ABB **Application Note**

Substation Automation and Protection Division

The Effect of Zero Sequence Infeed on Ground Distance Measurement

Introduction

Figure 1 shows a zero sequence infeed source on the protected line. The source is a constant zero sequence impedance source such as a grounding transformer providing only zero sequence current for ground faults. The source provides no positive or negative sequence current to any fault. An example is a three-phase wye-grounded-delta transformer connected to the line on the wye side. This source will cause the zone-1 ground impedance reach of the relay at Bus L to underreach the normal setting for faults between the infeed location and the Z_1 reach. Since this is an underreaching condition, caution is advised when compensating in order to prevent an overreaching scenario.

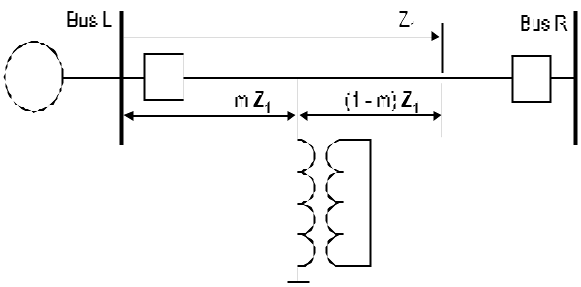

Figure 1 - Zero Sequence Infeed Source on the Protected Line

Application

The infeed effect can be compensated for with a multiplying factor, *F*, times the line zero sequence impedance reach value, Z_0. The new value, Z_0', is then used in all appropriate setting calculations.

$$Z_0' = FZ_0$$

$$F = m + \frac{1-m}{k_0}$$

$$k_0 = \frac{Z_{0T}}{Z_{0S} + mZ_0 + Z_{0T}}$$

The term m is the distance to the infeed source expressed in per unit of the Z_1 reach, k_0 is the zero sequence circuit current distribution factor and Z_{0T} is the zero sequence infeed source impedance as shown in Figure 2. Z_{1S}, Z_{2S} and Z_{0S} are the respective equivalent system source impedances. Figure 3 shows the value of F as a function of m and k_0. Derivation of the Factor *F* is provided later.

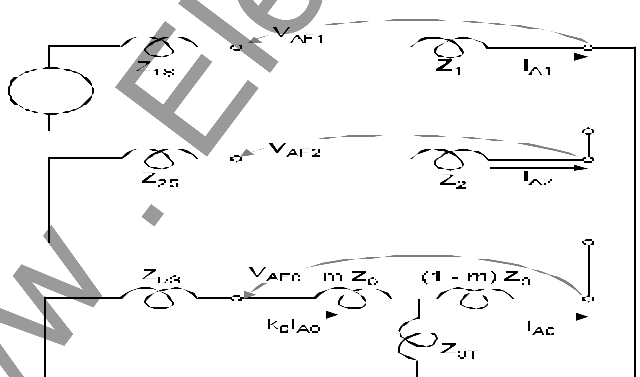

Figure 2 - Sequence Network Connection for a Phase-to-ground Fault

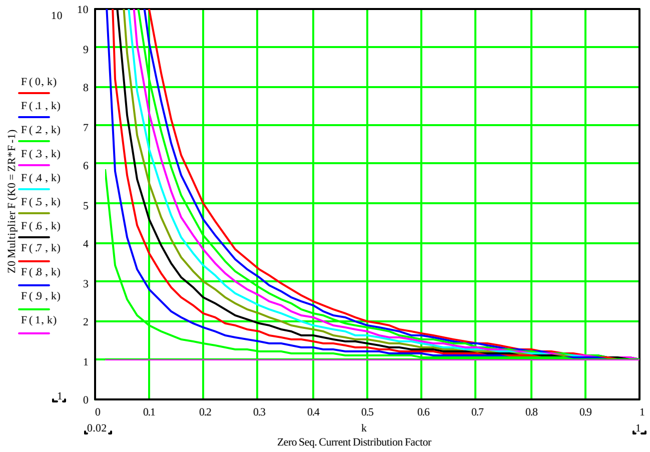

Figure 3 - Factor F as a Function of m *and* k_0

Specific procedures applicable to MDAR, REL 301/2 and REL 512 follows:

Setting MDAR and REL 301/2

1. Using the line impedance data, Z_1 and Z_0, and the zero sequence infeed source impedance, Z_{0T}, and location, m, compute k_0.

$$k_0 = \frac{Z_{0T}}{Z_{0S} + mZ_0 + Z_{0T}}$$

2. Compute and set Z1P, PANG per the instruction book.
3. Set Z1G to Z1P
4. Compute GANG and ZR.

$$Z1G = \frac{Z_{APP}}{1 + \left(\frac{k_0}{k_0 + 2}\right)(ZR - 1)}$$

$$GANG = PANG + \arg(ZR)$$

5. If ZR computes to be larger than 10, the maximum setting, then the Z1G setting can be modified. Compute the apparent impedance, Z_{APP}, using the computed large ZR value. Use the following equation to compute new Z1G and GANG values using a new ZR setting value that is within tolerance.

$$Z_0' = Z_0\left(m + \frac{1-m}{k_0}\right)$$

$$ZR = \left(\frac{Z_0'}{Z_1}\right)$$

$$GANG = \arg(Z_0')$$

$$Z1G = \frac{Z_{APP}}{1 + \left(\frac{k_0}{k_0 + 2}\right)(ZR - 1)}$$

$$GANG = PANG + \arg(ZR)$$

Setting the REL 512

1. Using the line impedance data, Z_1 and Z_0, and the zero sequence infeed source impedance, Z_{0T}, and location, m, compute k0.

$$k_0 = \frac{Z_{0T}}{Z_{0S} + mZ_0 + Z_{0T}}$$

2. Compute and set Z1 PH REACH, Z1 LINE ANG per the instruction book.
3. Set Z1 GND REACH to Z1 PHASE REACH
4. Compute Z1 K0 MAG and Z1 K0 ANG.

$$Z_R = \frac{Z_0}{Z_1}\left(m + \frac{1-m}{k_0}\right)$$

$$K_0 = Z_R - 1$$

$$Z1\_K0\_MAG = \left|K_0\right|$$

$$Z1\_K0\_ANG = \arg\left(K_0\right)$$

5. If Z1 K0 MAG computes to be larger than the maximum setting, then the Z1 GND REACH setting can be modified. Compute the apparent impedance, Z_{APP}, using the computed large Z1 K0 MAG and Z1 K0 ANG value of step 4. Use the following equation to compute a new Z1 GND REACH setting using a Z1 K0 MAG value of 10 and the Z1 K0 ANG value of step 4.

$$Z1\_GND\_REACH = \left|\frac{Z_{APP}}{1 + \left(\frac{k_0}{k_0 + 2}\right)K_0}\right|$$

6. It is desired to have the angle of Z1 GND REACH computed in 5 to be within reasonable tolerance of the set LINE ANGLE. If necessary appropriately modify the Z1 K0 ANG value and recompute the equation of step 5. Set the relay with the resulting values.

Other Distance Relays

The above procedures can be modified to accommodate any ground impedance relay. The relay can be set using the following equations where Z_R is the zero to positive sequence line zone-1 impedance ratio and K_0 is the zero sequence current compensation factor (not to be confused with k_0).

$$Z_R = \frac{Z_0'}{Z_1}$$

$$K_0 = Z_R - 1$$

Derivation of Equations

The equation for V_{AG} at the relay is computed with the symmetrical sequence components of Figure 2.

$$V_{AG} = V_{AF1} + V_{AF2} + V_{AF0}$$
$$V_{AG} = I_{A1}Z_1 + I_{A2}Z_2 + k_0 I_{A0} m Z_0 + I_{A0}(1-m)Z_0$$
$$V_{AG} = I_{A1}Z_1 + I_{A2}Z_2 + k_0 I_{A0} Z_0 (m + \frac{1-m}{k_0})$$
$$Z_0' = Z_0(m + \frac{1-m}{k_0})$$
$$Z_1 = Z_2$$
$$V_{AG} = I_{A1}Z_1 + I_{A2}Z_1 + k_0 I_{A0} Z_0' \frac{Z_1}{Z_1}$$
$$V_{AG} = Z_1\left(I_{A1} + I_{A2} + k_0 I_{A0}\frac{Z_0'}{Z_1}\right)$$
$$V_{AG} = Z_1\left((I_{A1} + I_{A2} + \underline{k_0 I_{A0}}) + k_0 I_{A0}\frac{Z_0'}{Z_1} - \underline{k_0 I_{A0}}\right)$$
$$I_A = (I_{A1} + I_{A2} + k_0 I_{A0})$$
$$V_{AG} = Z_1\left(I_A + k_0 I_{A0}\left(\frac{Z_0'}{Z_1} - 1\right)\right)$$

Compute the term $k_0 I_0$ as a function of I_A at the relay.

$$I_A = I_{A1} + I_{A2} + k_0 I_{A0}$$
$$I_{A1} = I_{A2} = I_{A0}$$
$$I_A = 2I_{A0} + k_0 I_{A0}$$
$$I_A = k_0 I_{A0}\left(\frac{2 + k_0}{k_0}\right)$$
$$k_0 I_{A0} = I_A\left(\frac{k_0}{k_0 + 2}\right)$$

Substitute and solve for the apparent ground impedance V_{AG} / I_A:

$$V_{AG} = Z_1\left(I_A + I_A\left(\frac{k_0}{k_0 + 2}\right)\left(\frac{Z_0'}{Z_1} - 1\right)\right)$$
$$\frac{V_{AG}}{I_A} = Z_{APP} = Z_1\left(1 + \left(\frac{k_0}{k_0 + 2}\right)\left(\frac{Z_0'}{Z_1} - 1\right)\right)$$

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