Application Note

Substation Automation and Protection Division

Current Differential Relay REL356 Current Pickup Calculation

Introduction

This note describes how to calculate the current pick-up level for different types of faults.

IT current

REL356 uses sequence filters to obtain positive, negative and zero sequence currents. These currents are then combined into one quantity:

$$I_T = -C1 \cdot I_1 + C2 \cdot I_2 + C0 \cdot I0$$

The positive, negative and zero sequence current is computed from the phase currents in conventional manner:

$$I_1 = \frac{I_A + aI_B + a^2 I_C}{3} = \frac{I_A + I_B\angle 120° + I_C\angle -120°}{3}$$

$$I_2 = \frac{I_A + a^2 I_B + aI_C}{3} = \frac{I_A + I_B\angle -120° + I_C\angle 120°}{3}$$

$$I_0 = \frac{I_A + I_B + I_C}{3}$$

Note that all sequence component currents are referenced to phase A current.

General calculation of IT

Based on input currents and C-settings, the IT current is calculated as follows:

Settings

C_1

C_2

C_0

Input currents

I_A

I_B

I_C

IT

$$I_T = -C_1 \cdot I_1 + C_2 \cdot I_2 + C_0 \cdot I_0 =$$

$$I_T = \frac{-C_1(I_A + I_B\angle 120° + I_C\angle -120°) + C_2(I_A + I_B\angle -120° + I_C\angle 120°) + C_0(I_A + I_B + I_C)}{3}$$

Example 1A, phase A to ground fault

With settings

$C_1 = 0.1$

$C_2 = 0.7$

$C_0 = 1.0$

and input currents

$I_A = 5.0\angle 0° A$

$I_B = 0$

$I_C = 0$

IT becomes:

$$I_T = \frac{-C_1(I_A + I_B\angle 120° + I_C\angle -120°) + C_2(I_A + I_B\angle -120° + I_C\angle 120°) + C_0(I_A + I_B + I_C)}{3}$$

$$I_T = \frac{-0.1 \cdot 5.0 + 0.7 \cdot 5.0 + 1.0 \cdot 5.0}{3} = 2.67A$$

Example 1B, phase B to ground fault

With settings

$C_1 = 0.1$

$C_2 = 0.7$

$C_0 = 1.0$

and input currents

$I_A = 0$

$I_B = 5.0\angle -120°$

$I_C = 0$

IT becomes:

$$I_T = \frac{-C_1(I_A + I_B\angle 120° + I_C\angle -120°) + C_2(I_A + I_B\angle -120° + I_C\angle 120°) + C_0(I_A + I_B + I_C)}{3}$$

$$I_T = \frac{-0.1(5.0\angle -120° + 120°) + 0.7(5.0\angle -120° - 120°) + 1.0(5.0\angle -120°)}{3} = 1.64A$$

That the IT current is different for a phase B to ground fault compared to phase A to ground is due to the fact that the symmetrical component computations are made *referenced to phase A*.

REL356 Trip Criterion

REL356 operation equation is:

$$OP - 0.7RES > OTH$$

$$where$$

$$OP = |I_L + I_R|$$

$$RES = |I_L| + |I_R|$$

I_L = local I_T current, I_R = remote I_T current and OTH is set operating threshold.

Pickup calculation

To determine the theoretical pickup current for different types of fault, we need to determine that the output from the trip criterion exceeds the set operating threshold.

Set-up in loop-back or back-to-back is assumed so that $I_R = I_L = I_T$, i.e. the infeed current from both ends are equal in magnitude and in phase. This represents an internal fault.

Then

$$OP = |I_L + I_R| = 2 \cdot I_T$$

$$RES = |I_L| + |I_R| = 2 \cdot I_T$$

$$OP - 0.7RES = 0.6 \cdot I_T > OTH$$

$$I_T > \frac{OTH}{0.6}$$

In order to determine the required current threshold for operation for different types of faults the expressions above for I_T and sequence currents need to be entered into the formula, solving the phase current(s).

Phase A to ground fault

Input currents

$$I_A = I_a \angle 0° A$$
$$I_B = 0$$
$$I_C = 0$$

Pickup current phase A

$$I_T > \frac{OTH}{0.6}$$
$$-C_1 I_1 + C_2 I_2 + C_0 I_0 > \frac{OTH}{0.6}$$
$$\frac{-C_1 I_a + C_2 I_a + C_0 I_a}{3} > \frac{OTH}{0.6}$$
$$I_a > OTH \cdot \frac{3}{0.6(-C_1 + C_2 + C_0)}$$

Phase B to ground fault

Input currents

$$I_A = 0$$
$$I_B = I_b \angle -120°$$
$$I_C = 0$$

Pickup current phase B

$$I_T > \frac{OTH}{0.6}$$
$$-C_1 I_1 + C_2 I_2 + C_0 I_0 > \frac{OTH}{0.6}$$
$$\frac{-C_1 I_B \angle 120° + C_2 I_B \angle -120° + C_0 I_B}{3} > \frac{OTH}{0.6}$$
$$\frac{-C_1 I_b + C_2 I_b \angle -240° + C_0 I_b \angle -120°}{3} > \frac{OTH}{0.6}$$
$$I_b > OTH \cdot \frac{3}{0.6(-C_1 + C_2 \angle -240° + C_0 \angle -120°)}$$

Phase C to ground fault

Input currents

$$I_A = 0$$
$$I_B = 0$$
$$I_C = I_c\angle 120°$$

Pickup current phase C

$$I_T > \frac{OTH}{0.6}$$
$$-C_1 I_1 + C_2 I_2 + C_0 I_0 > \frac{OTH}{0.6}$$
$$\frac{-C_1 I_C \angle -120° + C_2 I_C \angle 120° + C_0 I_C}{3} > \frac{OTH}{0.6}$$
$$\frac{-C_1 I_c \angle 0° + C_2 I_c \angle 240° + C_0 I_c \angle 120°}{3} > \frac{OTH}{0.6}$$
$$I_c > OTH \cdot \frac{3}{0.6(-C_1 + C_2\angle 240° + C_0\angle 120°)}$$

Phase A to B fault

Input currents

$$I_A = I_{ab}\angle 0°$$
$$I_B = I_{ab}\angle 180°$$
$$I_C = 0$$

Pickup current phases A and B

$$I_T > \frac{OTH}{0.6}$$

$$-C_1 I_1 + C_2 I_2 + C_0 I_0 > \frac{OTH}{0.6}$$

$$\frac{-C_1(I_A + I_B\angle 120°) + C_2(I_A + I_B\angle -120°) + C_0(I_A + I_B)}{3} > \frac{OTH}{0.6}$$

$$\frac{-C_1(I_{ab} + I_{ab}\angle 180 + 120°) + C_2(I_{ab} + I_{ab}\angle 180 - 120°) + C_0(I_{ab} + I_{ab}\angle 180°)}{3} > \frac{OTH}{0.6}$$

$$I_{ab} > OTH \cdot \frac{3}{0.6\left[-C_1(1 + 1\angle 300) + C_2(1 + 1\angle 60°)\right]}$$

Phase B to C fault

Input currents

$$I_A = 0$$

$$I_B = I_{bc}\angle -120°$$

$$I_C = I_{bc}\angle 60°$$

Pickup current phases B and C

$$I_T > \frac{OTH}{0.6}$$

$$-C_1 I_1 + C_2 I_2 + C_0 I_0 > \frac{OTH}{0.6}$$

$$\frac{-C_1(I_B\angle 120° + I_C\angle -120°) + C_2(I_B\angle -120° + I_C\angle 120°) + C_0(I_B + I_C)}{3} > \frac{OTH}{0.6}$$

$$\frac{-C_1(I_{bc} + I_{bc}\angle 60 - 120°) + C_2(I_{bc}\angle -240° + I_{bc}\angle 60 + 120°) + C_0(I_{bc}\angle -120 + I_{bc}\angle 60°)}{3} > \frac{OTH}{0.6}$$

$$I_{ab} > OTH \cdot \frac{3}{0.6\left[-C_1(1 + 1\angle -60°) + C_2(1\angle -240° + 1\angle 180°)\right]}$$

Phase C to A fault

Input currents

$$I_A = I_{ca}\angle -60$$
$$I_B = 0$$
$$I_C = I_{ca}\angle 120°$$

Pickup current phases C and A

$$I_T > \frac{OTH}{0.6}$$
$$-C_1 I_1 + C_2 I_2 + C_0 I_0 > \frac{OTH}{0.6}$$
$$\frac{-C_1(I_A + I_C\angle -120°) + C_2(I_A + I_C\angle 120°) + C_0(I_A + I_C)}{3} > \frac{OTH}{0.6}$$
$$\frac{-C_1(I_{ca}\angle -60° + I_{ca}) + C_2(I_{ca}\angle -60° + I_{ca}\angle 240°) + C_0(I_{ca}\angle -60 + I_{ca}\angle 120°)}{3} > \frac{OTH}{0.6}$$
$$I_{ca} > OTH \cdot \frac{3}{0.6\left[-C_1(1\angle -60° + 1) + C_2(1\angle -60° + 1\angle 240°)\right]}$$

Three phase ABC fault

Input currents

$$I_A = I_{abc}\angle 0°$$
$$I_B = I_{abc}\angle -120°$$
$$I_C = I_{abc}\angle 120°$$

Pickup current phases A, B and C

$$I_T > \frac{OTH}{0.6}$$
$$-C_1 I_1 + C_2 I_2 + C_0 I_0 > \frac{OTH}{0.6}$$
$$\frac{-C_1(I_A + I_B\angle 120° + I_C\angle -120°) + C_2(I_A + I_B\angle -120° + I_C\angle 120°) + C_0(I_A + I_B + I_C)}{3} > \frac{OTH}{0.6}$$
$$\frac{-C_1(I_{abc} + I_{abc} + I_{abc})}{3} > \frac{OTH}{0.6}$$
$$I_{ab} > OTH \cdot \frac{1}{-C1 \cdot 0.6}$$

Example 2A, Phase A to ground fault

With input currents:

$$I_A = I_a \angle 0° A$$

$$I_B = 0$$

$$I_C = 0$$

and settings:

$$OTH = 0.5$$

$$C1 = 0.1$$

$$C2 = 0.7$$

$$C0 = 1.0$$

the required phase A current becomes:

$$I_a = OTH \cdot \frac{3}{0.6(-C_1 + C_2 + C_0)} = 0.5 \cdot \frac{3}{0.6(-0.1 + 0.7 + 1.0)} = 1.56A$$

Example 2B, Phase B to ground fault

With input currents:

$$I_A = 0$$

$$I_B = I_b \angle -120°$$

$$I_C = 0$$

and settings:

$$OTH = 0.5$$

$$C1 = 0.1$$

$$C2 = 0.7$$

$$C0 = 1.0$$

the required phase B current becomes:

$$I_b = OTH \cdot \frac{3}{0.6(-C_1 + C_2 \angle -240° + C_0 \angle -120°)} = 0.5 \cdot \frac{3}{0.6\left(-0.1 + 0.7\angle -240° + 1.0\angle -120°\right)} = 2.54A$$

That the pickup current is higher for a phase B to ground fault compared to phase A to ground is due to the fact that the symmetrical component computations of IT are made *referenced to phase A.*

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