Differential Protection
SPAD 346 C3

Application and Setting Guide

kansikuva_bw

Contents:

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1. Scope

The present document introduces the setting calculation for the differential protection relay module SPCD 3D53 of the protection relay type SPAD 346 C3. The calculations with illustrative examples apply to two-winding power transformer applications.

Further, the document deals with differential protection of three-winding power transformers, motors, generators, motor and autotransformer combinations, motors with frequency converter control and differential protection of short cable and overhead lines. All applications include setting recommendations.

Finally, the need for interposing CTs is discussed and illustrated with examples.

KEYWORDS: differential protection, power transformer protection, generator protection, motor protection, differential relay, SPCD 3D53, SPAD 346 C.

2. Introduction

Stabilized differential protection provides fast and reliable winding short-circuit, interturn fault, earth-fault and short-circuit protection for power transformers, and interwinding and pole short-circuit protection for generators and motors.

The differential protection relay compares the phase currents on both sides of the object to be protected. Should the differential current of the phase currents in one of the phases exceed the set start value of the stabilized operation characteristic or the instantaneous protection stage, the relay generates an operate signal.

The key features of differential relays are speed of operation, stability for out-of-zone faults and sensitivity to in-zone faults. For a reliable and correct operation of the protection relay the current transformers (CT) have to be carefully chosen (see reference "Calculation of the Current Transformer Accuracy Limit Factor") and the relay settings have to be calculated and selected with care.

3. Technical implementations

3.1. Protection of two-winding power transformers

This part of the document describes how to calculate the settings for two-winding power transformer differential protection. Figure 3.1.-1 shows an example application for which the calculations will be done.

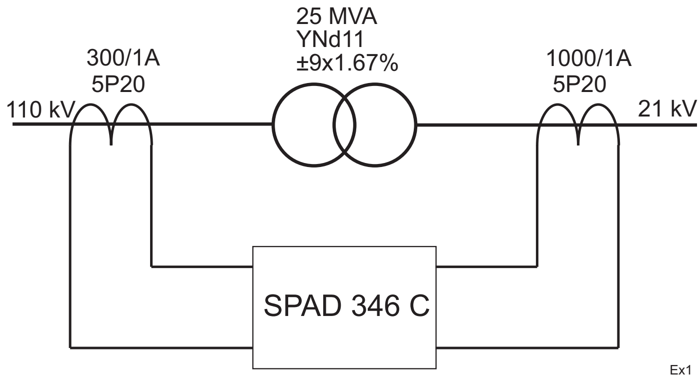


Fig. 3.1.-1 Example of two-winding power transformer differential protection.

More application examples with connection diagrams for the protection of two-winding power transformers can be found in the SPAD 346 C User's manual and Technical description (see references).

3.1.1. Vector group matching (SGF1)

The vector group of the power transformer is numerically matched on the HV and the LV side by means of the switches SGF1/1...8. Thus no interposing CTs are needed. The matching is based on phase shifting and a numerical delta connection in the relay.

Table 3.1.1.-1 shows the switch positions representing the most common power transformer vector groups. The connection to be used, I or II, depends on the CT connections, see figures 3.1.1.-1 and 3.1.1.-2. The only difference between the CT connection types I and II is the 180° phase shift.

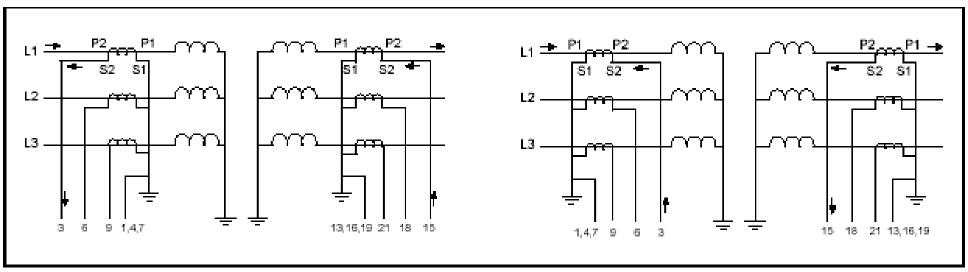


Fig. 3.1.1.-1 Connections of current transformers type I. The CT pilot wires are numbered according to the 1 A nominal current input terminals of the relay.

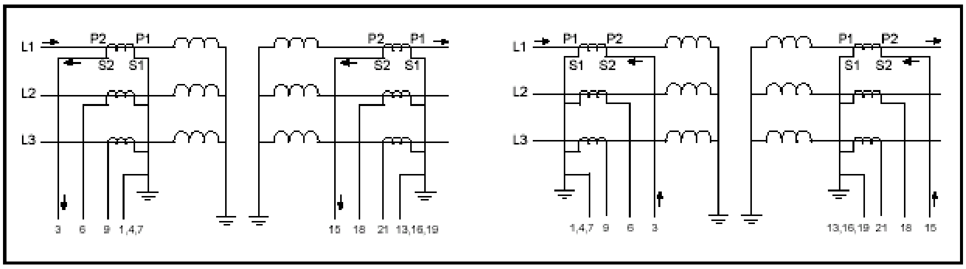


Fig. 3.1.1.-2 Connections of current transformers type II. The CT pilot wires are numbered according to the 1 A nominal current input terminals of the relay.

Table 3.1.1-1 Matching of the most common power transformer vector groups

Power transformer vector group I	II	Switches SGF1/1...8: 1	2	3	4	5	6	7	8	Checksum
Yy6	Yy0	0	0	0	0	0	0	0	0	0
YNyn8	YNyn2	0	0	1	0	1	1	0	0	52
YNyn10	YNyn4	0	0	1	0	0	0	1	0	68
YNyn6	YNyn0	1	1	0	0	0	0	0	0	3
Yy0	Yy6	0	0	1	1	0	0	0	0	12
YNyn2	YNyn8	0	0	1	0	1	0	0	1	148
YNyn4	YNyn10	0	0	1	0	0	1	0	1	164
YNyn0	YNyn6	1	1	1	1	0	0	0	0	15
Yd1	Yd7	0	0	0	1	0	0	0	0	8
YNd1	YNd7	0	0	0	0	0	0	0	1	128
Yd5	Yd11	0	0	1	0	0	0	0	0	4
YNd5	YNd11	0	0	0	0	0	1	0	1	160
Yd7	Yd1	0	0	1	0	1	0	0	0	20
YNd7	YNd1	0	0	0	0	0	1	0	0	32
Yd11	Yd5	0	0	0	0	1	0	0	0	16
YNd11	YNd5	0	0	0	0	0	0	1	0	64
Dd6	Dd0	0	0	0	0	0	0	0	0	0
Dd0	Dd6	0	0	1	1	0	0	0	0	12
Dy1	Dy7	0	0	0	0	0	0	0	1	128
Dyn1	Dyn7	0	0	0	1	0	0	0	0	8
Dy5	Dy11	0	0	0	0	0	1	0	1	160
Dyn5	Dyn11	0	0	1	0	0	0	0	0	4
Dy7	Dy1	0	0	0	0	0	1	0	0	32
Dyn7	Dyn1	0	0	1	0	1	0	0	0	20
Dy11	Dy5	0	0	0	0	0	0	1	0	64
Dyn11	Dyn5	0	0	0	0	1	0	0	0	16
YNzn1	YNzn7	1	0	0	0	0	0	0	1	129
YNzn5	YNzn11	1	0	0	0	0	1	0	1	161
YNzn7	YNzn1	1	0	0	0	0	1	0	0	33
YNzn11	YNzn5	1	0	0	0	0	0	1	0	65
Dzn0	Dzn6	1	0	1	1	0	0	0	0	13
Dzn2	Dzn8	0	0	0	1	0	1	0	0	40
Dzn4	Dzn10	0	0	1	0	0	1	0	1	164
Dzn6	Dzn0	1	0	0	0	0	0	0	0	1
Dzn8	Dzn2	0	0	1	0	1	1	0	0	52
Dzn10	Dzn4	0	0	1	0	0	0	1	0	68

3.1.1.1. Elimination of the zero-sequence component

If the neutral of a star-connected power transformer is earthed, any earth fault in the network will be perceived by the protection relay as differential current (Fig. 3.1.1.1-1). However, when the SGF1 setting is selected from the Table 3.1.1.-1, the zero-sequence component in the phase currents will be automatically eliminated.

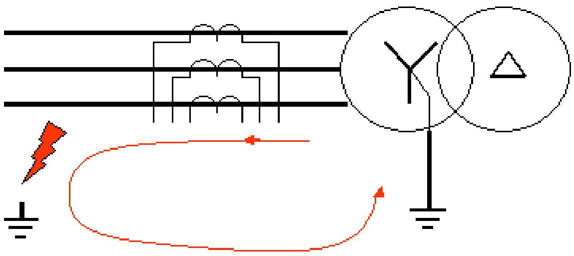


Fig. 3.1.1.1.-1 Earth-fault current at a star-connected transformer with neutral earthing.

Example

The power transformer vector group (Figure 3.1.-1) is YNd11. The CT connections are as shown in Figure 3.1.1.-2. Determine the correct setting for SGF1.

The connections of the CTs are of type II. The setting of SGF1 is presented in table 3.1.1.-1. Checksum of SGF1 = 160.

3.1.2. Transforming ratio correction of CTs (I_1/I_n, I_2/I_n)

Often the CT secondary currents differ from the rated current at the rated load of the power transformer. The CT transforming ratios can be corrected on both sides of the power transformer with the settings I_1/I_n (HV side) and I_2/I_n (LV side).

First, the rated load of the power transformer must be calculated (on both sides) when the apparent power and phase-to-phase voltage are known.

$$I_{nT} = \frac{S_n}{\sqrt{3} \times U_n} \qquad (1)$$

Where I_{nT} = rated load of the power transformer

S_n = rated power of the power transformer

U_n = rated phase-to-phase voltage

Next, the transforming ratio correction settings can be calculated (note that I_1/I_n is the symbolic name of the setting)

$$I_1/I_n = \frac{I_{nT}}{I_p} \qquad (2)$$

Where I_p = rated primary current of the CT

Note that the rated input current (1 A or 5 A) of the relay does not have to be the same for the HV and the LV side. On the HV side, for example, 5 A rated secondary current can be used, while 1 A is used on the LV side, or vice versa. Using 1 A secondary current improves the CT performance (increases the actual accuracy limit factor of the CTs).

Example

The rated power of the transformer is 25 MVA, the ratio of the CTs on the 110 kV side is 300/1 and that on the 21 kV side is 1000/1 (Figure 3.1.-1). Calculate the transforming ratio correction settings for both sides.

HV side: I_{nT} = 25 MVA / (1.732 x 110 kV) = 131.2 A

Setting I_1/I_n = 131.2 A / 300 A ≈ 0.44

LV side: I_{nT} = 25 MVA / (1.732 x 21 kV) = 687.3 A

Setting I_2/I_n = 687.3 A / 1000 A ≈ 0.69

3.1.3. Starting ratio (S)

Under ideal circumstances, and when there is no fault inside the protection zone, the differential current is zero. However, due to CT inaccuracies and varying tap changer positions (power transformer applications), the differential current deviates from zero in practice. An increasing the load current cause the differential current to grow at the same percentage rate.

The starting ratio setting (S) affects the slope of the relay operating characteristics between the 1st (fixed 0.5 x In) and the 2nd turning-point (setting I_{2tp}): an increase in the load current causes the differential current required for tripping to increase with the set percentage.

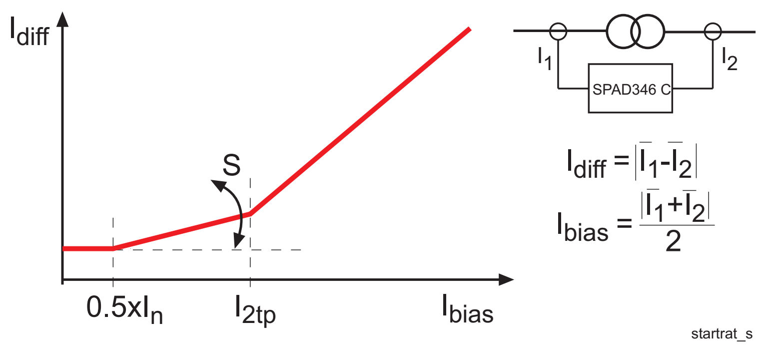


Fig. 3.1.3.-1 Effect of the starting ratio setting on the relay operating characteristics.

The S setting is calculated as the sum of the accuracies of the CTs on both sides, the tap changer regulation range, the relay operation accuracy (4%) and the desired margin (typically 5%).

Example

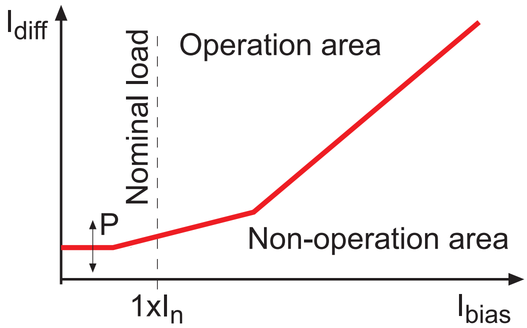
The CT on both sides are rated 5P10 (i.e. the composite error is max. 5%) and the tap changer range is ± 9 × 1.67% (figure 3.1.-1).

Calculate the starting ratio setting:

S-setting = 5% (HV CT)
+ 5% (LV CT)
+ 9 × 1.67% (tap changer)
+ 4% (relay)
+ 5% (margin)
≈ 34%

3.1.4. Basic start setting (P/I_n)

The basic setting (P) defines the minimum sensitivity of the protection. Basically, it allows for the no-load current of the power transformer, but it can also be used to influence the overall level of the operation characteristic. At rated current the no-load losses of the power transformer are less than 1 per cent at rated voltage. Should, however, the supply voltage of the transformer suddenly increase due to operational disturbances, the magnetizing current of the transformer increases as well. In general, the magnetic flux density of the transformer is rather high at rated voltage and a voltage rise of a few per cent will cause the magnetizing current to increase by tens of per cent. This should be considered in the basic setting.



basicstartsetting

Fig. 3.1.4.-1 Effect of the basic setting on the relay operating characteristics.

Taking into account the effective operation area for the S setting beginning from Ibias = 0.5 x In, and the no load losses of the transformer, we get P = 0.5 x S + P’, where P’ represents the no-load losses of the transformer at maximum voltage. Typically, P’ = 10% is used if the actual value is unknown.

Example

The S setting is 34% and the transformer no-load losses are assumed to be less than 10%. Calculate the P setting.

P setting = 0.5 x 34% + 10% = 27%

3.1.5. Second turning-point (I_{2tp}/I_n)

The 2nd turning-point defines the point in the operation characteristics at which the influence of the starting ratio S ends and a constant 100% slope begins. Beyond this point, the increase in the differential current is equal to the corresponding increase in the stabilizing current.

Finding settings for the differential protection is always balancing between stability and sensitivity. The smaller the 2^{nd} turning-point setting is, the more stable and less sensitive the protection is. And vice versa, the higher the setting is, the more sensitive and less stable the protection is.

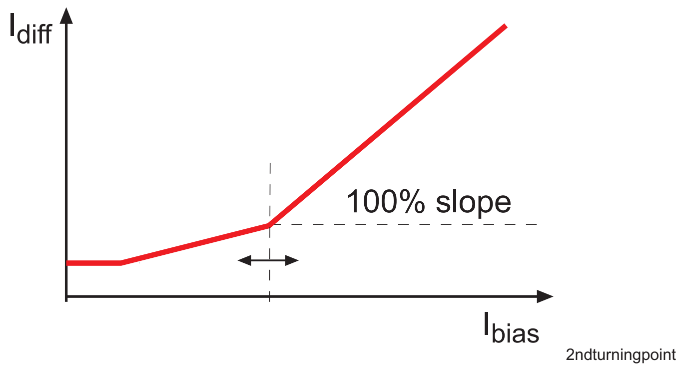


Fig. 3.1.5.-1 Effect of the 2^{nd} turning-point setting.

Recommendation

In a power transformer protection application the second turning-point I2tp/In is normally chosen in the range 1.5 ... 2. With the setting 1.5, the protection is somewhat more stable against out-of-zone faults, whereas the setting 2.0 provides somewhat more sensitive protection for in-zone faults.

3.1.6. Second harmonic blocking (I_{d2f}/I_{d1f}>)

Power transformers are ferromagnetic devices. At the moment of energization, the power transformer draws a magnetizing inrush current, which is perceived by the differential protection relay solely as a differential current.

Because the transformer magnetizing impedance is non-linear, the inrush current contains a lot of second order harmonics. A well-known principle is to detect an inrush situation from the content of the 2^{nd} order harmonics and block the differential protection relay (low-set stage) for the time of the inrush.

The recommended setting for the second harmonic blocking is 15% in power transformer protection. The harmonic blocking is enabled by setting switch SGF2/1 = 1.

It is also recommended to use the factory default setting for switch SGF2/2, i.e. position 1. This setting allows a special algorithm to inhibit the second harmonic blocking in case the algorithm detects a fault inside the protected area.

The content of 2^{nd} harmonics in the inrush current depends on transformer construction, material and remanence. Therefore, the setting for the 2^{nd} harmonic blocking cannot be calculated in a straightforward way. However, the relay will measure (register 7) the smallest value of the ratio of the second harmonic and the fundamental frequency component in a connection inrush situation. This value may be used in the search of the final setting for the second harmonic blocking.

It should be noted that if the transformer has been out of use for some time (i.e. after storage) its remanence may be very small, causing the 2nd harmonic blocking not to operate at the first energizing attempt. Therefore, the setting could be lowered to 10% for the first energizing attempt.

3.1.7. Instantaneous differential current stage (I_d/I_n>>)

It is recommended to use the instantaneous tripping limit I_d/I_n>> together with the low-set stage, because, in the event of a serious fault, it will provide faster protection than the low-set stage. Further, it will not be blocked by harmonics.

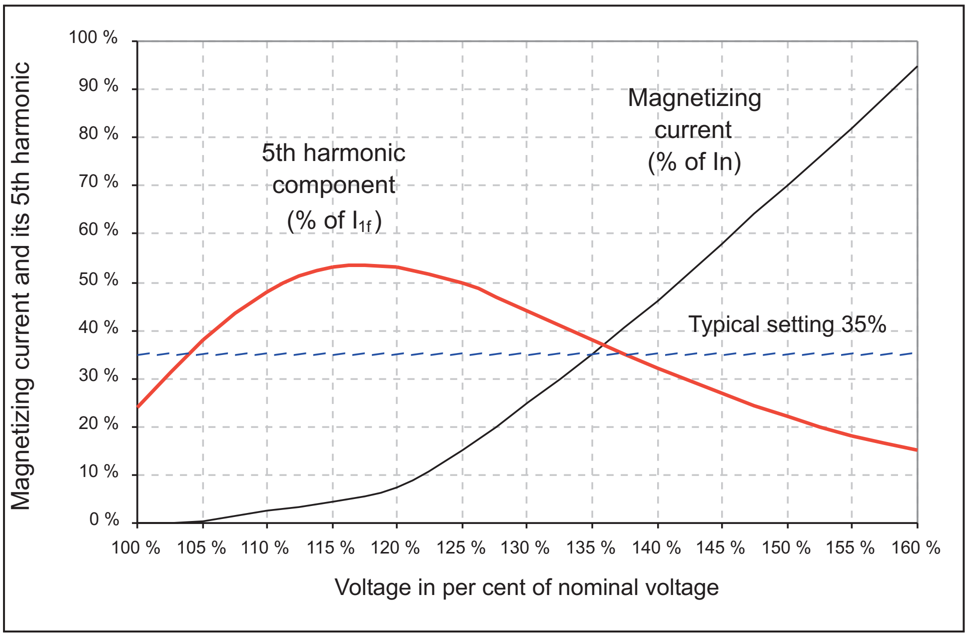
The I_d/I_n>> is set high enough to prevent the differential relay module from tripping when the transformer is energized. Normally, the peak value of the asymmetric inrush current of the transformer is considerably higher than the peak value of the symmetric inrush current. Typically, the amplitude of the fundamental frequency component is only half of the peak value of the inrush current. Thus the instantaneous tripping value I_d/I_n>> of the relay can be set below the peak value of the asymmetric inrush current.

In power transformer protection the setting value of the instantaneous differential current stage is typically 6...10.

3.1.8. Fifth harmonic blocking and deblocking (I_{d5f}/I_{d1f}>, I_{d5f}/I_{d1f}>>)

The purpose of this function is to block the relay operation at a sudden voltage rise (or frequency drop). The reason for blocking is the increasing magnetizing current flowing on the primary side which by the relay is perceived as an increase in the differential current.

According to numerous studies made the fifth harmonic component of the magnetizing current has proved to be most suitable for monitoring overexcitation of power transformers. There are two major reasons for that. Firstly, the proportional part of the fifth harmonic is clearly increasing when the transformer core is beginning to saturate. Secondly, other situations, for example, the saturation of current transformers do not produce so much fifth harmonics. Figure 3.1.8.-1 shows a typical behaviour of the proportion of the fifth harmonic to the fundamental component of the magnetizing current as a function of the overvoltage.



5th_harmonic

Fig. 3.1.8.-1 Magnetizing current and its 5^{th} *harmonic component in the windings of an overexcited power transformer.*

Figure 3.1.8.-1 illustrates how the proportion of the fifth harmonic initially increases until it reaches its maximum, and if the voltage continues rising, the transformer will go into an even deeper saturation and part of the fifth harmonic starts to decline.

The main problem when defining the setting values is that the fifth harmonic curve as a function of overvoltage should be known for the transformer concerned. The critical voltage values and the overcapacity of the magnetic circuits depend on the construction of the transformer. The only one to know the influence of overvoltage or the U/f ratio on the content of the fifth harmonic is the manufacturer of the power transformer. A value often used for blocking is 35%, but its usefulness in each separate case is very difficult to know without access to the real curves, which should be made available by the transformer manufacturer.

SPAD 346 C also has a separate settable deblocking limit, which can be toggled on and off. This gives the user more options. Sometimes tripping of the differential relay is requested if the voltage reaches values that may endanger the transformer even when there is no fault inside the protection area of the relay. In the Figure 3.1.8.-1 only the blocking is active and the limit is set to 35%. Then the relay is blocked when the line voltage reaches 104%. If the voltage continues to rise, the blocking will disappear when the voltage reaches 137% (no hysteresis). This kind of performance may be considered desirable with this type of transformer. For other transformer types in which the fifth harmonic of the magnetization current will reaches the top point much later, for example, when the voltage approaches 140%, the deblocking limit allows the blocking to be released already at the rising part of the curve. A value often used in these cases for deblocking is 50%.

It should also be noted that the release of the fifth harmonic blocking due to the set deblocking limit or a decrease in the fifth harmonic content when the overvoltage rises high enough, is not an absolute guarantee for tripping. Tripping will take place only if the extra magnetization current (differential current from the relay point of view) exceeds the tripping value at that point of the bias curve and so, for example, the load current has an effect on whether there will be a trip or not. Of this reason, separate overvoltage protection is recommended.

As a conclusion it can be stated that if the blocking/deblocking feature based on the fifth harmonic is to be used, the magnetization characteristic of the transformer should be known (contact the transformer manufacturer), because, when the voltage is increased, the degree of saturation and thus the harmonic content of the current depend on the design of the transformer. If the magnetization characteristic is known, or the current waveform has been recorded and the harmonic content has been analyzed while the voltage is increased, the setting values could be defined.

Recommendation

Usually, the magnetization characteristic of the power transformer is not know, and therefore it is recommended not to enable the 5^{th} harmonic blocking, i.e. SGF2/3 and SGF2/4 should be set in position 0 .

3.1.9. Disturbance recorder

The internal disturbance recording function of the relay module is a powerful tool for analysing, for example, transformer inrush currents and the cause of a trip. Therefore, attention should be paid to the disturbance recorder settings as well.

Settings for normal operation

The factory default settings are the most suitable settings for normal operation, because with these settings a disturbance will be recorded only if the relay operates.

Settings for inrush current study

The serial communication parameter V241 is used for selecting the internal signals to be used for triggering the disturbance recording. The factory default setting is 003, which means that only the operation of the 3DI> or the 3DI>> protection stage will trigger a recording. For inrush currents the parameter setting should be changed to 007 (i.e. the activation of the 2^{nd} harmonic blocking will also trigger a recording).

The serial communication parameter V245 is used to set the length, in cycles, of a recording, following disturbance recorder triggering . The factory default is 5, which means that the disturbance will include a history of 38-5 = 33 pre-triggering cycles and 5 post-triggering cycles. For an inrush current study a more appropriate setting would be 33.

Note for indication

The disturbance recorder is not able to start a new recording sequence before the recording memory has been emptied! The letter “d” to the right of the display indicates a memorized recording, when no measured, set or recorded value is displayed.

3.2. Protection of 3-winding power transformers

The SPAD 346 C relay can also be used in three-winding transformer or two-winding transformer applications with two output feeders (Figure 3.2.-1).

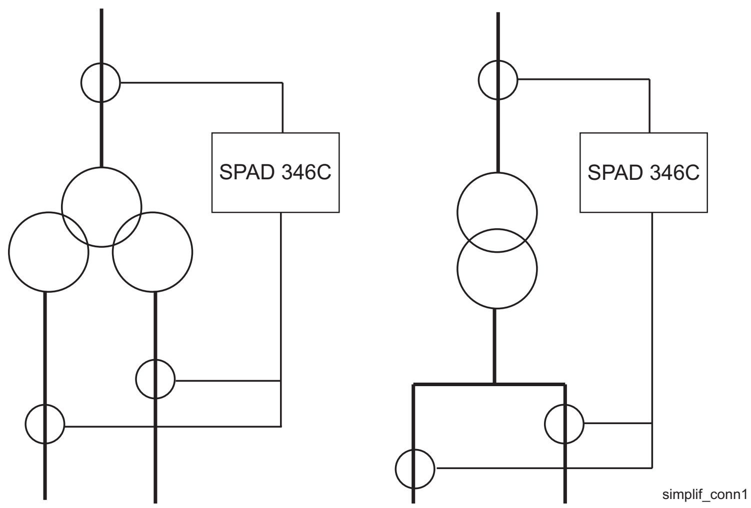


Fig. 3.2.-1 Simplified connection diagram for a 3-winding power transformer and a 2-winding power transformer with two output feeders. No interposing CTs for vector group matching are shown.

On the double-feeder side of the power transformer the current of the two CTs per phase must be summed by connecting the two CTs of each phase in parallel. Generally this requires interposing CTs (see examples 3 and 4) to handle the vector group and/or ratio mismatch between the two windings/feeders.

For the interposing CT, the accuracy limit factor Fa > 40 is still required. Please note that the interposing CT impose an additional burden to the main CTs.

The most important rule in these applications is that, at least 75% of the short-circuit power should be fed on the side of the power transformer with only one connection to the relay (Figure 3.2.-2).

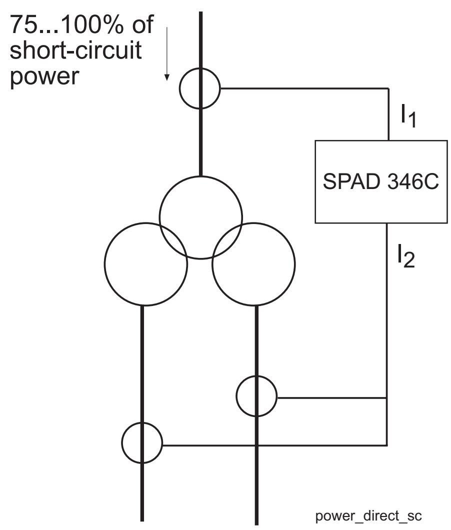


Fig. 3.2.-2 Power direction at short circuit.

The 75% requirement is important because of the bias current (stabilising current) calculation in the protection relay. The bias current is calculated as

$$I_{bias} = \frac{|\overline{I}_1 + \overline{I}_2|}{2} \qquad (3)$$

Where $\overline{I}_1$ = secondary current (phasor) on HV side
$\overline{I}_2$ = secondary current (phasor) on LV side

3.2.1. Example 1: Short-circuit current fed mainly from the HV side (step-down transformer)

Figure 3.2.1.-1 illustrates an external fault in a three-winding power transformer application, where most of the short-circuit current is fed from the HV side (where only one CT per phase is connected to the relay).

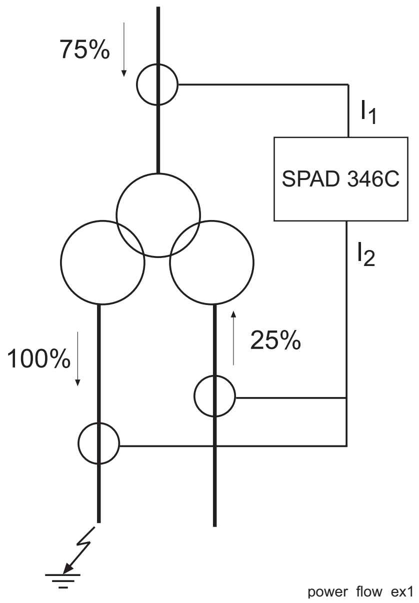


Fig. 3.2.1.-1 Power flow directions in example 1.

The bias current will now be:

$$I_{bias} = \frac{|\overline{I}_1 + \overline{I}_2|}{2} = \frac{75\% + (100\% - 25\%)}{2} = 75\%$$

The actual bias in true three-winding protection would be 100%, but when the mentioned 75% rule is used the bias current with SPAD 346 C is close enough and the stable (stabilized) operation is ensured.

3.2.2. Example 2: Short-circuit current fed mainly from the LV side (step-up transformer)

Figure 3.2.2.-1 illustrates an external fault in a three-winding power transformer application, in which most of the short-circuit power is fed from the LV side, where two CTs per phase are connected to the relay. This example clearly violates the 75% rule.

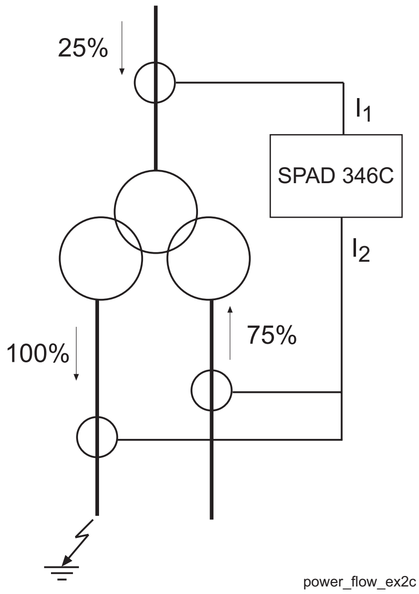


Fig. 3.2.2.-1 Power flow directions in example 2.

The bias current will now be:

$$I_{bias} = \frac{|\bar{I}_1 + \bar{I}_2|}{2} = \frac{25\% + (100\% - 75\%)}{2} = 25\%$$

But at external faults the bias current should be high. Now, the relay will operate as a non-stabilized (non-biased) relay because of the low bias. For applications like these SPAD 346 C3 is not recommended.

3.2.3. Example 3: Ratio matching with interposing CTs

If the ratios of the main CTs to be connected in parallel are unequal, an interposing CT is required to match the ratio difference. Figure 3.2.3.-1 illustrates an example where two output feeders have main CTs of different ratios. Calculate the ratio of the interposing CTs and relay CT correction ratio settings.

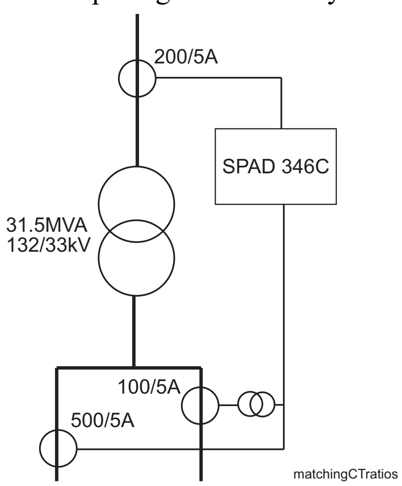


Fig. 3.2.3.-1 Matching CT ratios with interposing CTs (one per phase).

The ratio of one of the main CTs on the LV side is 500 A/5 A = 100. Therefore, the other main CT with the interposing CT should also have the ratio 100. The main CT is 100 A/5 A = 20, thus the interposing CT should have the ratio 100/20 = 5, for example 25 A/5 A.

An alternative connection of the interposing CT is shown in figure 3.2.3.-2. The interposing (summation) CT has both 5 A and 25 A primaries and a 5 A secondary.

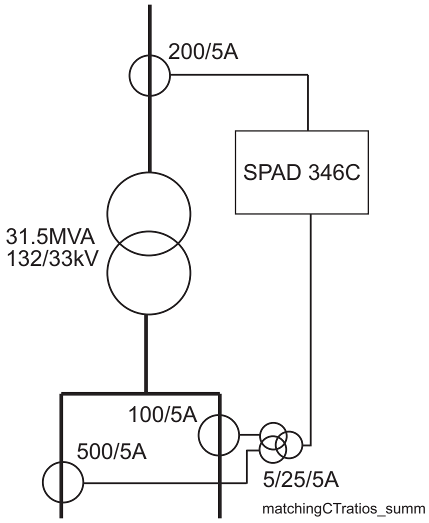


Fig. 3.2.3.-2 Matching CT ratios with summation CT.

The rated current of the HV side is:

$$I_{nT,\mathrm{HV}} = \frac{S_n}{\sqrt{3} \times U_{n,HV}} = \frac{31.5\ \mathrm{MVA}}{\sqrt{3} \times 132\mathrm{kV}} = 137.8\mathrm{A}$$

The CT ratio correction factor for the HV side is:

$$I_1 / I_n = \frac{I_{nT,HV}}{I_{p,HV}} = \frac{137.8\mathrm{A}}{200A} \approx 0.69$$

The rated load and CT ratio correction factor on the LV side are

$$I_{nT,LV} = \frac{S_n}{\sqrt{3} \times U_{n,LV}} = \frac{31.5\ \mathrm{MVA}}{\sqrt{3} \times 33kV} = 551.1\mathrm{A}$$

$$I_2 / I_n = \frac{I_{nT,LV}}{I_{p,LV}} = \frac{551.1\mathrm{A}}{500A} \approx 1.10$$

3.2.4. Example 4: Vector group with interposing CTs

Figure 3.2.4.-1 illustrates an example of three-winding power transformer protection where interposing CTs are used for vector group matching.

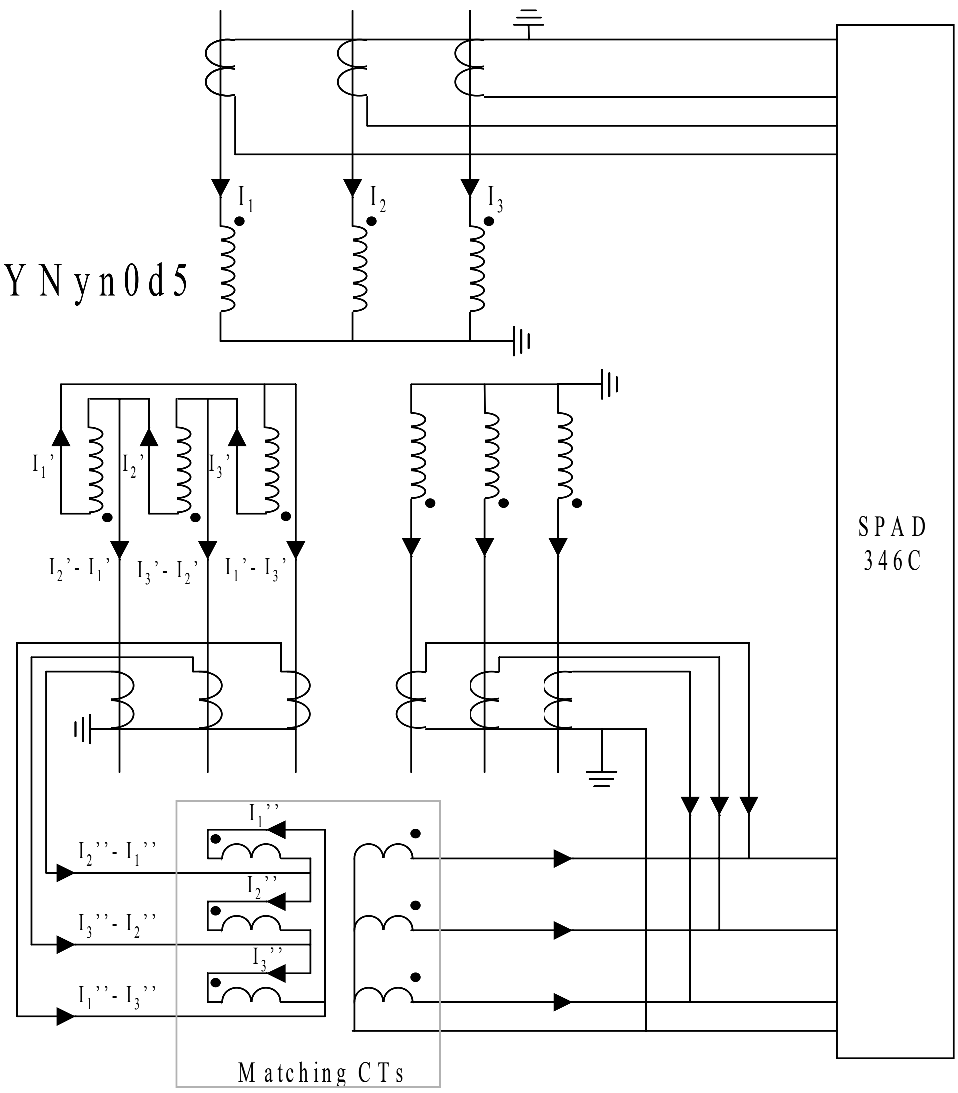


Fig. 3.2.4.-1 Vector group matching with interposing CTs.

3.3. Protection of motors and generators

The procedure of calculating settings for the motor or generator differential protection applications is very much the same as for power transformers. The following exceptions should, however, be noted.

3.3.1. Vector group matching (SGF1)

The vector group should be set to Yy0. Depending on the CT connection SGF1 = 012 (type I) or SGF1 = 000 (type II) .

3.3.2. Starting ratio (S)

The S setting is calculated as the sum of the CT accuracies on both sides, the relay operation accuracy (4%) and the desired margin (typically 2.5 .. 5%).

Example: Both sides have a 5P10 transformer:

S setting = 5% (CT)
+5% (CT)
+4% (relay)
+2.5% (margin)
= 16.5% or higher.

3.3.3. Basic start setting (P)

Typically, the P setting is calculated by adding 50% of the S setting to the safety margin (typically 2%).

Example: S setting is 16.5% and thus the P setting should be 0.5 x 16.5% + 2% ≈ 10%.

3.3.4. Second turning point (I_{2tp}/I_n)

During a motor run-up the currents (together with the dc component) may cause partial saturation of the CTs, which will produce differential currents of high magnitudes. Of this reason, the typical setting value used for motors is 1.0.

For generators, values between 1.0 and 1.5 are typically used.

3.3.5. Harmonic blocking

Motors and generators normally do not need 2^{nd} or 5^{th} harmonic blocking which means that the blocking function should be disabled.

3.3.6. CT requirement note

The requirements regarding the current transformers in motor and generator protection applications are the same as those for power transformer applications. If the requirements cannot be fulfilled, each case should be considered separately. With an accuracy limit factor as low as 25, for example, adequate protection can be achieved, although this is not recommended, by increasing the P and S setting and thus making the relay less sensitive. These cases typically require disturbance recordings from motor run-ups, and also a careful analysis.

3.4. Protection of motor and autotransformer combination

The differential relay measures the phase currents on either side of the protected object. When an autotransformer is used the zone of protection will include both the autotransformer and the motor. It should be noted that all currents between the autotransformer/motor combination and the network must be measured. Figure 3.4.-1 illustrates a typical measuring arrangement.

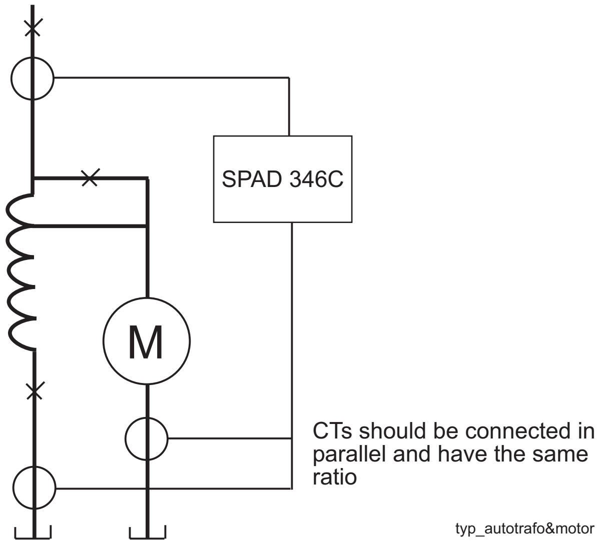


Fig. 3.4.-1 Typical connection for autotransformer & motor differential protection.

3.4.1. Settings

The settings for an autotransformer and motor differential protection application are the same as those for an ordinary motor protection application.

3.4.2. Operation of autotransformer

A typical start sequence for a motor and autotransformer combination is as follows:

1. Initially, (Fig. 3.4.2.-1) the motor is fed from the autotransformer.
2. Next, (Fig. 3.4.2.-2) after the motor has started, the circuit breaker on the neutral side of the autotransformer is opened and the autotransformer will work as a 3-phase shunt reactor.
3. Finally, (Fig. 3.4.2.-3) the autotransformer is by-passed and the motor will be connected directly on line.

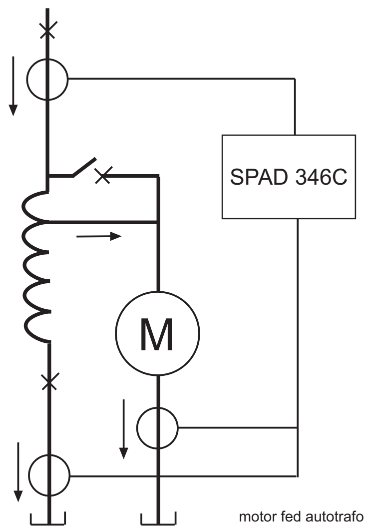


Fig. 3.4.2.-1 Motor fed from autotransformer.

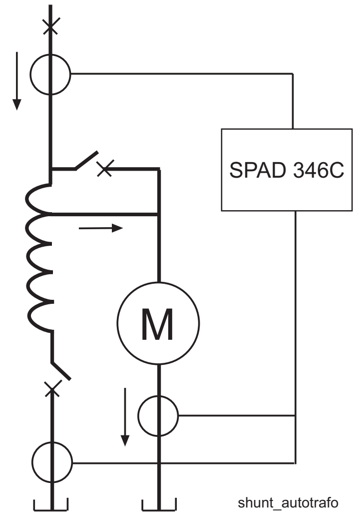


Fig. 3.4.2.-2 Autotransformer operating as a 3-phase shunt reactor.

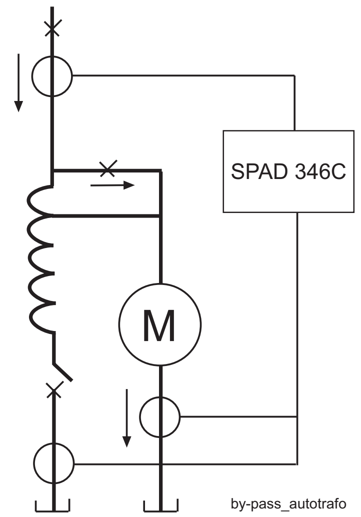


Fig. 3.4.2.-3 Autotransformer by-passed.

Other arrangements are also possible, but the idea of the phase current measurements will be the same.

3.5. Protection of frequency-controlled motors and their power transformers.

The SPAD 346 C can only be used for the protection of the power transformer feeding the frequency converter, as illustrated in Figure 3.5.-1.

In a SPAD 346 C differential protection relay, the fundamental frequency component is numerically filtered with a Fourier filter. This filter will suppress frequencies other than the set fundamental frequency, and therefore the relay is not adapted for measuring the output of the frequency converter, i.e. the relay is not suited for protecting of a power transformer or motor fed by a frequency converter.

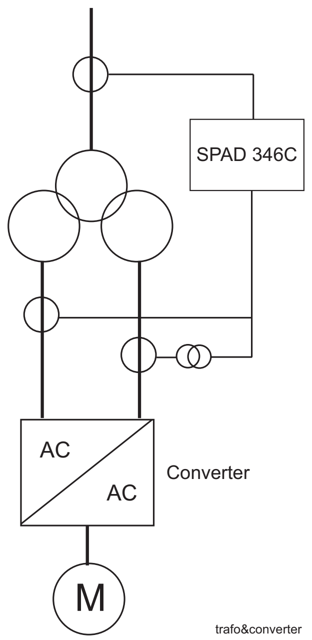


Fig. 3.5.-1 Protection of a power transformer feeding a frequency converter and motor.

3.6. Protection of a short overhead line or cable line

The SPAD 346 C can be used for differential protection of overhead lines or cable lines. Should the distance between the measuring points be relatively long, interposing CTs might be needed to reduce the burden of the CTs.

The longer the distance between the CT and the protection relay, the higher the CT burden (due to the resistance of the connection wires). Further, the actual accuracy limit factor of the CT may be too low to fulfil the requirements for differential protection.

It is often enough to use 1 A secondary currents instead of 5 A. If, for example, the total resistance of the secondary wires is 1.0 ohm, and 5 A rated secondary current is used, the CT burden will be $(5\ A)^2 \times 1.0\ \Omega = 25$ VA. Instead of oversizing the CT VA rating in order to compensate for the increased burden, the CT ratio should be increased. Should 1 A rated secondary current be used, the burden will only be $(1\ A)^2 \times 1.0\ \Omega = 1$ VA.

3.6.1. Example 1

Figure 3.6.1.-1 illustrates an example where the distance between the left-hand side CT and the relay is 1000 metres. Calculate the actual accuracy limit factor of the CTs.

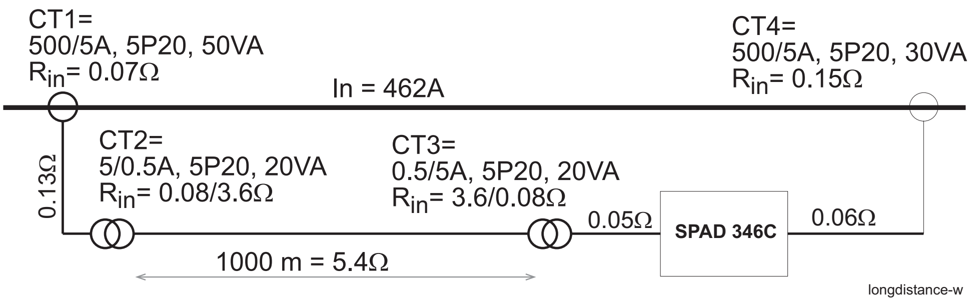


Fig. 3.6.1.-1 Example of long distance wiring.

The actual accuracy limit factor can be calculated (see references) as:

$$F_a = F_n \times \frac{S_{in} + S_{nct}}{S_{in} + S_a} \qquad (4)$$

Where:

F_n = rated CT accuracy limit factor
S_{in} = burden arising from the CT secondary winding resistance (I^2R)
S_{nct} = rated CT burden
S_a = actual CT burden (burden of wiring, relay and interposing CTs)

The relay input impedance in the above example is 0.02 ohm. On the right side, the actual accuracy limit factor of CT4 will be:

$$F_{a_{CT4}} = 20 \times \frac{(5A)^2 \times 0.15\Omega + 30VA}{(5A)^2 \times 0.15\Omega + (5A)^2 \times (0.06 + 0.02)\Omega} = 117.4$$

On the left side, first calculate the actual limit factor of the 2nd interposing CT.

$$F_{a_{CT3}} = 20 \times \frac{(5A)^2 \times 0.08\Omega + 20VA}{(5A)^2 \times 0.08\Omega + (5A)^2 \times (0.05 + 0.02)\Omega} = 117.3$$

Next, the burden of the 1st interposing CT is calculated by adding the burden of the 0.5 A circuit (pilot wire and 2nd interposing CT primary winding resistances) and the burden of the 5 A circuit (2nd interposing CT secondary winding, wire and relay input resistances):

$$S_{a_{CT2}} = (0.5\mathrm{A})^2 \times (5.4 + 3.6)\Omega + (5A)^2 \times (0.08 + 0.05 + 0.02)\Omega$$
$$= 6.0\mathrm{VA}$$

Next, the actual accuracy limit factor of the first interposing CT is calculated:

$$F_{a_{CT2}} = 20 \times \frac{(0.5A)^2 \times 3.6\Omega + 20VA}{(0.5A)^2 \times 3.6\Omega + 6.0\mathrm{VA}} = 60.6$$

Next, the burden of the main CT (CT1) is calculated:

$$S_{aCT1} = (5\text{A})^2 \times (0.13 + 0.8)\Omega + (0.5A)^2 \times (3.6 + 5.4 + 3.6)\Omega + 8.4\text{VA} \\ = 14.4\text{VA}$$

Finally, the actual accuracy limit factor of the main CT is calculated:

$$F_{aCT1} = 20 \times \frac{(5A)^2 \times 0.07\Omega + 50VA}{(5A)^2 \times 0.07\Omega + 14.4\text{VA}} = 64.0$$

All Fa values fulfil the requirements given for the CTs in the relay manual (Fa > 40).

3.6.2. Example 2

The relay rated input current (1 A or 5 A) does not have to be the same for the HV side and the LV side. The previous example (figure 3.6.1.-1) can be simplified by using only one set of interposing CTs and the 1 A nominal current input terminals of the relay. Furthermore, the CT sizes can be reduced as shown in Figure 3.6.2.-1.

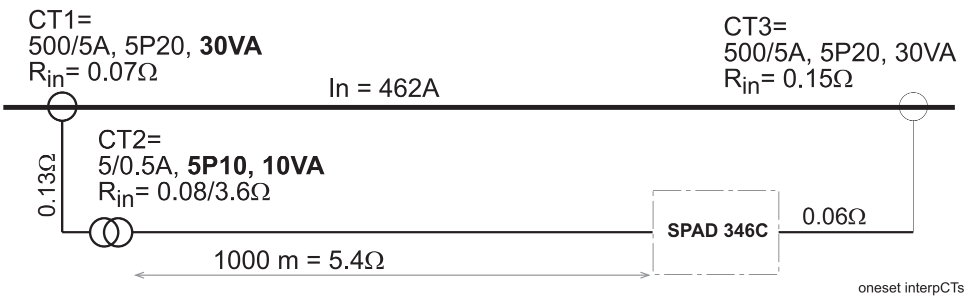


Fig. 3.6.2.-1 Example with only one set of interposing CTs.

The impedance of the 1 A nominal current input of the relay is 0.10 ohm. The actual accuracy limit factor of the interposing CT is calculated:

$$F_{aCT2} = 10 \times \frac{(0.5A)^2 \times 3.6\Omega + 10VA}{(0.5A)^2 \times 3.6\Omega + (0.5A)^2 \times (5.4 + 0.10)\Omega} = 47.9$$

Next, the burden of the main CT is calculated:

$$S_{aCT1} = (5\text{A})^2 \times (0.13 + 0.8)\Omega + (0.5A)^2 \times (3.6 + 5.4 + 0.10)\Omega \\ = 7.53VA$$

Finally, the actual accuracy limit factor of the main CT is calculated:

$$F_{aCT1} = 20 \times \frac{(5A)^2 \times 0.07\Omega + 30VA}{(5A)^2 \times 0.07\Omega + 7.53\text{VA}} = 68.4$$

4. SUMMARY

This document describes how to select and calculate the differential protection settings for the SPAD 346 C protection relay. The relay operation principles and the effect of the settings are described and the calculations are presented with examples. Examples and rules apply to two-winding power transformer applications. Furthermore, recommendations for the setting of the relay’s internal disturbance recorder are given.

Then, a protection application example for three-winding power transformers and a two-winding power transformer with two output feeders is described. The suitability of the SPAD 346 C relay for these applications is illustrated with examples.

Next, an application example for motor and generator protection is described. The differences compared to setting calculation for transformer protection applications are illustrated with examples. Further, an application example for a motor and autotransformer combination is given. The appropriate connection of the CTs is shown and the typical operation of the autotransformer at motor run-up is described.

Next, the suitability of the SPAD 346 C relay for frequency converter applications is discussed. Because the relay operation is based on the set fundamental frequency component of the phase currents, the relay is suitable only for the protection of the power transformer feeding the frequency converter.

Finally, the differential protection of a short overhead line or cable line is described with examples of calculating the actual accuracy limit factors of interposing CTs. The calculation examples are also relevant to other applications with a relatively long distance between the CTs and the relay.

5. References

1MRS 750096-MUM EN. SPAD 346 C Stabilized Differential Relay. User's manual and Technical description.

1MRS 755481. Calculation of the Current Transformer Accuracy Limit Factor. Application Note.

6. List of symbols

F_a	actual accuracy limit factor of the CT
F_n	rated accuracy limit factor of the CT
I_1	phase current at the HV side (secondary value)
I_2	phase current at the LV side (secondary value)
I_{1f}	phase current of the fundamental frequency (1^{st} harmonic)
I_1/I_n	transforming ratio correction setting of the HV side CTs
I_2/I_n	transforming ratio correction setting of the LV side CTs
I_{2tp}/I_n	second knee-point setting
I_{bias}	bias (stabilizing) current calculated by the protection relay
$I_{d2f}/I_{d1f}>$	second harmonic blocking setting
$I_{d5f}/I_{d1f}>$	fifth harmonic blocking setting
$I_{d5f}/I_{d1f}>>$	fifth harmonic deblocking setting
I_{diff}	differential current calculated by the protection relay
$I_d/I_n>>$	instantaneous differential current stage setting
I_{nT}	rated load of the protected transformer (primary value)
I_p	rated primary current of the CT
P/I_n	basic setting of start
P’	no-load losses of a power transformer
S	starting ratio setting
S_a	actual burden of the CT
S_{in}	internal burden of the CT secondary winding
S_{nct}	rated burden of the CT
S_n	rated power of the protected object
U_n	rated phase-to-phase voltage of the protected object

ABB Oy
Distribution Automation
P.O. Box 699
FI-65101 Vaasa
FINLAND
Tel. +358 10 22 11
Fax. +358 10 224 1094
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