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Short Communication

Comparison of five methods of compensation for the ground distance function and assessment of their effect on the resistive reach in quadrilateral characteristics

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ABSTRACT

This article compares five compensation methods for the ground distance function, in order to show the maximum fault resistances that the relays can see when they have quadrilateral characteristics. These five compensation methods are based on the description of real protective functions, found in manuals of commercial relays. For a power system taken as an example, the impedances seen by the relays are computed for each form of compensation and for different system conditions. The results show that: (a) the locus of the apparent impedance is very different for each compensation method; (b) the maximum fault resistance seen with each compensation method can be very different, although the same quadrilateral characteristic is adjusted in the relays. Three of these compensation methods (A–C) are based on the positive-sequence impedance of the line, and two of these compensation methods (D, E) are based on the impedance of the ground-fault loop. The results also show that: (a) methods D and E tend to over-reach or under-reach, for solid faults; (b) the coverage for resistive faults tend to be greater for methods A and B than for methods C, D, and E; (c) the loci of the apparent impedance tend to be flat only for method C. In general, the knowledge of the behavior of the compensation method for the ground distance function is important because it should be considered when the relay settings are computed and/or when the faults are analyzed.

Introduction

The behavior of the Ground Distance Function (GDF) has been analyzed for years. Fault type, pre-fault load flow and relay polarization are some factors that influence the reach of GDF when there are fault resistances. Recently, some research efforts have been driven towards: (a) the application of the concept of adaptive protection, in order to improve the behavior of GDF according to the impedance seen by it [1,2]; (b) the proposal of new ways of compensation for GDF [3,4].

The most analyzed GDF is based on the traditional use of the residual compensation factor (K_0). Loci of the impedance seen by this traditional GDF, as a function of fault resistance, are circles [5]. In commercial relays, the available methods for the GDF are diverse. Some articles [6,7] show details related to this diversity, but an academic comparison between the methods applied by different commercial relays was not available, and this article is a contribution about this topic.

For a power system taken as an example, this article compares: (a) the loci for five methods of compensation of the GDF; (b) the resistive reaches, for each method of compensation, when the relays have been adjusted with the same quadrilateral characteristics in the R–X plane. This article clearly shows that these resistive reaches are very different.

Description of the analyzed compensation methods

This description of the analyzed compensation methods is based on information found in manuals of commercial relays. For each compensation method, the apparent impedance is described for the GDF in the phase A.

Method A ("relay A")

This compensation method is one of the most known, usually it is described in classic textbooks, and it has been applied in commercial relays [8]. The impedance seen by the relay in this case (Z_A) is:

$$Z_A = V_A/(I_A + K_0 I_R) \quad (1)$$

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V_A, I_A, I_R are voltage of phase A, current of phase A, and residual current ($I_R = I_A + I_B + I_C$), respectively, measured by the relay. K_0 is the residual compensation factor (a setting of the relay). In this article, K_0 is assumed to be exactly adjusted to the complex value required to obtain the positive-sequence impedance of the line, up to the fault point:

$$K_0 = (Z_{L0} - Z_{L+})/(3Z_{L+}) \quad (2)$$

Z_{L+} and Z_{L0} are the positive-sequence impedance and zero-sequence impedance of the line, respectively.

Method B ("relay B")

This compensation method is similar to the previous one, but it uses arithmetic of real numbers. It is based on the description of some commercial relays [9]. The impedance seen by the relay in this case (Z_B) is:

$$Z_B = R_B + jX_B \quad (3)$$

$$R_B = (|V_A|\mathrm{Cos}\varphi)/(|I_A| + K_R|I_R|);$$
$$X_B = (|V_A|\mathrm{Sin}\varphi)/(|I_A| + K_X|I_R|]) \quad (4)$$

R_B and X_B are rectangular components of Z_B. K_R and K_X are compensation factors for R_B and X_B. φ is the lag angle of I_A relative to V_A. In this article, the compensation factors (K_R, K_X) are assumed to be exactly adjusted to:

$$K_R = (R_{L0} - R_{L+})/(3R_{L+}); \quad K_X = (X_{L0} - X_{L+})/(3X_{L+}) \quad (5)$$

R_{L0} and X_{L0} are rectangular components of Z_{L0}. R_{L+} and X_{L+} are rectangular components of Z_{L+}.

Method C ("relay C")

This method uses a mathematical artifice to reduce the effect of the system conditions on the reactive reach, and it is based on a commercial relay [10]. The impedance seen by the relay in this case (Z_C) is:

$$Z_C = mZ_{L+} + R_G \quad (6)$$

$$m = X_C/X_{L+} \quad (7)$$

$$X_C = \boldsymbol{Im}\{V_A(I_R)^*\}/\boldsymbol{Im}\{a_L(I_A + K_0I_R)(I_R)^*\} \quad (8)$$

$$R_G = \boldsymbol{Im}\{V_A[(I_A + K_0I_R)a_L]^*\}/\boldsymbol{Im}\{(3/2)(I_{A2} + I_{A0})[(I_A + K_0I_R)a_L]^*\} \quad (9)$$

m is the reactance seen by the relay, in per-unit of X_{L+}. X_C is the reactance seen by the relay, in ohms. X_{L+} is the positive-sequence reactance of the line. ***Im*** is the imaginary part of a complex number. R_G is the resistive effect of the ground-fault, seen by the relay. I_{A2} and I_{A0} are the negative-sequence current and zero-sequence current, respectively, measured by the relay. a_L is an unitary complex number whose angle is θ_{L+}. θ_{L+} is the angle of Z_{L+} (a setting of the relay). R_{L+} is the positive-sequence resistance of the line. The resistive component of the impedance seen by this relay is the sum of R_G and mR_{L+}.

Method D ("relay D")

This method is based on the ground-fault loop impedance (and not on the positive-sequence impedance of the line). It has been applied in commercial relays [11]. The impedance seen by the relay in this case (Z_D) is:

$$Z_D = V_A/I_A \quad (10)$$

The setting of this relay is based on the total line impedance for the ground-fault loop (Z_{LG}):

$$Z_{LG} = (2Z_{L+} + Z_{L0})/3 \quad (11)$$

This relation is strictly valid for faults without contribution from the remote line end, but this is not a general case.

Method E ("relay E")

This method is also based on the ground-fault loop impedance, but the form of computing the impedance is different. It is based on a commercial relay [12]. The impedance seen by the relay in this case (Z_E) is:

$$Z_E = nZ_{LG} + R_X \quad (12)$$

n is the line impedance seen by the relay, in per-unit of Z_{LG}. R_X is the resistive effect of the ground-fault, seen by the relay. n and R_X (real numbers) are computed by solving the equation of this relay (in complex variable) for ground-faults:

$$V_A = (nZ_{LG})I_A + R_XI_R \quad (13)$$

3. Description of the analyzed quadrilateral zones

Methods A, B and C are based on Z_{L+} (Fig. 1a), and methods D and E are based on Z_{LG} (Fig. 1b). Fig. 1 only shows the first quadrant because it is the region of main interest for this article.

Power system used as an example

A simplified model of a power system (Fig. 2) was used as an example. This model could be obtained as a reduction of a larger

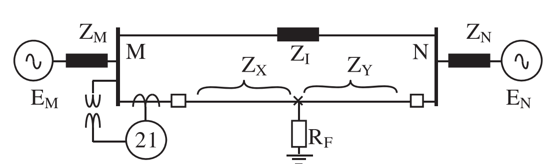

Fig. 2. Power system used as an example.

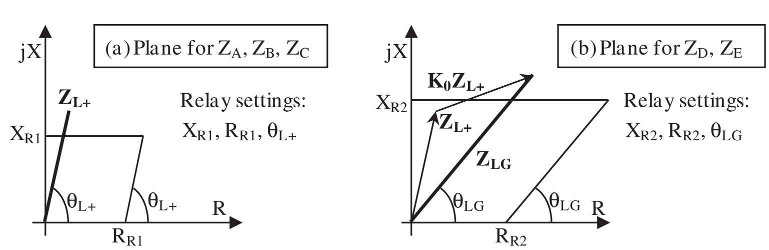

Fig. 1. Analyzed quadrilateral zones.