Improvement of resistive reach of distance protection through a power flow-based adaptive parameterization

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1. Introduction

Latest distance protection algorithms seek time performance improvements and sensitivity increase to detect all types of possible faults that may occur in the protected line. Adaptive algorithms improve in this sense the coverage of the distance protection against different types of faults in the electric network. However, to implement these algorithms in existing electrical substations (E/S) involves in most cases a considerable economic cost both to buy new protective relays neither change the firmware of existing ones.
This study develops an adaptive parameterization for distance protection based on the effect of pre-fault power flow in the apparent impedance locus. This adaptive application is integrated through a flexible operational logic to be implemented in many protection schemes currently used in E/S.
To mitigate the adverse effects of pre-fault power flow, settings criteria are presented for performing a selective coordination. These settings maximize the protection coverage by increasing the sensitivity for fault resistance in the protected line. The application restrictions over selectivity between protection zones of the distance relay are obtained by an algorithm that has been developed in order to analyze the performance of distance protection against three phase, double phase to earth and single phase to earth faults considering the pre-fault power flow and fault resistance expected in the protected line. This algorithm is based in the method of nodal matrix and its results have been compared with Fourier, Walsh and DEA (Differential Equation Algorithm) distance algorithm.
Conventionally, the protection parameters of distance relays have common values for both local and remote terminals of the protected line. However, through this adaptive parameterization each terminal has a different resistive reach depending on the direction of the line power flow, increasing the resistive faults coverage that could not be detected with conventional methods of distance coordination.

Keywords: distance protection, apparent impedance locus, R-X diagram, logical operation, resistive faults, adaptive distance protection.

2. Apparent impedance locus considering power flow in multiterminal networks

To simulate the effect of prefault power flow and fault resistance in the apparent impedance locus seen by the relay it is important to consider a series of equivalences in a multiterminal network.

A. Effect of power flow in the protected line
It is demonstrate that the locus of the apparent impedance describe a circle if all parameters are kept fixed except the fault resistance. Moreover, the fact that the terminal is exporting or importing energy in prefault state modifies the apparent impedance locus seen by the relay and could lead to a loss of selectivity between protection zones.
The apparent impedance during a fault, considering the prefault power flow, is determined as follows

$$Z_R = m \cdot Z_l^+ + K_x \cdot R_f \quad (1)$$

where Z_R is the apparent impedance seen by the distance relay, m is the distance to fault in per unit of protected line length, Z_l^+ is the positive sequence impedance of the protected line, R_f represents the fault resistance and K_x is a multiplication factor whose value varies depending on the type of fault and the distance to fault. For a three phase fault, K_x is determined as follows

$$K_{3\varphi} = \frac{Z_{rr}^+ + (m-1)\cdot Z_{pr}^+ - m\cdot Z_{qr}^+}{(Z_{rr}^+ + R_f)\cdot\left[\frac{N\cdot(1-m)}{(1-m)\cdot N + m}\right] - (1-m)\cdot(Z_{pr}^+ + R_f)} \quad (2)$$

for 0<m<1
being $K_{3\varphi}$ the multiplication factor for three phase faults, Z^+ the bus impedance matrix deduced for the electrical system under study and its subscripts *p, q, r* denotes the local terminal, remote terminal and point of fault in protected line, respectively. N is the prefault power flow indicator and is calculated as follows

$$N = \frac{E_p}{E_q} \quad (3)$$

where E_p and E_q are the local and remote voltage respectively.
For $m=0$, $K_{3\varphi}$ is determined as

$$K_{3\varphi} = \frac{Z_l^+}{(Z_l^+ + ZI_{qp}^+ + R_f) - \frac{(ZI_{pp}^+ + R_f)}{N}} \quad (4)$$

and, for $m=1$, $K_{3\varphi}$ is deduced as follows

$$K_{3\varphi} = \frac{Z_l^+}{N * (ZI_{qq}^+ + R_f) - (ZI_{pq}^+ + R_f)} \quad (5)$$

being ZI^+ the simplified bus impedance matrix once *m* fit the minimum or maximum value to avoid mathematical indetermination.

B. Programming for determining the apparent impedance locus

The effect of the power flow in the apparent impedance locus seen by relays has been analyzed by a program developed using MATLAB. The operation sequence of the program can be briefly described as follows:

- Charge of database from Excel to main routine in Matlab.
- For different points of fault, *m*, create the new row and column in the admittance matrix.
- Calculate the bus impedance matrix for positive sequence, $[Z^{+}]$, and zero sequence $[Z^{0}]$.
- Determine the apparent impedance, Z_R, for three phase, double phase to earth and single phase to earth faults, varying power flow, *N*, and fault resistance, R_f.
- Graphical and numerical output to established restrictions for selective coordination.

3. Integration of the adaptive parameterization to distance protection schemes

Adaptive parameterization is integrated through a flexible operational logic function that continuously monitors the direction of power flow. This application determines the protection parameters that shall be set at each terminal of the protected line.

The activation of each group depends on a logic input from a directional power relay (ANSI function 32), which switched to the proper group setting according to power flow in each instance of time. The operational logic scheme is shown in Fig. 1 for the case where carrier channels are available.

Note that over reach units are implemented with a logical scheme for detection of weak source to provide simultaneous operation between terminals.

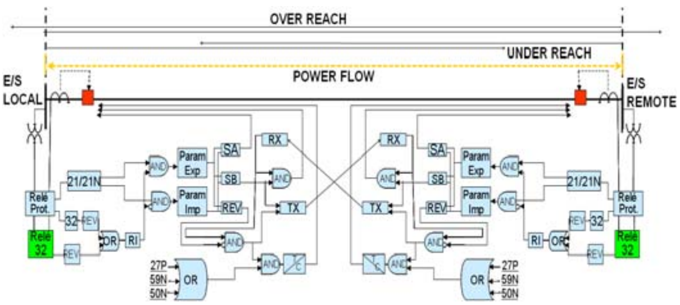


Fig. 1. Operational logic to integrate adaptive parameterization in distance protection schemes.

4. Power system simulation

The practical usefulness of the coordination through adaptive parameterization is shown in a case of study of a 69 kV multiterminal power system. This network is based in 19 E/S and 24 transmission lines with different source to line impedance relation (SIR). The results obtained for short and medium line length show an improvement of at least 50% in the coverage of the distance relay compared with conventional settings.

The apparent impedance seen by each distance relay position obtained from the presented program is compared by conventional distance algorithm. These algorithms are DFFT (Discrete Fast Fourier Transform), Walsh and DEA developed in PSCAD. The simulations are based in a set of faults for different inception angle (0º, 30º, 60º, 90º), load, and a fault resistance up to 55 ohm.

Fig. 2 shows the comparison of the reactance reach obtained by the nodal matrix method, Fourier, Walsh and DEA algorithm for single phase to ground faults at the study case, importing and exporting power, respectively.

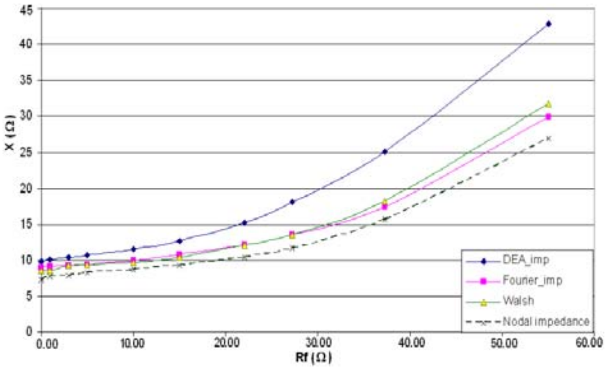
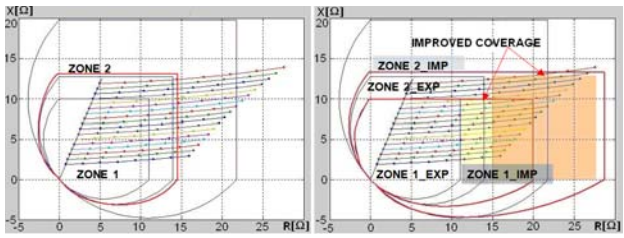


Fig. 2. Reactance reach determined by the nodal matrix method, Fourier, Walsh and DEA algorithm for single phase to ground faults at 50% of line B18-B19 of the study case, importing.

Fig. 3 shows the difference between the conventional settings for zone 1 and 2 compared with the parameters of adaptive protection. The remote terminal with import criteria settings covers a wider range of fault resistance.



(a) (b)

Fig. 3. Comparison between distance protection zones with (a) conventional settings and (b) adaptive parameterization.

5. Conclusions

The application of adaptive parameterization proposed in this study achieved a significant improvement in the coverage of protective relays against fault through resistance. This improvement is more appreciable for short and medium transmission lines.

The nodal matrix algorithm represents a straightforward method for determining the restriction limits for protection coordination with a reduced margin error between commonly used distance algorithm as Fourier, Walsh and DEA algorithm.

The criteria for allowing selective coordination between distance protection zones are more suitable for quadrilateral characteristic and mitigate in a higher grade the adverse effect of power flow over the apparent impedance locus. Additionally, the operational logic described allows the simultaneous clearing of faults in the protected line.