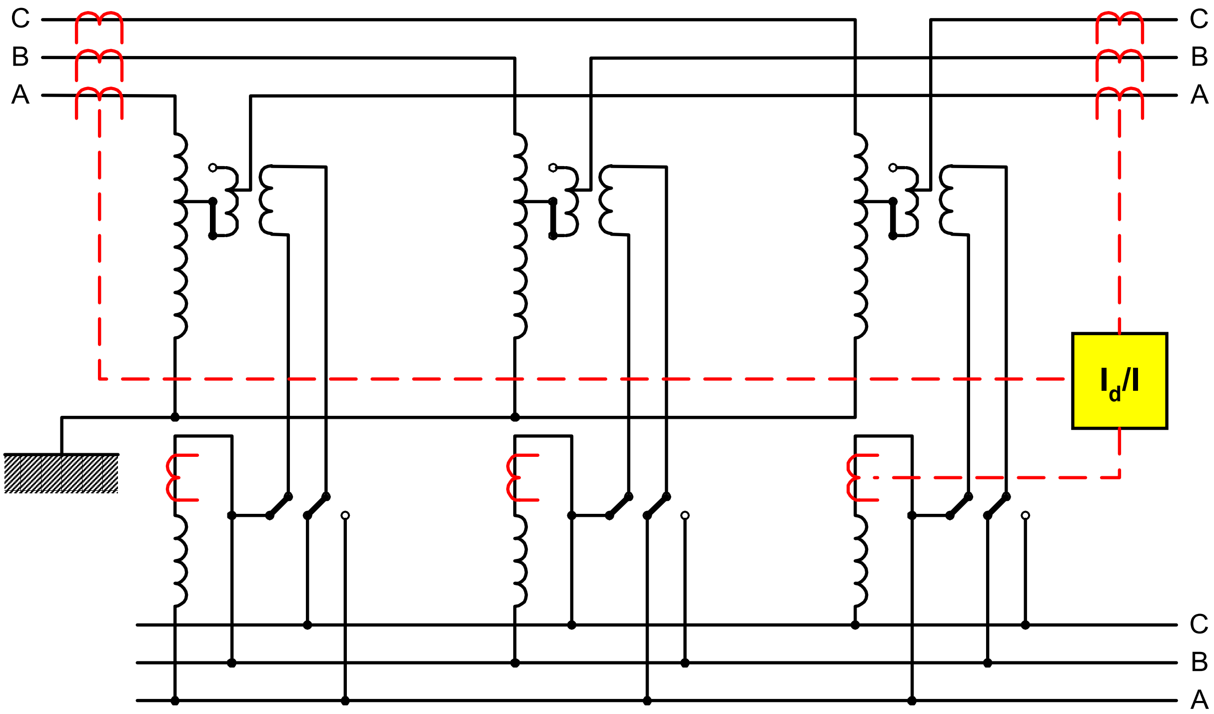
Because of the limb related measuring systems both vector group numbers have to be set to ‘0’.

➔ Zero-Sequence Current Filtering

Because of the inclusion of the neutral-to-ground current via measuring the current through the transformer coupled tertiary winding zero-sequence current filtering may be disabled for all three ends.

➔ Inrush Stabilization

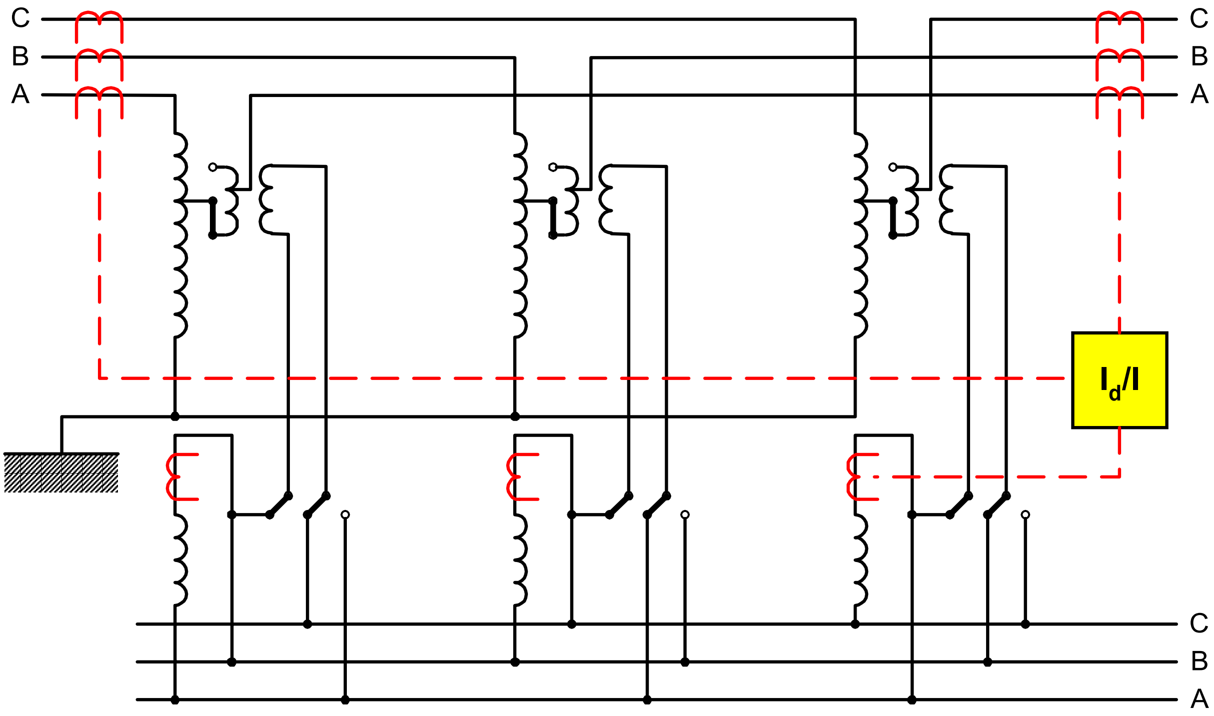
Because of the transformer coupling within the protected zone inrush stabilization has to be enabled.



The differential protection described above provides the same degree of ground fault sensitivity in comparison to the differential protection according to chapter 3.4.2 . Furthermore turn-to-turn faults can be detected on principle due to transformer coupling of the measured currents and the tertiary winding is included in the protected zone. Ground faults on the regulating winding will be detected too whereas the differential measuring systems are not affected by voltage adjustment. Only the requirement of inrush stabilization is unfavorable.

3.4.4 CTs outside Delta Tertiary Winding

If the CTs of the tertiary winding are not located in series but outside the delta winding a three-end differential protection may be applied likewise. This differential protection offers the largest protection zone in comparison to all the applications described above. However the requirement of zero-sequence current filtering leads to reduced ground fault sensitivity. The setting of the differential protection corresponds to the setting of a separate-winding transformer. The differential measuring systems are affected by in-phase or phase-angle regulation.



➔ Tripping Characteristic

This overall differential protection is affected by voltage adjustment. This has to be taken into consideration for the setting of the tripping characteristic according to chapter 3.3.

3.5 Generators and Motors

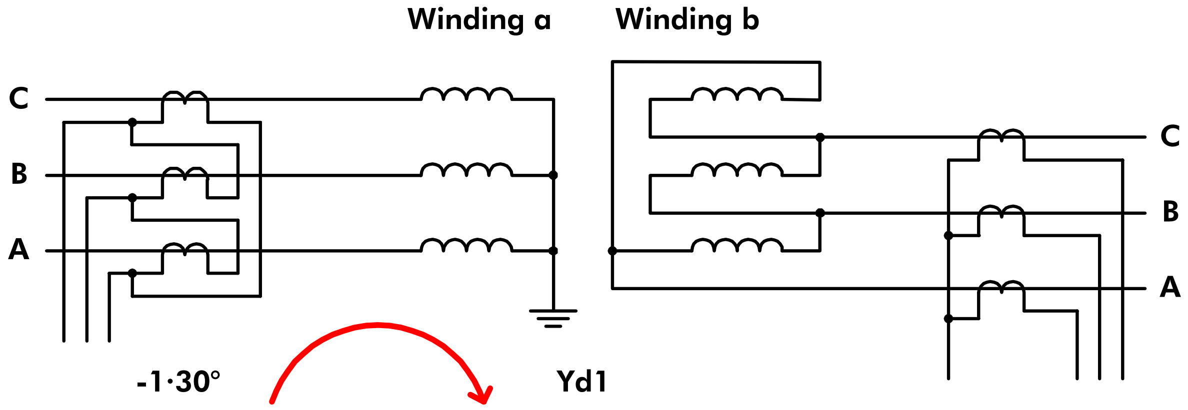
➔ Inrush Stabilization

In case of generators and motors there is no transformer coupling between both ends but a galvanic connection. Therefore inrush stabilization may be disabled.

3.6 CT Delta Connection

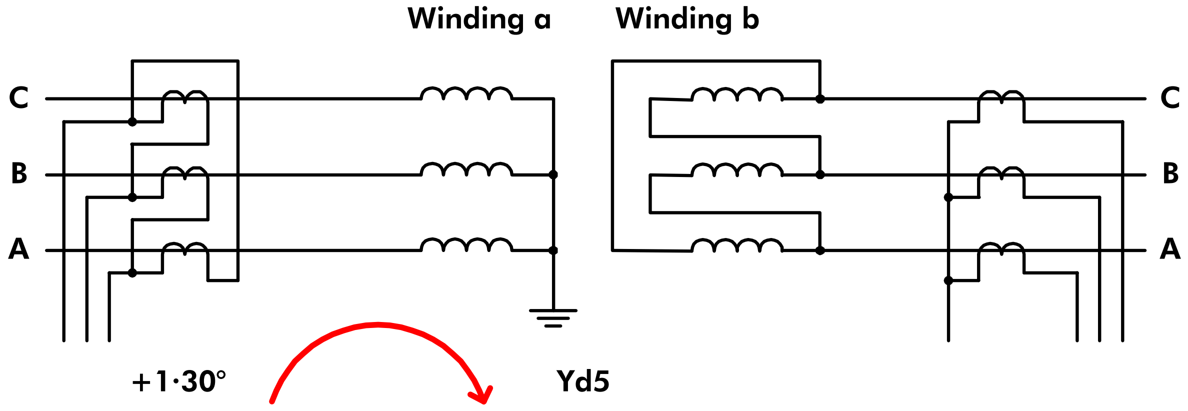
➔ Vector Matching

Power transformer Yd1 with **CT delta -30°** connection on **side a**:



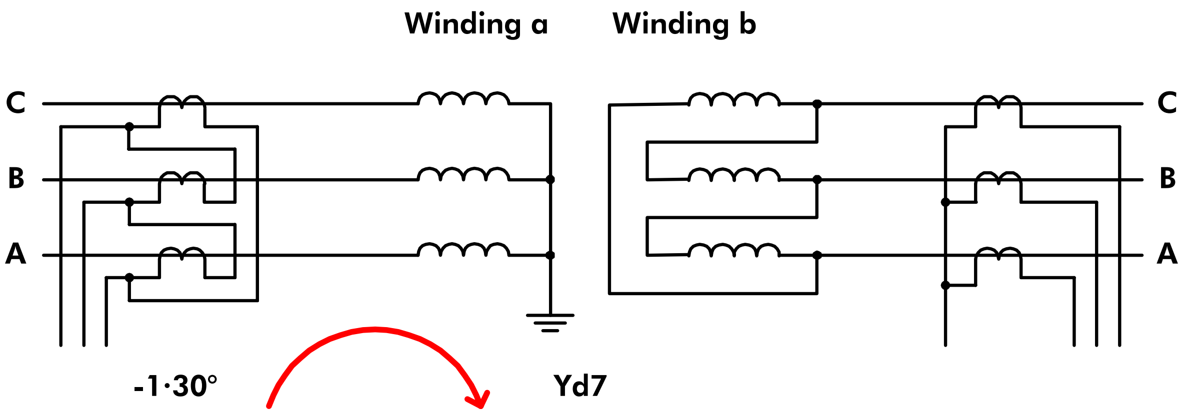
Setting for Vector Group ID: 1+(-1)=0

Power transformer Yd5 with **CT delta +30°** connection on **side a**:



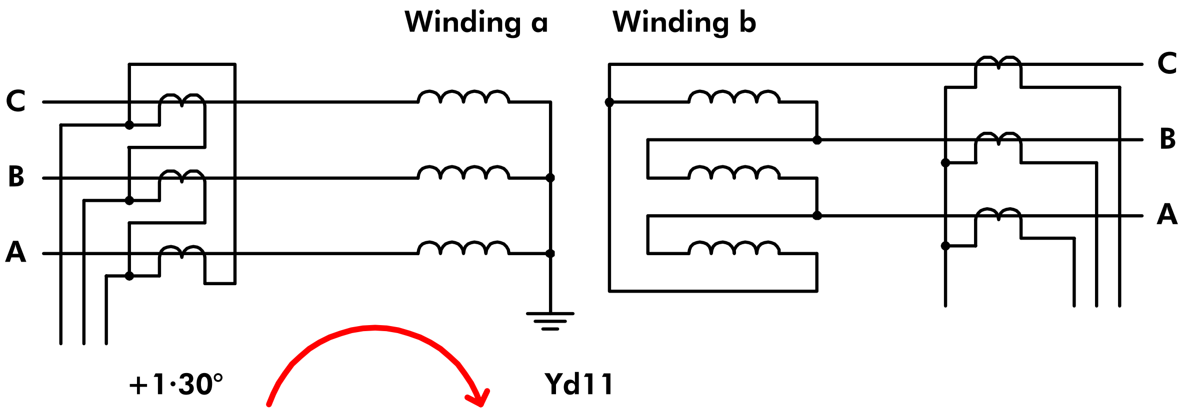
Setting for Vector Group ID: 5+(+1)=6

Power transformer Yd7 with **CT delta -30°** connection on **side a**:



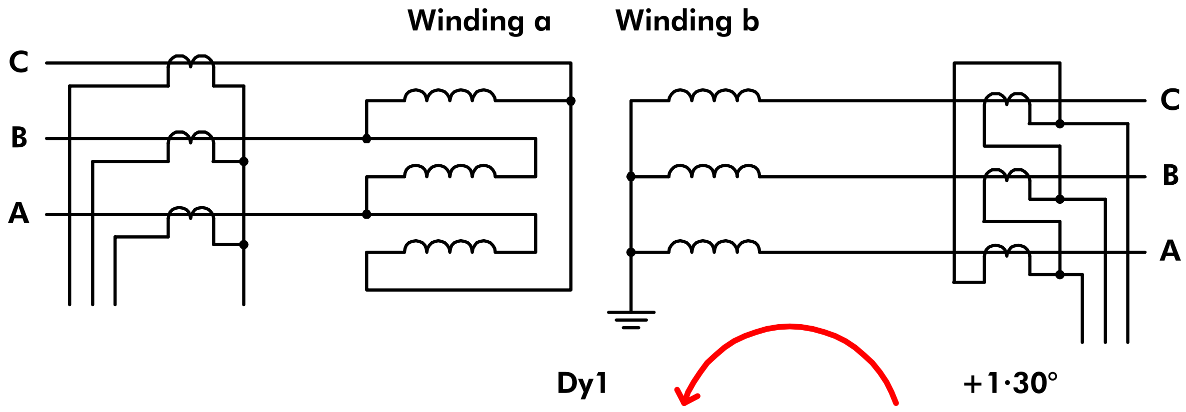
Setting for Vector Group ID: 7+(-1)=6

Power transformer Yd11 with **CT delta +30°** connection on **side a**:



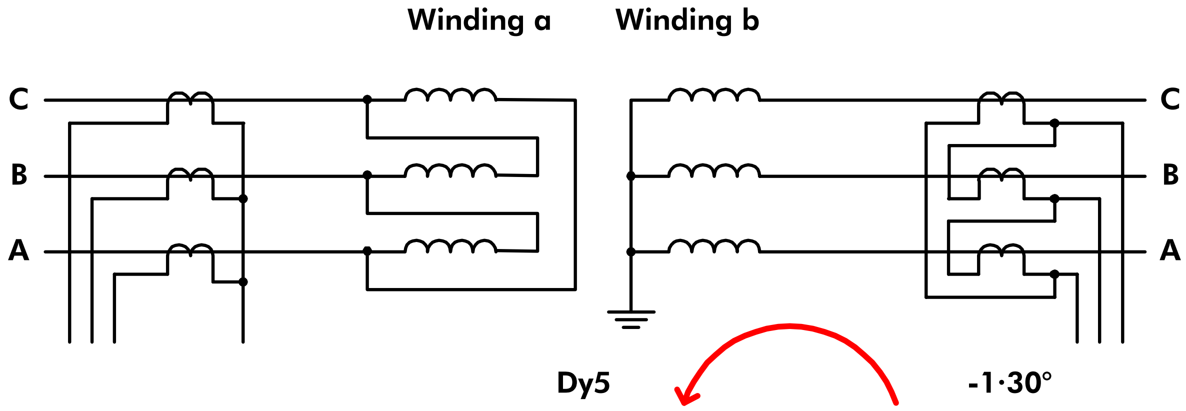
Setting for Vector Group ID: 11+(+1)=12→0

Power transformer Dy1 with **CT delta** +30° connection on **side b**:



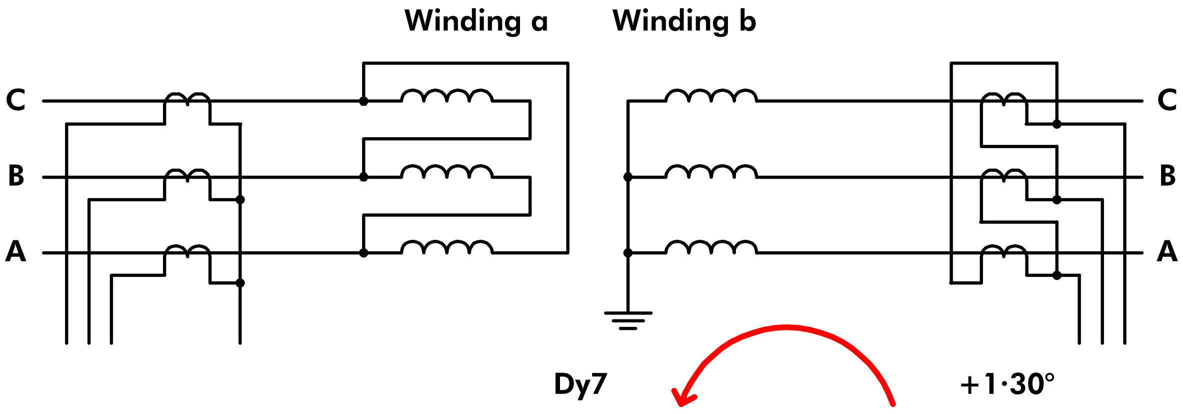
Setting for Vector Group ID: 1-(+1)=0

Power transformer Dy5 with **CT delta** -30° connection on **side b**:



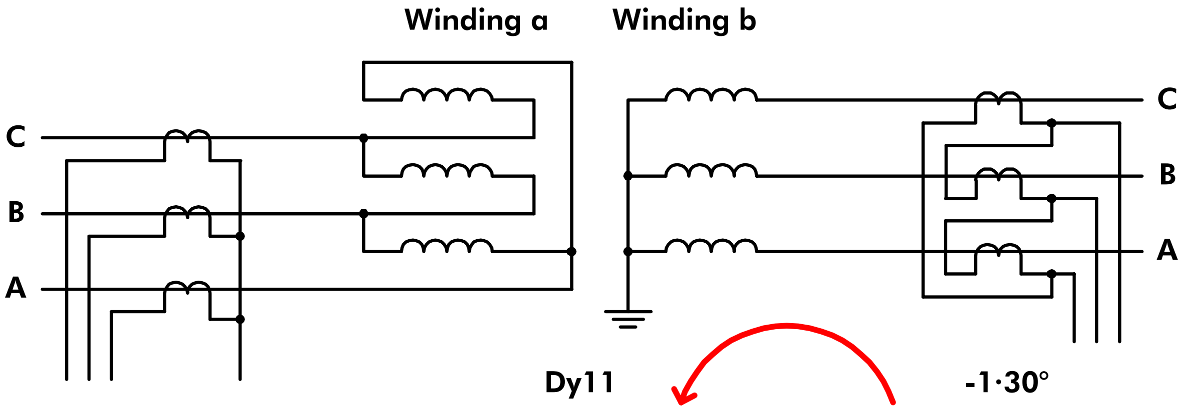
Setting for Vector Group ID: 5-(-1)=6

Power transformer Dy7 with **CT delta** +30° connection on **side b**:



Setting for Vector Group ID: 7-(+1)=6

Power transformer Dy11 with **CT delta** -30° connection on **side b**:



Setting for Vector Group ID: 11-(-1)=12→0

4 Instructions for Commissioning and Testing

4.1 Checking the Phase Angle of the Phase Currents

It is possible to make an estimate regarding correct connection of the phase currents by using the phase angles that are provided as measured operating values.

With an ideally symmetrical load through the transformer, the phase angles between the phase currents of a given end must be displayed as follows, depending on the rotary field direction in the system:

	Clockwise Rotating Field	Counterclockwise Rotating Field
	$\varphi_{AB,z} = \varphi_{BC,z} = \varphi_{CA,z} = 120°$	$\varphi_{AB,z} = \varphi_{BC,z} = \varphi_{CA,z} = -120°$

The setting of the function parameter for direction of rotating field has no effect in this case.

The phase angles of a given phase between the phase currents of two ends must be displayed as follows, depending on the transformer vector group:

Vector Group	
0	$\varphi_{x,a-z} = \pm 180°$
1	$\varphi_{x,a-z} = -150°$
2	$\varphi_{x,a-z} = -120°$
3	$\varphi_{x,a-z} = -90°$
4	$\varphi_{x,a-z} = -60°$
5	$\varphi_{x,a-z} = -30°$
6	$\varphi_{x,a-z} = \pm 0°$
7	$\varphi_{x,a-z} = 30°$
8	$\varphi_{x,a-z} = 60°$
9	$\varphi_{x,a-z} = 90°$
10	$\varphi_{x,a-z} = 120°$
11	$\varphi_{x,a-z} = 150°$

The setting for the function parameter for the vector group has no effect in this case. On the other hand, a change in the setting of the function parameter for the connection direction of a given main current transformer set affects the corresponding measured operating value by ±180°.

4.2 Checking the Basic Threshold Value of the Tripping Characteristic

The basic threshold value I_d> of the tripping characteristic can be easily checked by means of single-end current infeed (s. Section 2.3.2).

4.2.1 Single-End, Three-Phase Symmetrical Infeed

For single-end, three-phase symmetrical infeed, the operate current $I_{x,z}$ is obtained as follows, taking into account the amplitude matching factor $k_{amp,z}$:

$$I_{x,z} = \frac{I_d >}{k_{amp,z}} \cdot I_{nom,z}$$

The differential and restraining currents displayed as measured operating values are obtained as follows:

$$I_{d,y} = \frac{k_{amp,z} \cdot I_{x,z}}{I_{nom,z}}$$

$$I_{R,y} = \frac{1}{2} \cdot \frac{k_{amp,z} \cdot I_{x,z}}{I_{nom,z}}$$

4.2.2 Single-End, Single-Phase Infeed

In the case of single-end, single-phase infeed, it is necessary to consider not only the amplitude matching factor $k_{amp,z}$ but also another matching factor $k_{vec,z}$ corresponding to the vector group matching and zero-sequence current filter settings. The tripping current $I_{x,z}$ is then obtained as follows:

$$I_{x,z} = \frac{I_d >}{k_{amp,z} \cdot k_{vec,z}} \cdot I_{nom,z}$$

The corresponding matching factor $k_{vec,z}$ can be taken from the following tables.

The differential and restraining currents displayed as measured operating values are obtained as follows:

$$I_{d,y} = \frac{k_{amp,z} \cdot k_{vec,z} \cdot I_{x,z}}{I_{nom,z}}$$

$$I_{R,y} = \frac{1}{2} \cdot \frac{k_{amp,z} \cdot k_{vec,z} \cdot I_{x,z}}{I_{nom,z}}$$

Matching factor $k_{vec,z}$ for the individual measuring systems y as a function of the supplied phase x for the high-voltage side:

	x = A			x = B			x = C		
	y = 1	y = 2	y = 3	y = 1	y = 2	y = 3	y = 1	y = 2	y = 3
	1/0.67	0/0.33	0/0.33	0/0.33	1/0.67	0/0.33	0/0.33	0/0.33	1/0.67

Without $\underline{I}_{zero}$ filtering / with $\underline{I}_{zero}$ filtering

Matching factor $k_{vec,z}$ for the individual measuring systems y as a function of the supplied phase x and as a function of the set vector group for the low-voltage side in question:

Vector Group	x = A			x = B			x = C		
	y = 1	y = 2	y = 3	y = 1	y = 2	y = 3	y = 1	y = 2	y = 3
0	1/0.67	0/0.33	0/0.33	0/0.33	1/0.67	0/0.33	0/0.33	0/0.33	1/0.67
1	0.91/0.58	0.33/0	0.24/0.58	0.24/0.58	0.91/0.58	0.33/0	0.33/0	0.24/0.58	0.91/0.58
2	0/0.33	0/0.33	1/0.67	1/0.67	0/0.33	0/0.33	0/0.33	1/0.67	0/0.33
3	0.33/0	0.91/0.58	0.24/0.58	0.24/0.58	0.33/0	0.91/0.58	0.91/0.58	0.24/0.58	0.33/0
4	0/0.33	1/0.67	0/0.33	0/0.33	0/0.33	1/0.67	1/0.67	0/0.33	0/0.33
5	0.24/0.58	0.91/0.58	0.33/0	0.33/0	0.24/0.58	0.91/0.58	0.91/0.58	0.33/0	0.24/0.58
6	1/0.67	0/0.33	0/0.33	0/0.33	1/0.67	0/0.33	0/0.33	0/0.33	1/0.67
7	0.24/0.58	0.33/0	0.91/0.58	0.91/0.58	0.24/0.58	0.33/0	0.33/0	0.91/0.58	0.24/0.58
8	0/0.33	0/0.33	1/0.67	1/0.67	0/0.33	0/0.33	0/0.33	1/0.67	0/0.33
9	0.33/0	0.24/0.58	0.91/0.58	0.91/0.58	0.33/0	0.24/0.58	0.24/0.58	0.91/0.58	0.33/0
10	0/0.33	1/0.67	0/0.33	0/0.33	0/0.33	1/0.67	1/0.67	0/0.33	0/0.33
11	0.91/0.58	0.24/0.58	0.33/0	0.33/0	0.91/0.58	0.24/0.58	0.24/0.58	0.33/0	0.91/0.58

Without $\underline{I}_{zero}$ filtering / with $\underline{I}_{zero}$ filtering

Note:
For the devices P631/632/633/634 the addition of zero-sequence current in case of odd numbered vector groups are not realized for SW versions -601 and -602. For these SW versions the value related to ‚without $\underline{I}_{zero}$ filtering' has to be considered to be equal to ‚with $\underline{I}_{zero}$ filtering' in case of odd numbered vector groups.

Appendix

A Vector Groups and Transformer Configurations

The vector group identifies the connection of the windings and the phase relation of the voltage phasors assigned to them. It consists of code letters that specify the connection of the phase windings and a code number that defines the phase displacement.

For three-phase alternating current, a distinction is made between the following phase winding connections:

- Delta connection (D,d)
- Wye connection (Y,y)
- Zigzag connection (Z,z)

The upper-case letters are used for the high-voltage windings, and the lower-case letters for the medium and low-voltage windings. The upper-case letter appears first in the vector group. If several windings have the same nominal voltages, the upper-case letter is assigned to the winding having the highest nominal power, and if the windings have identical nominal powers, the upper-case letter is assigned to the winding that is first according to the order of connections given above. If the neutral point of a winding is wye-connected or zigzag-connected, then the identifying symbol is YN or ZN – or yn or zn, respectively.

For phase displacement, the phasor of the high-voltage winding is considered to be the reference quantity. The code number, when multiplied by 30°, specifies the angle by which the phasor of the low-voltage winding lags behind the phasor of the high-voltage winding. For multi-winding transformers, the phasor of the high-voltage winding is the reference quantity; the symbol for this winding is given first. The other symbols follow in the order of decreasing nominal winding voltages.

By definition, therefore, the vector group is a function of the viewing direction. The vector groups related to the two viewing directions are complementary and add up to the number 12.

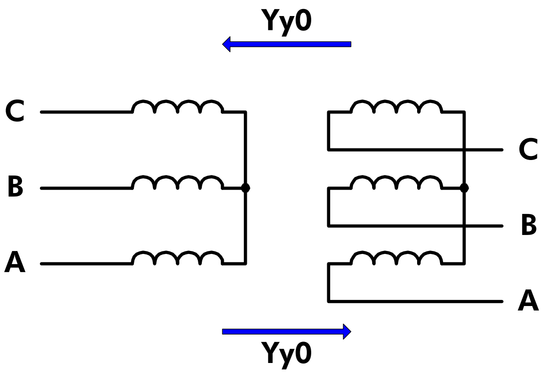
Vector groups for which the corresponding phase windings belong to the same phase are referred to as "true" vector groups. The following listing includes *only* "true" vector groups; it also contains *all* the "true" vector groups that are possible.

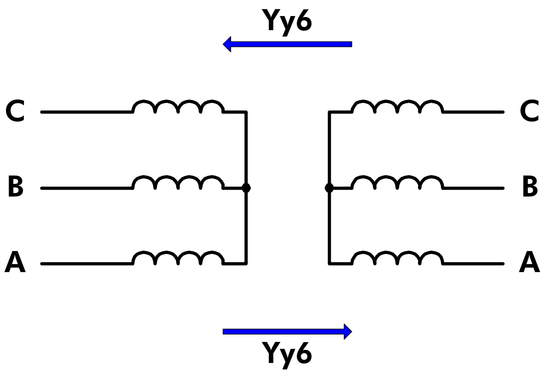
"Untrue" vector groups are formed from the "true" vector groups by cyclical reversal or transposition of phases.

By transposing phases A with C, B with A, and C with B, we obtain the following:
- from the "true" vector group Yy0: the "untrue" vector group Yy4
- from the "true" vector group Yy6: the "untrue" vector group Yy10
- from the "true" vector group Yy5: the "untrue" vector group Yy9

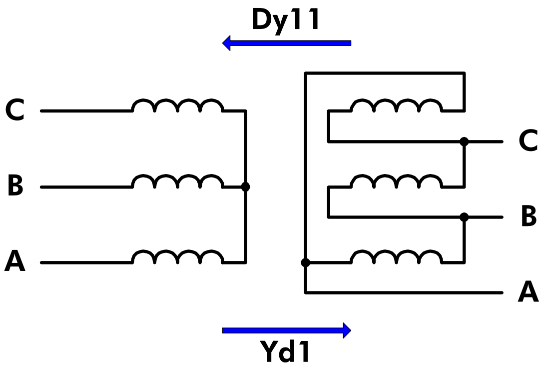
By transposing phases A with B, B with C, and C with A, we obtain the following:
- from the "true" vector group Yy0: the "untrue" vector group Yy8
- from the "true" vector group Yy6: the "untrue" vector group Yy2
- from the "true" vector group Yy7: the "untrue" vector group Yy3

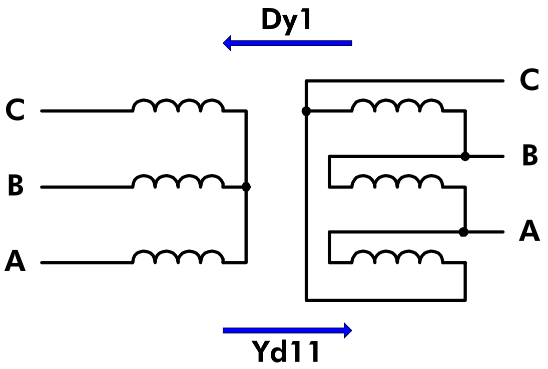
All "true" vector groups with Yy connections:

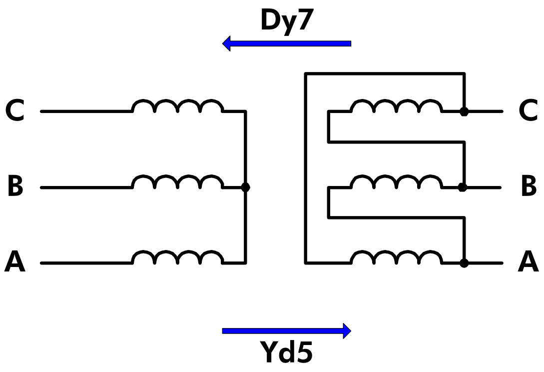


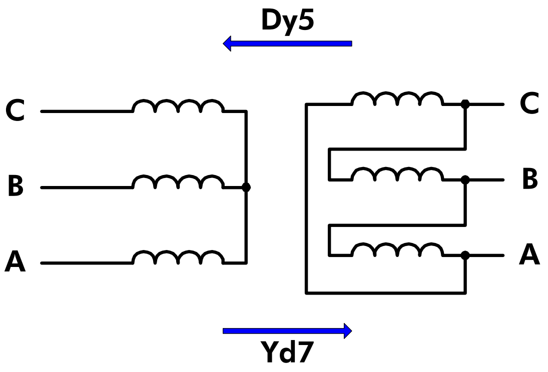


All "true" vector groups with Dy or Yd connections:

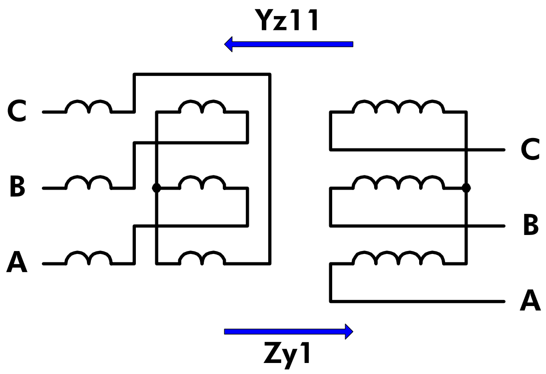


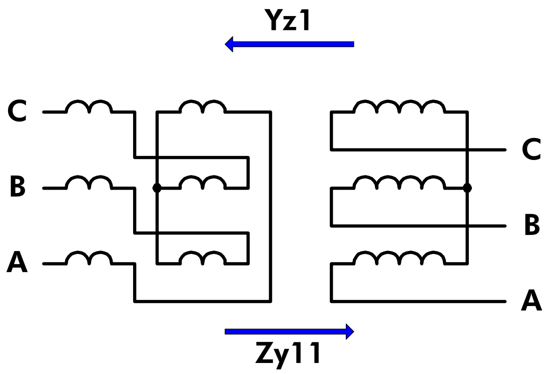


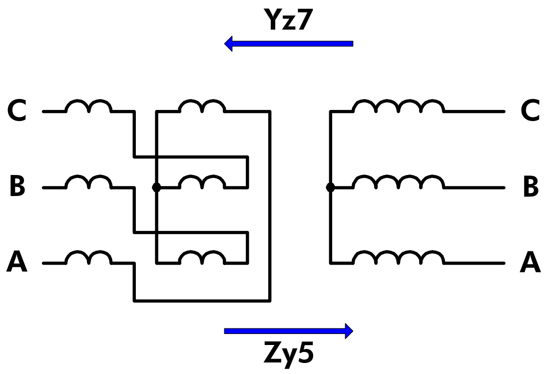


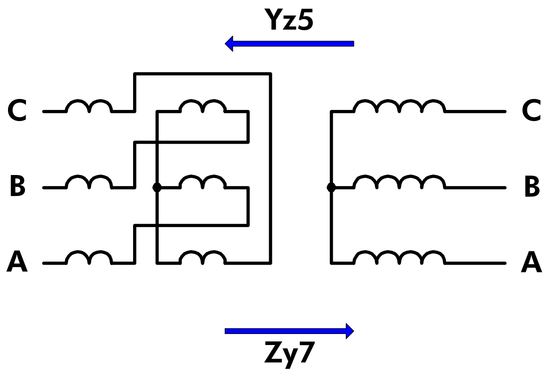


All "true" vector groups with Yz or Zy connections:

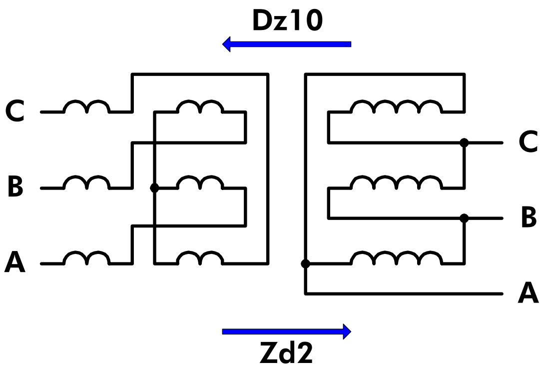


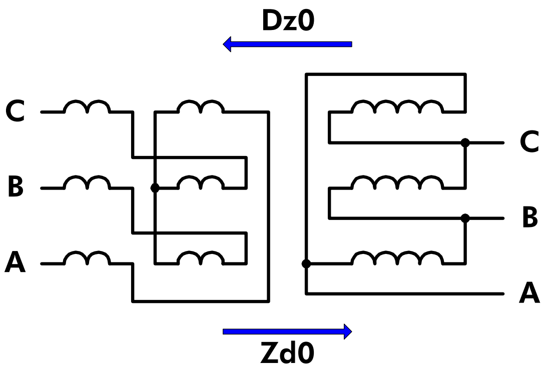


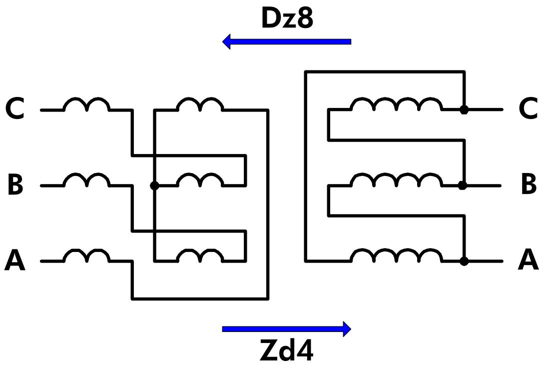


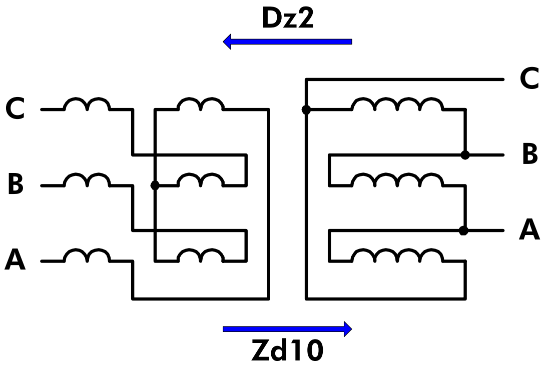


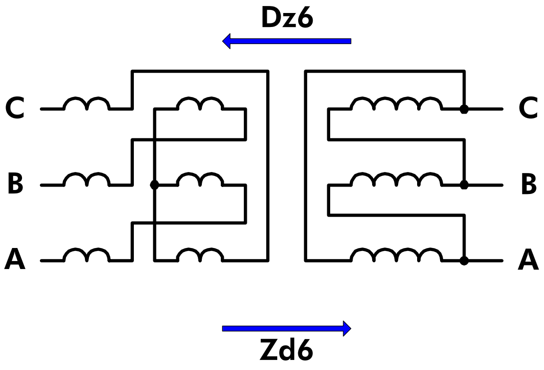
All "true" vector groups with Dz or Zd connections:

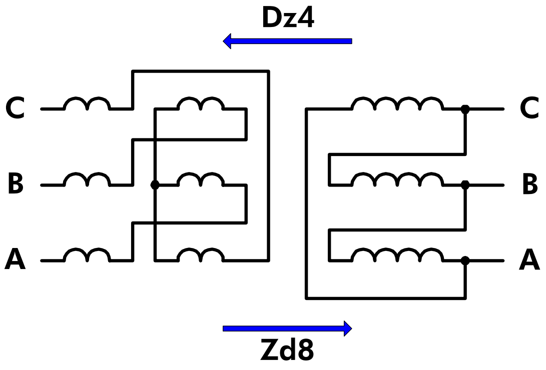












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