

Earth-fault Protection SPAD 346 C

Application and Setting Guide



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ABB

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1. Scope

The present document describes how to implement earth-fault protection for power transformers, generators or motors using the earth-fault relay module SPCD 2D55 of the stabilized differential relay SPAD 346 C. The operation principles offered by the relay module, and the settings, are presented. The document also describes the use of the non-directional earth-fault stages in the combined overcurrent and earth-fault relay module SPCJ 4D28.

Further, five power transformer application examples with connection diagrams are given. The examples are applicable for generator and motor earth-fault protection as well.

Finally, guidelines for setting the disturbance recording of the SPCD 2D55 module are given.

KEYWORDS: earth-fault protection, transformer protection, generator protection, motor protection, SPCD 2D55, SPCJ 4D28, SPAD 346 C.

2. Introduction

Earth-fault protection is applied on power transformers, motors and generators in order to detect earth faults. The sensitivity of a stabilized differential protection relay might not be sufficient for detecting single-phase earth-faults. Therefore, the stabilized differential protection relay SPAD 346 C has been provided with an earth-fault relay module SPCD 2D55 and a combined overcurrent and earth-fault relay module SPCJ 4D28.

Selectivity, also known as discrimination, is one of the fundamental qualities of a protection relay. Selectivity of non-unit type protection devices is achieved by grading the operation times of the relays.

The term absolute selectivity refers to a unit protection arrangement, which only detects and responds to abnormal conditions within the zone of protection of the device. The operation time of a unit protection device can be set to the minimum.

The relay module SPCJ 4D28 provides two-stage non-directional earth-fault protection just for the LV side (relay terminals X0/37-39). This is not a unit protection device because it cannot determine whether the fault is inside or outside the protection zone. Therefore, this protection is suitable mainly for back-up protection. However, the SPCJ 4D28 earth-fault protection module can be given either definite time or inverse time operation characteristic, whereas the relay module SPCD 2D55 only features definite time characteristic.

The relay module SPCD 2D55 provides single-stage protection for both the HV and the LV side. The protection can be implemented using four different principles: the numerical stabilized differential current principle, the high-impedance principle, the neutral or measured residual overcurrent principle and the calculated residual overcurrent principle. The two first-mentioned principles provide absolute selectivity, whereas the other two do not.

From the relay point of view, the neutral overcurrent principle and the measured residual overcurrent principle is the same. However, in this document both principles are presented separately.

The two protection stages of the relay module SPCD 2D55 can operate with different protection principles. Typically, one stage is used for the HV-side and the other for the LV-side protection, but with some restrictions both stages can be used for either the HV or the LV side.

3. Technical implementations

3.1. Stabilized differential current principle

3.1.1. Purpose and connections

The stabilized differential current principle provides stabilized low-impedance earth-fault protection. A absolute selectivity is obtained with this protection (unit protection).

Because of the biased (stabilized) operation characteristics no external stabilizing resistor is needed. The protection is based on the fundamental components of the currents. The DC component and harmonics are suppressed by a digital filter.

The phase current transformers (CT) are connected to the relay the usual way (terminals X0/1-9 on the HV side and terminals X0/13-21 on the LV side). The SPAD 346 C will calculate the sum of the phase currents (ΣI) internally. The neutral CT is connected to the I_0 input (terminals X0/25-26-27 on the HV side and terminals X0/37-38-39 on the LV side).

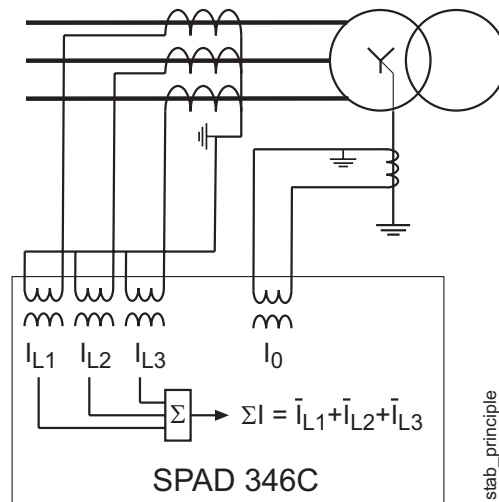


Fig. 3.1.1.-1 Stabilized differential current principle.

The operation is based on the comparison of the amplitude and the phase difference (φ) between the sum of the phase currents (ΣI) and the neutral current (I_0). The differential current (I_d) is calculated as the absolute value of the difference between the sum of the phase currents and the neutral current:

$$I_d = |\Sigma I - I_0| \quad (1)$$

The directional differential current ($I_d \times \cos \varphi$), which is used for protection, is based on the differential current (I_d) and the angle between the sum of the phase currents and the neutral current. $\cos \varphi$ is specified to be 1, when the phase difference is 180° . Further, tripping is possible only when the phase difference is between 90° and 270° .

For the relay to operate, three next criteria must be fulfilled:

Operation criterion 1 – differential current

The calculated directional differential current ($I_d \times \cos\phi$) must exceed the value of the operation characteristics (fig 3.1.1.-2).

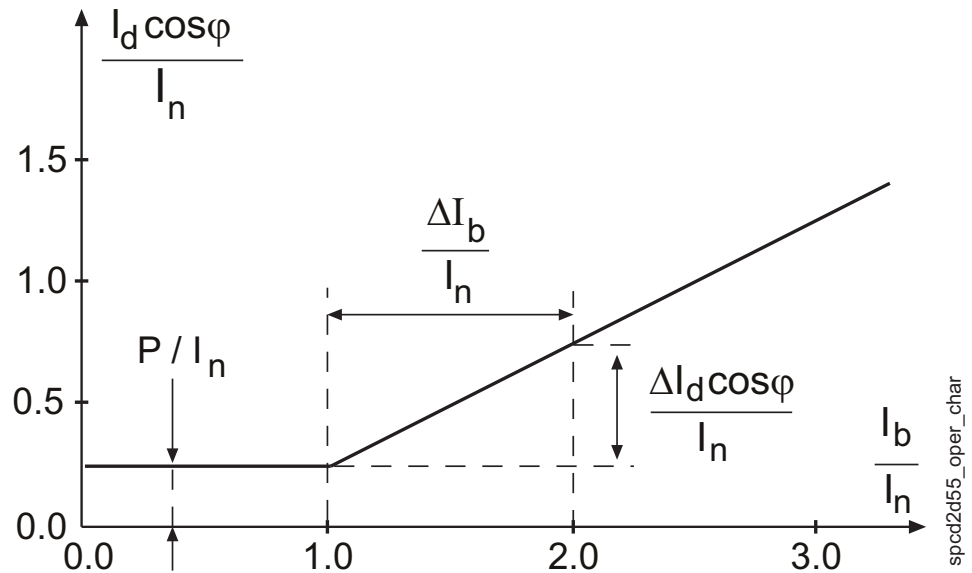


Fig. 3.1.1.-2 Operation characteristic for the stabilized differential current principle.

The calculated residual current (ΣI) is the vector sum of the phase currents. The residual current seen by the relay is:

$$\Sigma I' = \frac{|\overline{I_{L1}} + \overline{I_{L2}} + \overline{I_{L3}}|}{I_1/I_n} \quad (2)$$

where I_{L1}, I_{L2}, I_{L3} = measured phase currents

I_1/I_n = phase current CT ratio correction setting on HV side
(I_2/I_n for LV side)

The biasing (stabilizing) current (I_b) is the average of the phase current amplitudes. The biasing current seen by the relay is:

$$I_b' = \frac{|I_{L1}| + |I_{L2}| + |I_{L3}|}{3 \times I_1/I_n} \quad (3)$$

The $\cos\phi$ factor is defined to be 1 for internal faults. For the correct polarity, the connection of the CTs must be set with the switches SGF2/1 (HV side) and SGF2/2 (LV side), fig. 3.1.1.-3. (for more information, see the relay manual)

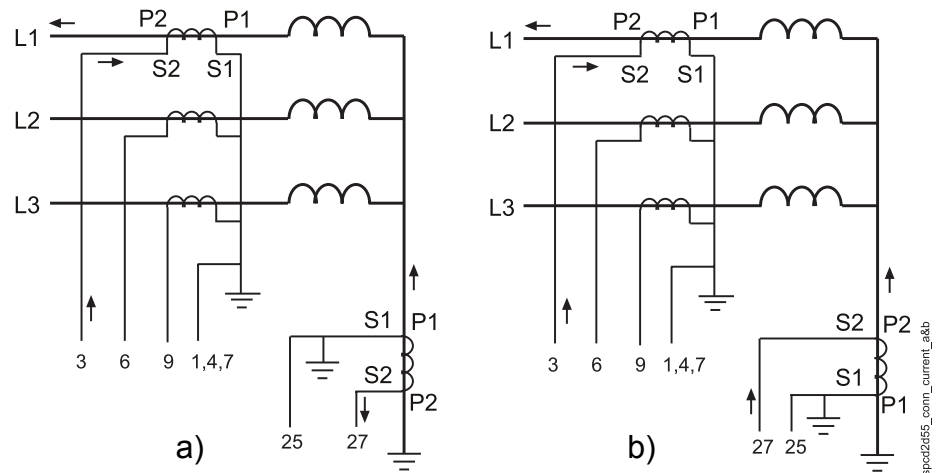


Fig. 3.1.1.-3 The connected phase currents and neutral current have a) opposite directions, b) equal directions, at an external earth fault. The CT wires are numbered according to the 1 A nominal current input terminals of the relay.

The neutral current seen by the relay is:

$$I_0' = \frac{I_{01}}{I_{01}/I_n} \quad (4)$$

where I_{01} = neutral current measured on the HV side (I_{02} for the LV side)

I_{01}/I_n = neutral current CT ratio correction setting on HV-side (I_{02}/I_n for the LV side)

As figure 3.1.1.-2 indicates, the basic setting ($P_1/I_n\%$) alone defines when the relay operates, as long as the I_b is below 1.0. Beyond $I_b = 1.0$, the required differential current (at $\cos\phi = 1$) depends on the basic setting and the level of I_b :

$$\text{Required diff. current} = \frac{I_b - 1.0}{2} + \frac{P}{100\%} \quad (5)$$

where I_b = biasing current calculated according to equation 2

P = basic setting ($P_1/I_n\%$ and $P_2/I_n\%$ for HV and LV sides, respectively)

Operation criterion 2 – neutral connection current

This criterion is optional. If the minimum ratio setting of $I_0/\Sigma I$ is above 0%, the measured ratio is required to exceed the setting:

$$\frac{I_0}{\Sigma I} \times 100\% \geq I_{01}/\Sigma I_1 \quad (6)$$

where I_0 = measured neutral current

ΣI = sum of measured phase currents (residual current)

$I_{01}/\Sigma I_1$ = minimum ratio setting for HV side ($I_{02}/\Sigma I_2$ for LV side)

When the CT ratio correction settings for both residual and neutral current are considered, the previous equation will be:

$$\frac{I_0}{I_{01}/I_n} \times \frac{\Sigma I}{I_1/I_n} \times 100\% \geq I_{01}/\Sigma I_1 \quad (7)$$

where I_{01}/I_n = CT ratio correction setting for neutral current on HV side
(I_{02}/I_n on LV side)

I_1/I_n = CT ratio correction setting for phase currents on HV side
(I_2/I_n on LV side)

Operation criterion 3 – magnitude of 2nd harmonic

If the 2nd harmonic blocking function has been selected and the 2nd harmonic content of the neutral current exceeds the setting (I_{2f}/I_{1f}) the trip operation will be blocked.

3.1.2.

Settings

The settings for the stabilized differential current principle are given in the table 3.1.2.-1.

Table 3.1.2-1 Settings for the stabilized differential current principle.

	Setting on HV side				Setting on LV side			
Operation principle	SGF1/1 1	SGF1/2 0	SGF1/3 0	SGF1/4 0	SGF1/5 1	SGF1/6 0	SGF1/7 0	SGF1/8 0
CT ratio corrections	I_1/I_n for phase CTs and I_{01}/I_n for neutral CT				I_2/I_n for phase CTs and I_{02}/I_n for neutral CT			
Basic setting (sensitivity)	P_1/I_n				P_2/I_n			
Operate time	$t_{01}>$				$t_{02}>$			
Min. ratio of $I_0/\Sigma I$	$I_{01}/\Sigma I_1$				$I_{02}/\Sigma I_2$			
CT connection type	SGF2/1				SGF2/3			
2 nd harmonic blocking	$I_{2f}/I_{1f}(I_{01})>$ SGF2/3: 1 = enabled, 0 = disabled				$I_{2f}/I_{1f}(I_{02})>$ SGF2/4: 1 = enabled, 0 = disabled			

The basic setting is used for selecting the start value of the earth-fault protection. It also has an effect on the level of the whole operation characteristic.

At an external fault, the phase CTs can be partially saturated, causing the earth-fault protection to start. To avoid unwanted relay operation, the operate time should be longer than the DC time constant of the network. The time constant (L/R) is defined mainly by the inductance of the power transformer and the resistance of the transformer and network cables. The smaller the basic setting is, the longer the operate time setting should be.

Furthermore, to avoid relay operation at phase CT saturation caused by the power transformer inrush current, either the operate time has to be prolonged or the harmonic blocking should be enabled.

The CT ratio correction settings are used to correct transforming ratios of the CTs:

$$I_1/I_n = \frac{I_{EF}}{I_{pp}} \quad I_{01}/I_n = \frac{I_{EF}}{I_{pn}} \quad (8)$$

Where I_{EF} = primary earth-fault current

I_{pp} = rated primary current of the phase CT

I_{pn} = rated primary current of the neutral CT

3.2. High-impedance principle

3.2.1. Purpose and connections

A well known and conventional protection method is the high-impedance principle, also known as the Restricted Earth-Fault (REF) principle. The advantages of this protection principle are absolute selectivity (unit protection) and fast operation, even though the CTs are partially saturated.

The operation is based on peak-to-peak measurement and no harmonics are suppressed. As the relay only sees the differential current, there is no need for harmonic blocking.

When this principle is used, the residual current measured (Holmgreen connection of the phase CTs) and the neutral current are summed at the I_0 input of the relay (terminals X0/25-26-27 on the HV side and terminals X0/37-38-39 on the LV side). A stabilizing resistor and often also a non-linear voltage limiting resistor are required.

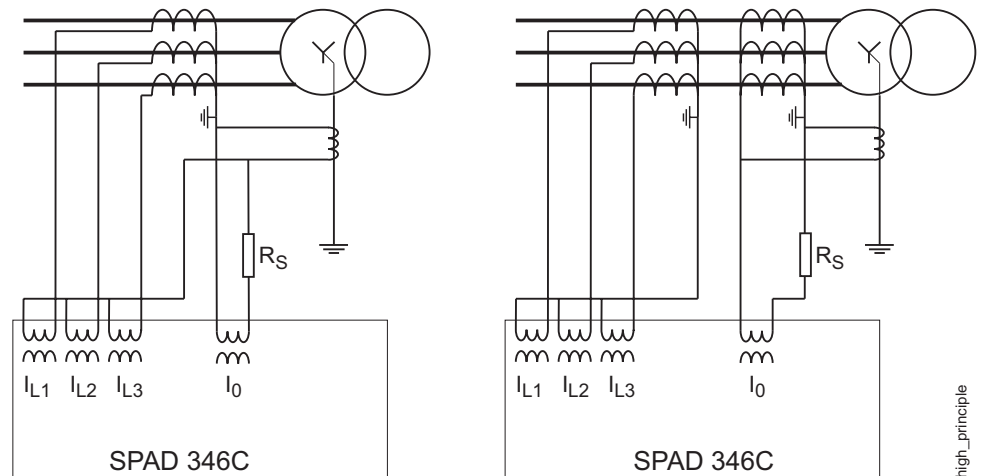


Fig. 3.2.1.-1 High-impedance principle (voltage limiting resistor not shown).

3.2.2. Settings

The settings for the high-impedance principle are given in Table 3.2.2.-1. The other settings ($I_{01}/\Sigma I_1$, $I_{02}/\Sigma I_2$, I_1/I_n and I_2/I_n) have no effect.

Table 3.2.2-1 Settings for the high-impedance principle.

	Setting on HV side				Setting on LV side			
Operation principle	SGF1/1 0	SGF1/2 0	SGF1/3 0	SGF1/4 1	SGF1/5 0	SGF1/6 0	SGF1/7 0	SGF1/8 1
CT ratio correction	I_{01}/I_n				I_{02}/I_n			
Basic setting (sensitivity)	P_1/I_n				P_2/I_n			
Operate time	$t_{01}>$				$t_{02}>$			
2 nd harmonic blocking	Disabled (Not needed)				Disabled (Not needed)			

The sensitivity of the protection depends on the CT ratio correction setting and on the basic setting:

$$I_{Operation} = \frac{P}{I_{01}} \quad (9)$$

where P = basic setting

I_{01} = CT ratio correction setting for the neutral connection CT, HV side (I_{02} for the LV side).

When the high-impedance principle is used the operation time should be set at the minimum.

3.3. Neutral current principle

3.3.1. Purpose and connections

When the neutral current principle is used, a current transformer is installed to the neutral to earth connection of a power transformer star point. The same principle can also be used for measuring the neutral current of an earthing transformer.

In this principle the relay cannot see where the fault is, i.e. this is no unit protection. The protection is based on the fundamental frequency components of the current. The DC component and harmonics are suppressed by a digital filter.

The current transformer is connected to the I_0 input (terminals X0/25-26-27 on the HV side and terminals X0/37-38-39 on the LV side).

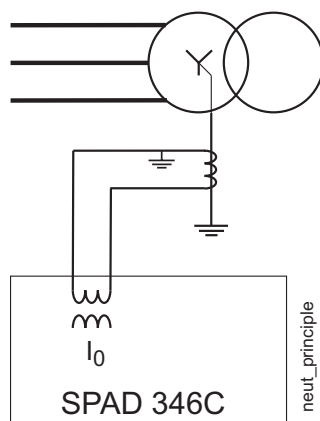


Fig. 3.3.1.-1 Neutral current principle.

3.3.2.

Settings

The settings for the neutral current principle are given in Table 3.3.2.-1. The other settings ($I_{01}/\Sigma I_1$, $I_{02}/\Sigma I_2$, I_1/I_n and I_2/I_n) have no effect.

Table 3.3.2-1 Settings for the neutral current principle.

	Setting on HV side				Setting on LV side			
Operation principle	SGF1/1 0	SGF1/2 0	SGF1/3 1	SGF1/4 0	SGF1/5 0	SGF1/6 0	SGF1/7 1	SGF1/8 0
CT ratio correction	I_{01}/I_n				I_{02}/I_n			
Basic setting (sensitivity)	P_1/I_n				P_2/I_n			
Operate time	$t_{01}>$				$t_{02}>$			
2 nd harmonic blocking	$I_{2f}/I_{1f}(I_{01})>$ SGF2/3: 1 = enabled, 0 = disabled				$I_{2f}/I_{1f}(I_{02})>$ SGF2/4: 1 = enabled, 0 = disabled			

The sensitivity of the protection depends on the CT ratio correction setting and on the basic setting:

$$I_{Operation} = \frac{P}{I_{01}} \quad (10)$$

where P = basic setting

I_{01} = CT ratio correction setting for the neutral connection CT, HV side (I_{02} for the LV side).

3.4.

Measured residual overcurrent principle

3.4.1.

Purpose and connections

From the relay point of view, this principle is the same as the previous neutral current principle. From the application point of view, residual overcurrent is measured with the residual connection of the phase CTs (known as the Holmgreen

connection) or with a core-balance current transformer (also known as ring CT). Typically, this principle is used only when the power transformer is delta connected or star connected with unearthed neutral.

The residual connection can be used when the sensitivity requirement of the protection is about 10% of the CT nominal current or above. For more sensitive protection the use of a core-balance CT is recommended.

The phase currents are summed at the I_0 input (terminals X0/25-26-27 on the HV side and terminals X0/37-38-39 on the LV side). Alternatively, a core-balance CT can be connected to the I_0 input.

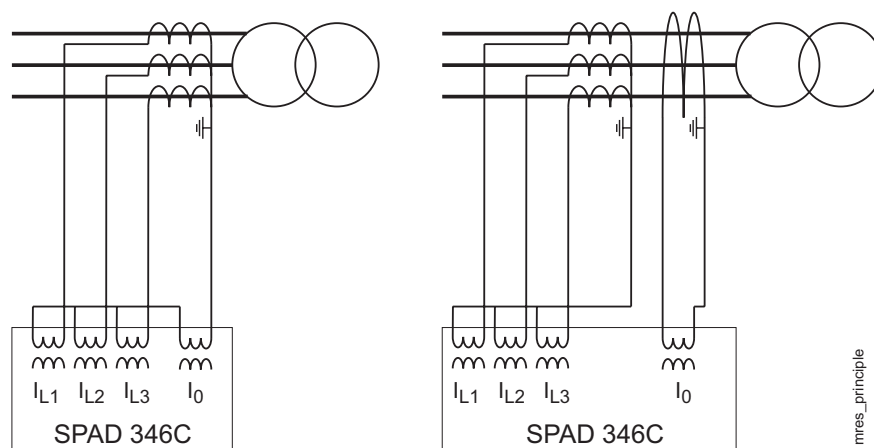


Fig. 3.4.1.-1 Residual current measurement using a residual connection of three line current CTs (left) or core balance CT (right).

The settings are the same as those used at the neutral current principle.

The operate time has to be long enough (up to several seconds) to prevent unwanted tripping due to CT saturation when a very asymmetric inrush current or start-up current is passing through the protected object.

3.5.

Calculated residual overcurrent principle

3.5.1.

Purpose and connections

When the calculated residual overcurrent principle is used, the phase current transformers are connected to the relay in the usual manner. The relay will then calculate the residual current from the phase currents (virtual I_0).

This principle can be used when the sensitivity requirement is about 10% of the CT nominal current, or above. For more sensitive protection the neutral current principle is recommended.

Note: When this principle is used on the HV side, the I_0 input (terminals X0/25-26-27) is left unconnected. On the LV side, the I_0 input (terminals X0/37-38-39) can be used by the SPCJ 4D28 module (see Chapter 3.8.5 Example 5).

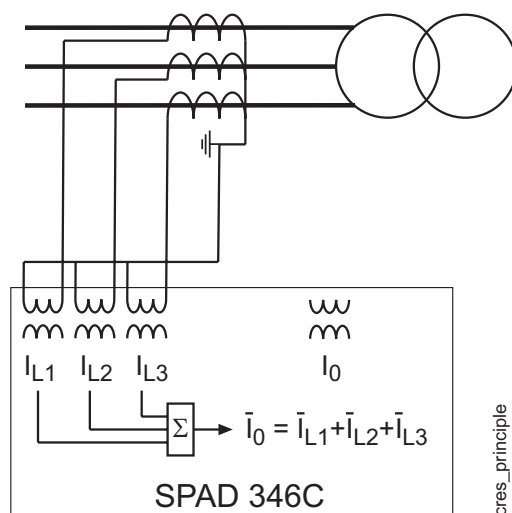


Fig. 3.5.1.-1 Calculated residual overcurrent principle.

3.5.2.

Settings

The settings for the calculated residual overcurrent principle are given in table 3.5.2.-1. Other settings (I_{01}/I_n , $I_{01}/\Sigma I_1$, I_{02}/I_n and $I_{02}/\Sigma I_2$) have no effect.

Table 3.5.2-1 Settings for the calculated residual overcurrent principle.

	Setting on HV side				Setting on LV side			
Operation principle	SGF1/1 0	SGF1/2 1	SGF1/3 0	SGF1/4 0	SGF1/5 0	SGF1/6 1	SGF1/7 0	SGF1/8 0
CT ratio correction	I_1/I_n				I_2/I_n			
Basic setting (sensitivity)	P_1/I_n				P_2/I_n			
Operate time	$t_{01}>$				$t_{02}>$			
2 nd harmonic blocking	Disabled (Not needed)				Disabled (Not needed)			

The sensitivity of the protection depends on the CT ratio correction setting and on the basic setting:

$$I_{Operation} = \frac{P}{I_1/I_n} \quad (11)$$

where P = basic setting

I_1/I_n = CT ratio correction setting for the phase current CT, HV side (I_2/I_n for the LV side).

The operate time has to be long enough (up to several seconds) to prevent unwanted tripping due to CT saturation when a very asymmetric inrush current or start-up current is passing through the protected object.

3.6. Setting guide for the 2nd harmonic blocking

Some protection principles allows blocking based on the 2nd harmonic content of the measured I_0 current.

The 2nd harmonic is used to detect the inrush current of a power transformer, because, in an inrush situation, neutral current can flow in the neutral earthed star-winding. The correct setting for the blocking limit can be derived from the data recorded by the relay at energization of the transformer one or several times on trial.

The drawback of using the 2nd harmonic blocking is that the operate time of the protection relay may be prolonged in the event of a real earth fault. Often a better solution is not to use 2nd harmonic blocking, but to increase the operation time of the protection slightly to avoid unwanted operations due to inrush current.

3.7. Earth-fault protection in the SPCJ 4D28 module

The SPCJ 4D28 module measures the phase currents on the HV side, but the I_0 current on the LV side, i.e. both the earth-fault protection of the SPCJ 4D28 module and the earth-fault protection of the SPCD 2D55 module on the LV use the I_{02} input (terminals X0/37-38-39).

Table 3.7.-1 Differences between the earth-fault protection of the SPCD 2D55 and SPCJ 4D28 modules.

Module	SPCD 2D55	SPCJ 4D28
Number of stages	One stage on both LV and HV side	Two stages ($I_0>$ and $I_0>>$) on LV side
Operation time	Definite time	$I_0>$ stage with inverse or definite time operation. $I_0>>$ always with definite time operation.
Operation principle	Selectable	Always neutral/measured residual current principle
2nd harmonic blocking	Possible with some operation principles	No internal blocking

3.8. Application examples

3.8.1. Example 1

In the example below, the stabilized differential current principle is used for the earth-fault protection of the HV side of the power transformer and the high-impedance principle is used for the earth-fault protection of the LV side. Both protection principles provide absolute selectivity (unit protection).

The earth-fault protection of the SPCJ 4D28 module cannot be used as it is connected to the LV side, which is already protected using the high-impedance principle.

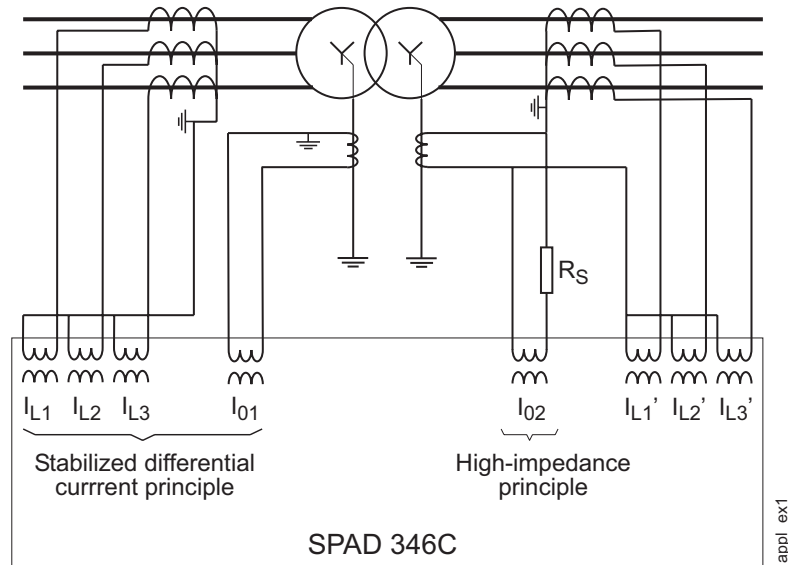


Fig. 3.8.1.-1 Example 1 (voltage limiting resistor not shown).

3.8.2.

Example 2

In this example, the stabilized differential current principle is used for the earth-fault protection of the HV side of the power transformer. This type of protection provides absolute selectivity.

The LV side protection (I_{02} input) is used as back-up protection for the HV side. The neutral current principle does not discriminate the fault location and thus both the HV side of the power transformer and the HV side network are protected.

The earth-fault protection of the SPCJ 4D28 module (which also uses the I_{02} input) can be used instead of or together with the SPCD 2D55 module.

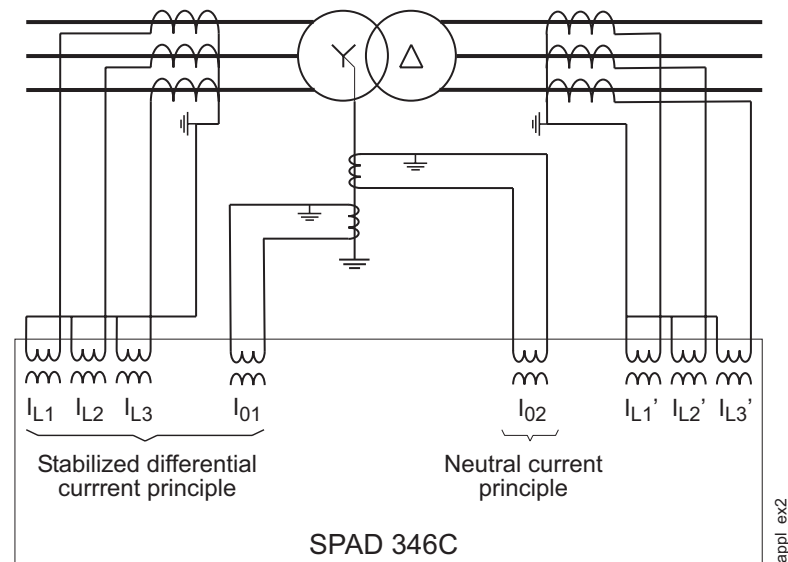


Fig. 3.8.2.-1 Example 2.

3.8.3.

Example 3

In this example, the measured residual current principle is used for the earth-fault protection of the HV side of the power transformer and the network. The neutral current principle of the SPCD 2D55 module and/or the SPCJ 4D28 module is used for implementing the earth-fault protection on the LV side.

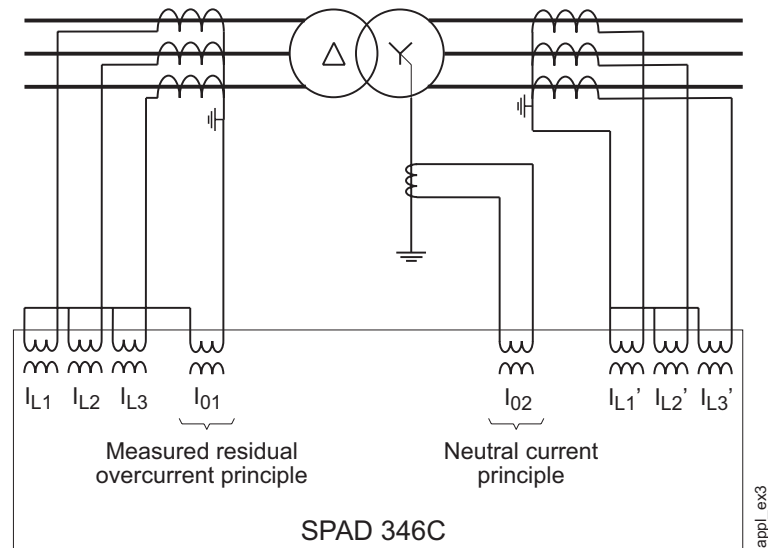


Fig. 3.8.3.-1 Example 3.

3.8.4.

Example 4

This example is the same as example 3, except that the residual current of the HV side is measured with a core-balance CT.

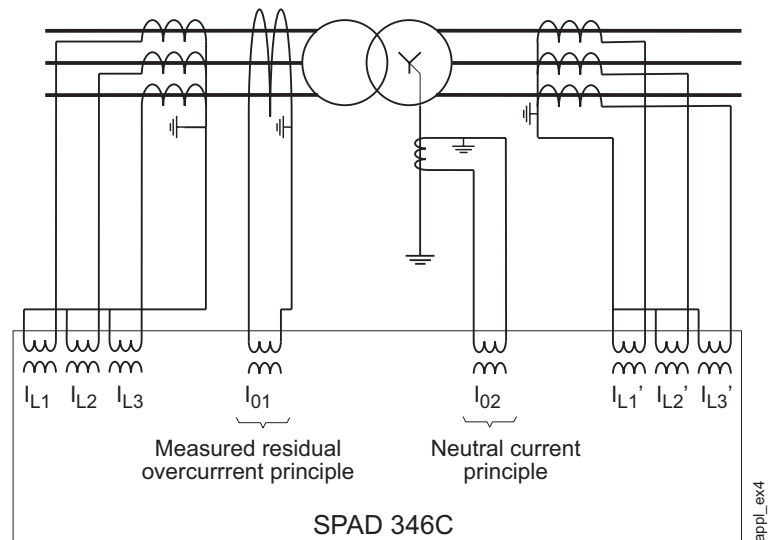


Fig. 3.8.4.-1 Example 4.

3.8.5.**Example 5**

In this example, the high-impedance principle is used on the HV side, whereas the calculated residual overcurrent principle is used on the LV side. This protection principle is based on the sum of the phase currents of the LV side and the SPCD 2D55 module does not use the I_{02} input. Therefore, the I_{02} input can be used for the SPCJ 4D28 module to provide back-up protection for the HV side.

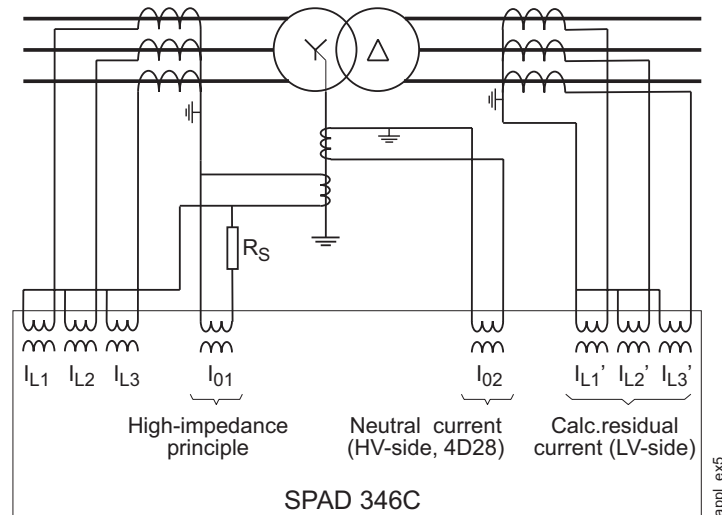


Fig. 3.8.5.-1 Example 5 (voltage limiting resistor not shown).

3.8.6.**Examples in the relay manual**

The user's manual and the technical description of the SPAD 346 C relay (see reference) introduce three application examples.

Example 1 in the relay manual:

- The stabilized differential current principle (or neutral current principle) of the relay module SPCD 2D55 is used for the protection of the HV side and the LV side.
- The protection stages of the SPCJ 4D28 module are used for back-up protection on the LV-side (definite or inverse operation times).

Example 2 in the relay manual:

- The high-impedance protection principle of the SPCD 2D55 module (HV-side protection stage) is used on the HV side.
- The LV-side protection stage of the SPCD 2D55 module is connected to measure HV-side neutral current. The neutral current protection principle used. As the neutral current principle allows 2nd harmonic blocking, the blocking signal can be used, for instance, for blocking the SPCJ 4D28 earth-fault protection.
- The protection stages of the SPCJ 4D28 are used for back-up protection on the HV side (inverse time mode of operation).

Example 3 in the relay manual:

- The high-impedance protection principle of the SPCD 2D55 module is used on the HV side and on the LV side.
- The protection stages of SPCJ 4D28 are not used.

3.9.**Disturbance recording (SPCD 2D55)**

The internal disturbance recording function of the relay module is a powerful tool for analyzing the cause of a CB trip. Therefore, attention should be paid to the disturbance recorder settings.

The factory default setting of the serial communication parameter V241 allows the disturbance recorder to be triggered by the start of the HV or LV side protection relay. The parameter V245 is used to set the length, in cycles, of the recording following the triggering of the disturbance recorder. The factory setting is 5, which means that the disturbance will include a history of $30 - 5 = 25$ pre-triggering cycles and 5 post-triggering cycles.

It should be noted that the recorder is triggered by the start signal, not the trip signal of the SPCT 2D55 module. Longer operate times require longer post-triggering times. When, for example, the set operate time is 0.15 s, the setting $V245 = 10$ would give 20 cycles (0.4 s at 50 Hz network) before the start and 10 cycles (0.2 s at 50 Hz) after the start.

Note for indication

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

4. Summary

This document describes the operation principles of the earth-fault protection of the stabilized differential relay SPAD 346 C. The earth-fault relay module SPCD 2D55 allows four different operation principles to be used. As some principles have alternative connections they are here presented as five principles.

The purpose of and the relay connections for each principle are presented. For the stabilized differential current principle the operation criteria are completed with some equations to better illustrate the operation of the relay.

All relay module settings are not effective with all operation principles. Therefore, a list of the settings not affecting the operation principle in question is given together with the settings. Some guidelines for relay setting and for the use of the 2nd harmonic blocking are given as well.

Then, the operation principle of the combined overcurrent and earth-fault relay module SPCJ 4D28 is presented in comparison to the SPCD 2D55 module.

Next, the three application examples given in the SPAD 346 C relay manual are referred to and five new examples with connection diagrams are presented.

Finally, the use of disturbance recording in the SPCD 2D55 module is discussed.

5. References

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

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

6. List of symbols

I_0	neutral current (HV or LV side)
I_0'	neutral current, seen by the relay
I_{0I}	measured neutral current at HV side
I_{01}/I_n	CT ratio correction setting for HV side neutral current
I_{02}/I_n	CT ratio correction setting for LV side neutral current
$I_{01}/\Sigma I_1$	minimum ratio setting for HV side
$I_{02}/\Sigma I_2$	minimum ratio setting for LV side
I_{L1}, I_{L2}, I_{L3}	phase currents
I_1/I_n	CT ratio correction setting for HV side phase currents
I_2/I_n	CT ratio correction setting for LV side phase currents
$I_{2f}/I_{1f} (I_{01}) >$	setting for second harmonic blocking at HV side
$I_{2f}/I_{1f} (I_{02}) >$	setting for second harmonic blocking at LV side
I_b	bias current
I_d	differential current
I_d'	differential current, seen by the relay
$I_{d \times \cos \varphi}$	calculated directional differential current
I_{EF}	primary earth-fault current
$I_{Operation}$	current at which the protection operates
I_{pp}	rated primary current of the phase CT
I_{pn}	rated primary current of the neutral CT
$P, P_1/I_n, P_2/I_n$	basic setting
φ	phase angle
ΣI	sum of the phase currents (HV or LV side)
$\Sigma I'$	sum of the phase currents, seen by the relay



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