Stabilizing Resistor in Motor Earth-Fault Protection

Application Note

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1. Scope

This document explains how to calculate the value of the stabilising resistor used in motor earth-fault protection. Typically, a stabilising resistor is needed when residually connected current transformers are used to measure the earth-fault (residual) current. The purpose of the stabilising resistor is to prevent the relay from operating due to saturation of the current transformers during motor start-up.

This document introduces the formulas needed for the calculation of the stabilising resistor and contains a calculation example.

The principles described can be generally used for motor earth-fault protection and for calculating, for example, the protection settings for SPACOM and RED 500 series protection relays.

KEYWORDS: earth-fault protection, motor protection, current transformer saturation, stabilising resistor

2. Introduction

The earth-fault current can be measured in different ways. One way is to use a core balance current transformer. The core balance current transformer is preferred when high sensitivity is needed. A stabilising resistor is not used with the core balance current transformer. Another method is to measure the earth-fault current through a residual connection of the three phase CTs. This connection is also called the Holmgreen connection. The residual connection can be used when the sensitivity requirement is about 10% of the CT nominal current, or higher. For very sensitive protection a core balance current transformer has to be used.

When the residual connection of the three phase CTs is used, an unwanted operation of the earth-fault protection relay sometimes occurs during motor start-up. The reason for the unwanted relay operation may be that the start-up current of the motor occasionally causes one or more of the three phase CTs in residual connection to saturate. The CT saturation is caused by the DC component of the unsymmetrical start-up current. To avoid this problem a suitable stabilising resistor can be connected in series with the earth-fault current input of the protection relay. The stabilising resistor forces the current fed by a non-saturated current transformer to flow through the secondary circuit of a saturated current transformer.

3. Technical implementation

3.1. Connection diagram

Fig. 3.1-1 illustrates the connection principle when the earth-fault current is measured through the residual connection of the three phase CTs. The stabilising resistor is connected in series with the earth-fault current input of the protection relay. The purpose of the voltage-dependent resistor is to limit the voltage of the secondary circuit to a safe level. The need for a VDR is case-specific and can be checked by calculation.

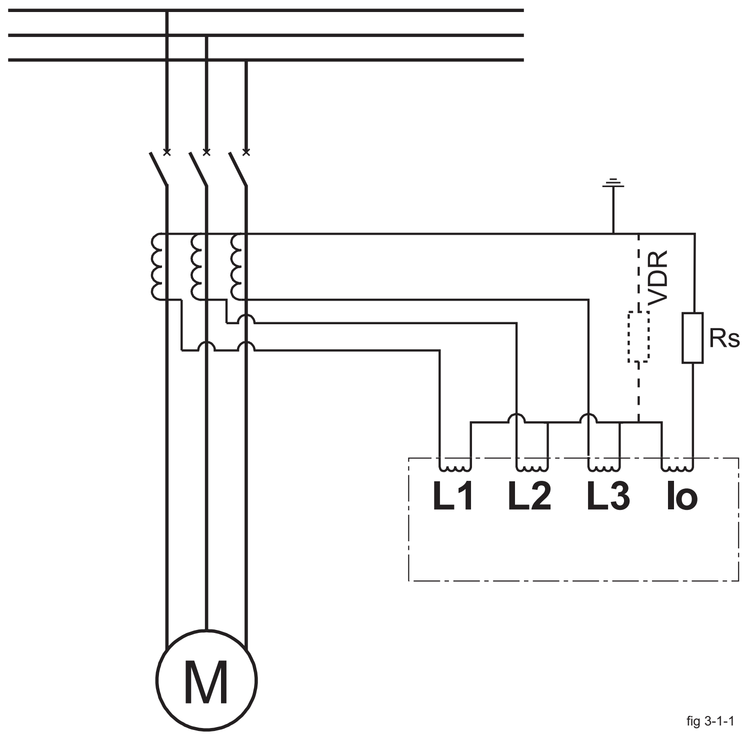

Fig. 3.1.-1 Residual connection of three phase CTs and application with a stabilising resistor (Rs) and a voltage-dependent resistor (VDR).

3.2. Calculation of stabilising voltage

The stabilising voltage U_s is calculated assuming that one of the residually connected current transformers will be fully saturated at motor start-up:

$$U_s = \frac{I_{start}}{n} \times (R_{ct} + R_m) \qquad (1)$$

Where:

I_{start} start-up current (primary value) of the motor
n CT ratio
R_{ct} internal resistance of the CT
R_m resistance of the longest loop of the CT secondary circuit

The current transformer knee-point voltage U_{kn} has to be at least twice as high as the stabilising voltage U_s.

3.3. Calculation of the relay setting

The sensitivity of the protection can be calculated as:

$$I_{prim} = n \times (I_s + 3 \times I_e + I_u) \qquad (2)$$

where:

I_{prim} primary current at which the relay starts
n CT ratio
I_s start current (secondary value) of the earth-fault protection
I_e magnetizing current of the CT at the voltage U_s
I_u current through the VDR at the voltage U_s

The relay start current can be calculated using formula (2), when the primary sensitivity requirement for the protection is known:

$$I_s = \frac{I_{prim}}{n} - (3I_e - I_u) \qquad (3)$$

The relay setting is then simply:

$$I_r = \frac{I_s}{I_2} \qquad (4)$$

where:

I_2 rated current of the relay (typically 1 A or 5 A)

3.4. Calculation of the stabilising resistor

The stabilising resistor R_s is calculated as:

$$R_s = \frac{U_s}{I_s} = \frac{I_{start} \times (R_{ct} + R_m)}{I_s \times n} \qquad (5)$$

where:

I_{start} start-up current (primary value) of the motor
R_{ct} internal resistance of the CT
R_m resistance of the longest loop of the secondary circuit
n CT ratio
I_s start current (secondary value) of the earth-fault protection

The power rating of the stabilising resistor R_s is calculated as:

$$P \geq \frac{(U_{kn})^2}{R_s} \qquad (6)$$

where:

U_{kn} knee-point voltage of the CT

A wire wound resistor type is recommended. When selecting the resistor it should be noted that the measuring wires can be reliably connected to the resistor, that a suitable installation kit is included and the voltage withstand is high enough for the application concerned.

3.5. Calculation of the voltage-dependent resistor

During faults inside the zone of protection the voltage of the measuring circuit may grow high enough to exceed the isolation level the relay, current transformers and the wires. This can be avoided by installing a voltage-dependent resistor into the circuit. The voltage-dependent resistor is typically needed if the peak voltage during a fault is 3 kV or higher.

The voltage U_f, which ignores the CT saturation, during the fault can be calculated as follows:

$$U_f = \frac{I_{max}}{n} \times (R_s + R_{ct} + R_m + R_r) \qquad (7)$$

where:

I_{max} maximum earth-fault current

The peak voltage, u_{peak}, which includes the CT saturation, can be estimated from the following formula (given by P.Mathews 1955):

$$u_{peak} = 2\sqrt{2U_{kn}(U_f - U_{kn})} \qquad (8)$$

3.6. Calculation example

The power system is low-impedance earthed. The maximum earth-fault current is limited to 400 A. The required motor earth-fault protection sensitivity is assumed to be 20% of the full load current. The starting current of the motor is assumed to be 4.8 x I_{nm}. The resistance of the longest loop of the secondary circuit is 0.2 Ω and the relay input impedance is 0.02 Ω. Calculate a suitable stabilising resistor value as follows:

Motor data

Rated power, P_{nm} 2800 kW

Rated voltage, U_{nm} 3300 V

Rated current, I_{nm} 549 A

The CT specifications from the CT manufacturer's catalogue are assumed to be:

600/5 A , 5P10 , 15 VA, R_{ct} = 0.28 ohm, U_{kn} = 34.0 V, I_m = 100 mA (at U_{kn})

First the stabilising voltage is calculated using formula (1):

$$U_s = \frac{4.8 \times 549A}{120} \times (0.82\Omega + 0.2\Omega) \approx 10.5\text{V}$$

In this case the requirement for the current transformer knee-point voltage is fulfilled because $U_{kn} > 2U_s$.

The magnetising curve of the CT is assumed to be linear. The magnetising current at the stabilising voltage will then be:

$$I_e = \frac{10.5\text{V}}{34.0\text{V}} \times 100mA \approx 31mA$$

The secondary start current of the relay is calculated using formula (3). The current through the voltage-dependent resistor is assumed to be zero.

$$I_s = \frac{0.2 \times 549A}{120} - 3 \times 31mA \approx 822mA$$

The relay setting is then calculated using formula (4):

$$I_r = \frac{0.82\text{A}}{5A} \approx 0.16$$

The resistance of the stabilising resistor is calculated using formula (5):

$$R_s = \frac{10.5\text{V}}{0.82A} \approx 13\Omega$$

The power of the stabilising resistor is calculated using formula (6):

$$P \geq \frac{34.0\text{V}^2}{13\Omega} \approx 89W$$

Based on formula (7), the need for the voltage-dependent resistor is checked:

$$U_f = \frac{400A}{120}(13\Omega + 0.82\Omega + 0.2\Omega + 0.02\Omega) \approx 44V$$

The voltage-dependent resistor is not needed in this case, because the voltage during the fault is much lower than 3 kV. Formula (8) does not have to be used in this case, because formula (7) already gives a low voltage value.

4. Summary

This document describes how to select a suitable stabilising resistor to be introduced in a motor earth-fault protection scheme. The information given is valid for ABB's SPACOM and RED 500 protection relays. The required calculation formulas are presented and a calculation example is included to show how to use the formulas. The correctly selected stabilising resistor prevents undesired operation of the earth-fault protection due to CT saturation. If the voltage during an in-zone fault can be expected to grow so high that it will exceed the insulation level of the circuit, a voltage-dependent resistor should be inserted in the circuit.

5. References

IEC 60044-1. Instrument transformers – Part 1: Current transformers.

6. List of symbols

I_2	rated current of the relay
I_e	magnetizing current of the CT at the voltage U_s
I_{max}	maximum earth-fault current
I_{nm}	rated current of the motor
I_{prim}	primary current at which the relay starts
I_s	start current (secondary value) of the earth-fault protection
I_{start}	start-up current (primary value) of the motor
I_r	relay setting
I_u	current through the VDR at the voltage U_s
n	CT ratio
P	rated power of the stabilising resistor
P_{nm}	rated power of the motor
R_{ct}	internal resistance of the CT
R_m	resistance of the longest loop of the CT secondary circuit
R_r	relay input impedance
R_s	stabilising resistor
U_f	voltage which ignores the CT saturation
U_{kn}	knee-point voltage of the CT
U_{nm}	rated voltage of the motor
U_s	stabilising voltage
u_{peak}	peak voltage which includes the CT saturation
VDR	voltage-dependent resistor

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