

UR Family

T60 Restricted Ground Fault Protection Calculations

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This document outlines ground fault protection calculations for the GE Universal Relay (UR) T60 Transformer Protection System.

Introduction

The T60 is equipped with a number of restricted ground fault (RGF) protection elements.

The RGF element uses a novel algorithm where the restraint current is a maximum of pre-calculated values based on positive-, negative-, and zero-sequence symmetrical components derived from measured winding phase currents. The actual ratio of the ground differential and restraint currents is then compared to the quantity formed by the pickup and a single slope RGF characteristic.

Settings calculation example

Consider a transformer with the following nameplate data:

- Transformer type — Delta/Wye 30°
- Rated MVA — 10 MVA
- Nominal phase-phase voltage — 33 kV (Winding 1) / 11 kV (Winding 2)
- Phase and Neutral CT ratios — 600:1
- Impedance — 10%
- Winding neutral grounded through resistance — $R_g = 6.3 \Omega$

The rated load current of the Wye connected winding is calculated as

$$I_{\text{rated}} = \frac{\text{Rated MVA}}{\sqrt{3} \times \text{Winding 2 Nominal Voltage}} = \frac{10 \text{ MVA}}{\sqrt{3} \times 11 \text{ kV}} = 525 \text{ A} \quad \text{Eq. 1}$$

The maximum phase-to-ground primary fault current is calculated as

$$I_{\text{gf(max)}} = \frac{\text{Winding 2 Nominal Voltage}}{\sqrt{3} R_g} = \frac{11 \text{ kV}}{\sqrt{3} \times 6.3 \Omega} = 1000 \text{ A} \quad \text{Eq. 2}$$

For a winding fault point at 5% distance from the transformer neutral, the phase-to-ground primary fault current is calculated as

$$I_{\text{fault}} = 0.05 \times I_{\text{gf(max)}} = 50 \text{ A} \quad \text{Eq. 3}$$

Increases in phase current (I_{ph}) due to the fault are negligible, meaning that $3I_0 \approx 0$.

The ground differential pickup setting can be calculated as

$$I_{\text{GD}} = \left| 3\vec{I}_0 - \vec{I}_g \right| = \left| 0 - \frac{I_{\text{fault}}}{\text{Phase CT Primary}} \right| = \frac{50 \text{ A}}{600} = 0.08 \text{ pu} \quad \text{Eq. 4}$$

Note that phase CT primary is used as a unit for calculating the RGF settings. Hence, magnitude scaling is applied to the measured ground current.

The restraint calculation algorithm provides very secure behavior of the element on external faults and CT saturation, and high sensitivity on internal faults. The setting of the slope is selected based on the following two criteria:

- Reliable detection of the internal fault currents corresponding to the point of the selected distance from the grounded neutral
- Security on external faults with or without CT saturation

Let us consider the case of an internal ground fault that occurs on in the winding at 5% distance from the transformer neutral. According to the data from the example, the primary fault current of 50 A is

$$I_G = 0.08 \text{ pu} \quad \text{Eq. 5}$$

Based on 100% transformer load currents of 525 A on the Wye winding, the phase unit currents are

$$I_A = I_B = I_C = 0.875 \text{ pu} \quad \text{Eq. 6}$$

and the symmetrical components are

$$I_1 = 0.875 \text{ pu}; \quad I_2 = I_0 = 0 \text{ pu} \quad \text{Eq. 7}$$

The ground differential current is calculated according to the following equation:

$$I_{\text{GD}} = \left| \vec{I}_G + \vec{I}_N \right| = 0.08 \text{ pu} + 0 \text{ pu} = 0.08 \text{ pu} \quad \text{Eq. 8}$$

The restraint current used by the relay algorithm is defined as the maximum from the IR1, IR2, IR0 quantities, based on the following symmetrical components calculations:

$$I_{\text{GR}} = \max(\text{IR1}, \text{IR2}, \text{IR0}) \quad \text{Eq. 9}$$

The value of IR1 is calculated using the positive-sequence current as follows:

$$\begin{aligned} \text{If } |I_{-1}| > 1.5 \text{ pu of phase CT, and } |I_{-1}| > |I_{-0}|, \text{ then } \text{IR1} &= 3 \times (|I_{-1}| - |I_{-0}|) \\ \text{else } \text{IR1} &= 0 \end{aligned} \quad \text{Eq. 10}$$

However, if $|I_{-1}| < 1.5 \text{ pu}$, then $\text{IR1} = \frac{|I_{-1}|}{8}$.

The value of IR2 is calculated using the negative-sequence current.

In this case, $\text{IR2} = |I_{-2}|$ for the first two cycles, following complete de-energization of the winding (all three phase currents below 5% of nominal for at least five cycles). Otherwise, $\text{IR2} = 3 \times |I_{-2}|$.

The value of IR0 is calculated using the zero-sequence current

$$\text{IR0} = \left| \vec{I}_G - \vec{I}_N \right| = \left| \vec{I}_G - (I_A - I_B - I_C) \right| \quad \text{Eq. 11}$$

Applying these formulas to our example gives us the following values:

$$\text{IR1} = \frac{|I_{-1}|}{8} = \frac{0.875 \text{ pu}}{8} = 0.194 \text{ pu} \quad (\text{since } |I_{-1}| < 1.5 \text{ pu}) \quad \text{Eq. 12}$$

$$\text{IR2} = 3 \times |I_{-2}| = 3 \times 0 \text{ pu} = 0 \quad \text{Eq. 13}$$

$$\text{IR0} = \left| \vec{I}_G - \vec{I}_N \right| = |0.08 \text{ pu} - 0| = 0.08 \text{ pu} \quad \text{Eq. 14}$$

Therefore, the ground differential current is

$$I_{GD} = \left| \vec{I}_G + \vec{I}_N \right| = |0.08 \text{ pu} + 0| = 0.08 \text{ pu} \quad \text{Eq. 15}$$

and the ground restraint current is

$$I_{GR} = \max(I_{R1}, I_{R2}, I_{R0}) = \max(0.194 \text{ pu}, 0, 0.08 \text{ pu}) = 0.194 \text{ pu} \quad \text{Eq. 16}$$

The RGF element therefore calculates a ground differential/restraint ratio of

$$\frac{I_{GD}}{I_{GR}} \times 100\% = \frac{0.08 \text{ pu}}{0.194 \text{ pu}} \times 100\% = 41.2\% \quad \text{Eq. 17}$$

Thus, the slope should be set at some level below 41.2%.

Ideally, if no CT saturation is involved, the RGF protection detects no differential current during ground faults that are external to the zone. However, the RGF slope setting should also be selected to maintain the security on external faults with CT saturation.

External solid phase A to ground fault with no CT saturation

Consider an external solid phase a to ground fault with no CT saturation. Given the following currents and corresponding secondary values:

Primary currents	Secondary values
$I_A = 1000 \text{ A}$	$I_A = 1000/600 = 1.67 \text{ pu} \angle 0^\circ$
$I_B = 0 \text{ A}$	$I_B = 0 \text{ pu}$
$I_C = 0 \text{ A}$	$I_C = 0 \text{ pu}$
$I_N = 1000 \text{ A}$	$I_N = 1000/600 = 1.67 \text{ pu} \angle 0^\circ$
$I_G = 1000 \text{ A}$	$I_G = 1000/600 = 1.67 \text{ pu} \angle 180^\circ$

The symmetrical components derived from the phase unit currents are

$$I_1 = I_2 = I_0 = 0.557 \text{ pu} \quad \text{Eq. 18}$$

The ground differential current is

$$I_{GD} = \left| \vec{I}_G + \vec{I}_N \right| = 1.67 \text{ pu} \angle 0^\circ + 1.67 \text{ pu} \angle 180^\circ = 0 \text{ pu} \quad \text{Eq. 19}$$

The IR1, IR2, and IR0 currents are

$$IR1 = \frac{|I_{-1}|}{8} = \frac{0.557 \text{ pu}}{8} = 0.07 \text{ pu} \quad \text{Eq. 20}$$

$$IR2 = 3 \times |I_{-2}| = 3 \times 0.557 \text{ pu} = 1.67 \text{ pu} \quad \text{Eq. 21}$$

$$IR0 = \left| \vec{I}_G - \vec{I}_N \right| = |1.67 \text{ pu} \angle 180^\circ - 1.67 \text{ pu} \angle 0^\circ| = 3.34 \text{ pu} \quad \text{Eq. 22}$$

The restraint current is the maximum of the three currents IR1, IR2, and IR0 as follows:

$$I_{GR} = \max(IR1, IR2, IR0) = 3.34 \text{ pu} \quad \text{Eq. 23}$$

Therefore

$$\frac{I_{GD}}{I_{GR}} \times 100\% = \frac{0 \text{ pu}}{3.34 \text{ pu}} \times 100\% = 0\% \quad \text{Eq. 24}$$

and the protection element is effectively in a non-operating stage.

External phase A to ground fault with saturation on the ground CT

Consider an external phase A to ground fault where the ground CT saturates as a result, producing only 5% of the total fault current on its secondary winding. As per the previous example, the phase fault currents (primary and secondary) are given as follows:

Primary currents	Secondary values
$I_A = 1000 \text{ A}$	$I_A = 1000/600 = 1.67 \text{ pu } \angle 0^\circ$
$I_B = 0 \text{ A}$	$I_B = 0 \text{ pu}$
$I_C = 0 \text{ A}$	$I_C = 0 \text{ pu}$
$I_N = 1000 \text{ A}$	$I_N = 1000/600 = 1.67 \text{ pu } \angle 0^\circ$
$I_G = 50 \text{ A}$	$I_G = 0.05 \times 1000/600 = 0.0835 \text{ pu } \angle 180^\circ$

The symmetrical components derived from the secondary phase currents are

$$I_1 = I_2 = I_0 = 0.557 \text{ pu} \quad \text{Eq. 25}$$

The differential ground current is calculated as

$$I_{GD} = |\vec{I}_G + \vec{I}_N| = 1.67 \text{ pu } \angle 0^\circ + 0.0835 \text{ pu } \angle 180^\circ = 1.587 \text{ pu} \quad \text{Eq. 26}$$

The IR1, IR2, and IR0 currents are

$$IR1 = \frac{|I_{-1}|}{8} = \frac{0.557 \text{ pu}}{8} = 0.07 \text{ pu} \quad \text{Eq. 27}$$

$$IR2 = 3 \times |I_{-2}| = 3 \times 0.557 \text{ pu} = 1.67 \text{ pu} \quad \text{Eq. 28}$$

$$IR0 = |\vec{I}_G - \vec{I}_N| = |0.0835 \text{ pu } \angle 180^\circ - 1.67 \text{ pu } \angle 0^\circ| = 1.753 \text{ pu} \quad \text{Eq. 29}$$

The restraint current is the maximum of the three currents IR1, IR2, and IR0 as follows:

$$I_{GR} = \max(IR1, IR2, IR0) = 1.753 \text{ pu} \quad \text{Eq. 30}$$

Therefore

$$\frac{I_{GD}}{I_{GR}} \times 100\% = \frac{1.587 \text{ pu}}{1.753 \text{ pu}} \times 100\% = 90.5\% \quad \text{Eq. 31}$$

This is well above the restraint characteristic in the operating region if no special treatment to the restraint is provided.

For cases of CT saturation and switch-off conditions, the ground restraint I_{GR} is set to decay slowly. Since the CTs do not immediately saturate at the same instant the fault occurs, the restraint current is equal to the initial fault current value of 3.34 pu (as in the no-saturation case). The restraint drops to 50% of its original value after 15.5 cycles, so that if the worst case of saturation occurs after a cycle, the restraint current is approximately 3.23 pu, giving the following ratio:

$$\frac{I_{GD}}{I_{GR}} \times 100\% = \frac{1.587 \text{ pu}}{3.23 \text{ pu}} \times 100\% \approx 49\% \quad \text{Eq. 32}$$

During CT saturation differential current will be increasing gradually and restraint decreasing gradually as CT enters into saturation. This calculations shows that due to memory effect of the restraint current in RGF element, the relay will use the higher restraint value and the application remains secure.

Summary

These examples help to identify the boundaries from the security/sensitivity range for setting the RGF slope. In our case, the slope has to be above 50% (assuming very severe saturation leading to only 5% current from the saturated ground CT), and below 70% (assuming detection of faults on the winding at 5% distance from the neutral point).

For further assistance

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