Application Note

REL352
AN-93L-02

Substation Automation and Protection Division

Phase Comparison Relay REL352 Current Pickup Calculation

Introduction

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

IT current

REL352 uses sequence filters to obtain positive, negative and zero sequence currents. These currents are then combined into one quantity:

$$I_T = -C1 \cdot I_1 + C2 \cdot I_2 + C0 \cdot I_0$$

The positive, negative and zero sequence current is computed from the phase currents by the use of Clarke's components based on sample currents that can mathematically be expressed as:

$$I_1 = \frac{I_A \cdot 0.966\angle -15° + I_B \cdot 0.983\angle 104.43° + I_C \cdot 0.983\angle -134.43°}{3}$$

$$I_2 = \frac{I_A \cdot 0.966\angle -15° + I_B \cdot 0.983\angle -134.43° + I_C \cdot 0.983\angle 104.43°}{3}$$

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

The advantage of using Clarke's components is that they give a close approximation of symmetrical components while not having the need of using complex numbers.

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

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

$$I_T = \frac{-C_1(I_A \cdot 0.966\angle -15° + I_B \cdot 0.983\angle 104.43° + I_C \cdot 0.983\angle -134.43°)}{3} +$$

$$+\frac{C_2(I_A \cdot 0.966\angle -15° + I_B \cdot 0.983\angle -134.43° + I_C \cdot 0.983\angle 104.43)}{3} + \frac{C_0(I_A + I_B + I_C)}{3}$$

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:

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

$$I_T = \frac{-C_1(5.0 \cdot 0.966\angle -15°)}{3} + \frac{C_2(5.0 \cdot 0.966\angle -15°)}{3} + \frac{C_0(5.0)}{3} = 2.65A$$

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:

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

$$I_T = \frac{-C_1(5.0 \cdot 0.983\angle 104.43° - 120°)}{3} + \frac{C_2(5.0 \cdot 0.983\angle -134.43° - 120°)}{3} + \frac{C_0(5.0\angle -120°)}{3} = 1.33A$$

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 Clarke's symmetrical component computations are made *referenced to phase A*.

REL352 Trip Criterion

REL352 operates when the IT RMS current exceeds the LP setting, assuming that the relay is connected in loop-back or back-to-back (with the same current fed into the two relays):

$I_T > LP$

where

$I_T =$ composite current

$LP =$ set operating threshold

It is also assumed that all other settings (IPL, IGL, ITA1, ITA2) are set so that they do not restrict tripping at the set LP level.

Sometimes, ITA2 is the limiting threshold, and then the operating criterion will be:

$$I_T > ITA2$$
$$where$$
$$I_T = \text{composite current}$$
$$ITA2 = \text{set operating threshold}$$

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.

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

$$I_T > LP$$

$$-C_1 I_1 + C_2 I_2 + C_0 I_0 > LP$$

$$\frac{-C_1 \cdot I_a \cdot 0.966\angle -15° + C_2 \cdot I_a \cdot 0.966\angle -15° + C_0 \cdot I_a}{3} > LP$$

$$I_a > LP \cdot \frac{3}{(-C_1 \cdot 0.966\angle -15° + C_2 \cdot 0.966\angle -15° + C_0)}$$

Phase B to ground fault

Input currents

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

Pickup current phase B

$$I_T > LP$$

$$-C_1 I_1 + C_2 I_2 + C_0 I_0 > LP$$

$$\frac{-C_1 \cdot I_b \cdot 0.983\angle -15.57° + C_2 \cdot I_b \cdot 0.983\angle -254.43° + C_0 \cdot I_b \angle -120°}{3} > LP$$

$$I_b > LP \cdot \frac{3}{(-C_1 \cdot 0.983\angle -15.57° + C_2 \cdot 0.983\angle -254.43° + C_0 \angle -120°)}$$

Phase C to ground fault

Input currents

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

Pickup current phase C

$$I_T > LP$$

$$-C_1 I_1 + C_2 I_2 + C_0 I_0 > LP$$

$$\frac{-C_1 \cdot I_c \cdot 0.983\angle -14.43° + C_2 \cdot I_c \cdot 0.983\angle 224.43° + C_0 \cdot I_c \angle 120°}{3} > LP$$

$$I_c > LP \cdot \frac{3}{(-C_1 \cdot 0.983\angle -14.43° + C_2 \cdot 0.983\angle 224.43° + C_0 \angle 120°)}$$

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

$$I_T > LP$$

$$-C_1 I_1 + C_2 I_2 + C_0 I_0 > LP$$

$$\frac{-C_1(I_{ab} \cdot 0.966\angle -15° + I_{ab} \cdot 0.983\angle 284.43°) + C_2(I_{ab} \cdot 0.966\angle -15° + I_{ab} \cdot 0.983\angle 45.57°)}{3} > LP$$

$$I_{ab} > LP \cdot \frac{3}{[-C_1(0.966\angle -15° + 0.983\angle 284.43°) + C_2(0.966\angle -15° + 0.983\angle 45.57°)]}$$

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

$$I_T > LP$$

$$-C_1 I_1 + C_2 I_2 + C_0 I_0 > LP$$

$$\frac{-C_1(I_{bc}\cdot 0.983\angle -15.57° + I_{bc}\cdot 0.983\angle -74.43°) + C_2(I_{bc}\cdot 0.983\angle -254.43° + I_{bc}\cdot 0.983\angle 164.43°)}{3} > LP$$

$$I_{bc} > LP\cdot\frac{3}{[-C_1(0.983\angle -15.57° + 0.983\angle -74.43°) + C_2(0.983\angle -254.43° + 0.983\angle 164.43°)]}$$

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

$$I_T > LP$$

$$-C_1 I_1 + C_2 I_2 + C_0 I_0 > LP$$

$$\frac{-C_1(I_{ca} \cdot 0.966\angle -75° + I_{ca} \cdot 0.983\angle -14.43°) + C_2(I_{ca} \cdot 0.966\angle -75° + I_{ca} \cdot 0.983\angle 224.43°)}{3} > LP$$

$$I_{ca} > LP \cdot \frac{3}{[-C_1(0.966\angle -75° + 0.983\angle -14.43°) + C_2(0.966\angle -75° + 0.983\angle 224.43°)]}$$

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

$$I_T > LP$$

$$-C_1 I_1 + C_2 I_2 + C_0 I_0 > LP$$

$$\frac{-C_1(I_{abc} \cdot 0.966\angle -15° + I_{abc} \cdot 0.983\angle -15.57° + I_{abc} \cdot 0.983\angle -14.43)}{3} +$$
$$\frac{C_2(I_{abc} \cdot 0.966\angle -15° + I_{abc} \cdot 0.983\angle -254.43° + I_{abc} \cdot 0.983\angle 224.43)}{3} > LP$$

$$I_{abc} > LP \frac{3}{-C_1(0.966\angle -15° + 0.983\angle -15.57° + 0.983\angle -14.43°) + C_2(0.966\angle -15° + 0.983\angle -254.43° + 0.983\angle 224.43)}$$

Theoretically, there should be no negative sequence current for a three phase fault, but Clarke introduces a small value. However, the formula for three phase fault pickup current can be simplified by removing the C2 term. The error by doing so will result in less than 10% error. Note however, that the below formula gives *a 10% higher* theoretical result (i.e. the actual test current required for operation is lower).

Simplified ABC current formula

$$I_{abc} > LP \frac{3}{-C_1(0.966\angle -15° + 0.983\angle -15.57° + 0.983\angle -14.43°)}$$

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:

$LP = 1.5$

$C1 = 0.1$

$C2 = 0.7$

$C0 = 1.0$

the required phase A current becomes:

$$I_T > LP$$

$$-C_1 I_1 + C_2 I_2 + C_0 I_0 > LP$$

$$\frac{-0.1 \cdot I_a \cdot 0.966\angle -15° + 0.7 \cdot I_a \cdot 0.966\angle -15° + 1.0 \cdot I_a}{3} > LP$$

$$I_a > LP \cdot \frac{3}{(-0.1 \cdot 0.966\angle -15° + 0.7 \cdot 0.966\angle -15° + 1.0)} = 2.87$$

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:

$I_T > LP$

$$-C_1 I_1 + C_2 I_2 + C_0 I_0 > LP$$

$$\frac{-0.1 \cdot I_b \cdot 0.983\angle -15.57° + 0.7 \cdot I_b \cdot 0.983\angle -254.43° + 1.0 \cdot I_b \angle -120°}{3} > LP$$

$$I_b > LP \cdot \frac{3}{(-0.1 \cdot 0.983\angle -15.57° + 0.7 \cdot 0.983\angle -254.43° + 1.0\angle -120°)} = 5.63$$

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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