An Overview of Impedance-Based Fault Location Techniques in Electrical Power Transmission Network

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Abstract: Fault location is an important task in power system analysis because an accurate distance-to- fault will assist to restore the power supply in the shortest possible time so as to prevent them from possible damages to people, property and environment. Faults on power system transmission lines need to be detected and located rapidly, classified correctly and cleared as fast as possible. This paper discusses an overview of impedance- based fault location techniques in electrical power transmission network. Fault location techniques reviewed include the variance-based sensitivity method, the one-ended impedance method such as Takagi method, Modified Takagi method, Erikson method, Novosel *et al* method, the two-ended impedance based method, synchronised two-ended method, unsynchronised two-ended method and unsymmetrical current-only two-ended method. The input data requirements for each technique were clearly discussed and the sensitivity of each approach to different sources of error were emphasised. Fault data availability forms a basic for choosing the most suitable fault-location technique. The result of this paper shows that the simple reactance technique is the simplest of all the impedance - based fault location techniques. The fault resistance and the load current make the technique to deteriorate in accuracy. The Takagi method was developed to correct these lapses because of its robustness to load and sensitivity. Source impedance parameters were used by the Modified Takagi and Erikson methods for elimination of any source of errors. The mutual coupling in double-circuit transmission lines and an uncertain value of zero-sequence line impedance are responsible for the inaccuracy of one-ended impedance-based technique. This problem was overcome by two-ended fault location technique that used measurements from both ends of transmission line and are attractive for tracking down the specific position where the fault is to be located. Availability of data is one of the most important factors in selecting the best technique for fault location. The failure of the two-ended fault location technique is due to the fact that it was not meant for use in a three-terminal line. Additional equipment needed to be installed for improving the accuracy of fault location technique is very useful. Fault event data can also be used to estimate the value of fault resistance, which is useful for validating system modelling parameters. This paper will form a basis for choosing an appropriate fault location technique for electrical power transmission network.

Keywords: Fault Location, Impedance-Based Fault Location, Sensitivity, Transmission Network, Takagi, Modified Takagi

I. INTRODUCTION

Electrical faults due to lightning strikes during stormy weather conditions, or tree contacts with transmission lines or insulation failure in power system equipment affect transmission lines to a large exten (Saha 2002, Ziranovic 2008).

A) Types of faults

There are two types of fault which can occur in any transmission lines namely: balanced and unbalanced faults Most of the faults that occur on the power systems are unbalanced faults. In addition, faults can be categorized as shunt faults and series faults (Dalcastagne and Zimath 2013, Nunez et al 2010, Mora- Florez *et al* 2008).

Series faults are those types of faults which occur in the impedance of the line and does not involve any interconnection between the phases. In this type of fault, there is increase of voltage and frequency and decrease of current levels in the faulted phases (Lotfifard *et al* 2013, Mirzael *et al* 2009, Hashim et al 2009, Schweitzer 2009). Shunt faults are the unbalance between phases or between ground and phases. In this type of fault there is an increase of current and decrease of frequency and voltage level in the faulted phases (Saha 2010, Takagi *et al* 2002, Tziouva et al 2001, Amberg 2012, Eriksson, 2005).

The shunt faults can be classified into four types namely: phase to ground fault,

a) Phase to Ground Fault

In this type of fault, any one line makes connection with ground, phase to phase fault, double phase to ground fault and three phase fault (Norsel *et al* 2008, Schweitzer 2003).

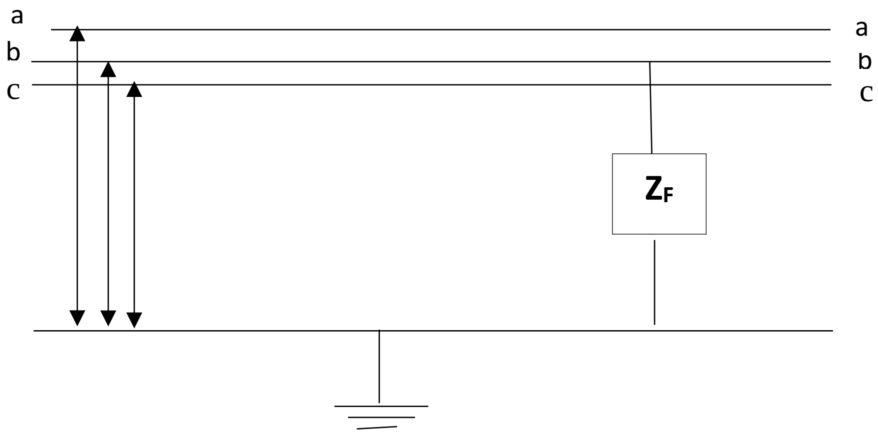

Figure 1.4: Single line to ground fault

b) Phase to Phase Fault

In this type of fault, a connection is established between the phases.

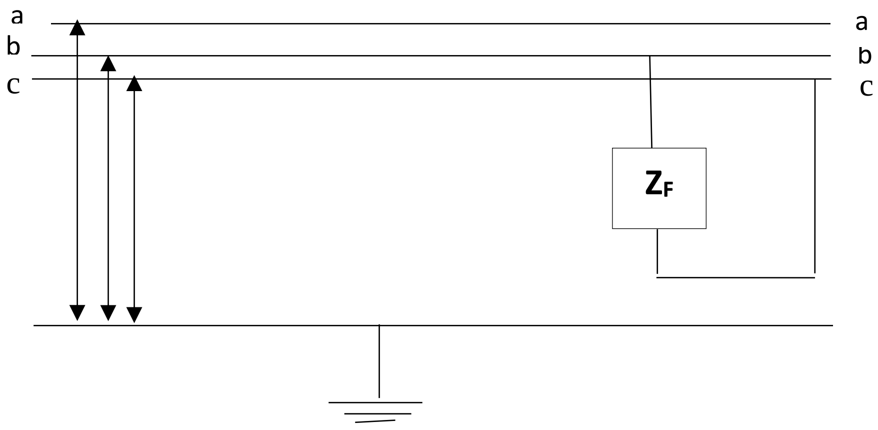

Figure 1.5: Phase to phase fault

c) Double Phase to Ground Fault

In this type of fault, two phases established the connection with the ground.

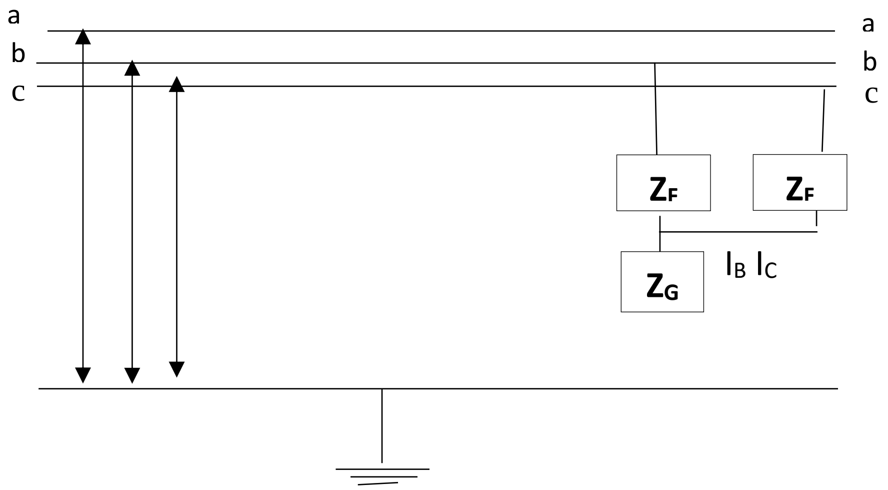

Figure 1.6: Double phase to ground fault.

d) Three Phase Fault

In this type of fault, three phases make connection with the ground. This is a severe fault.

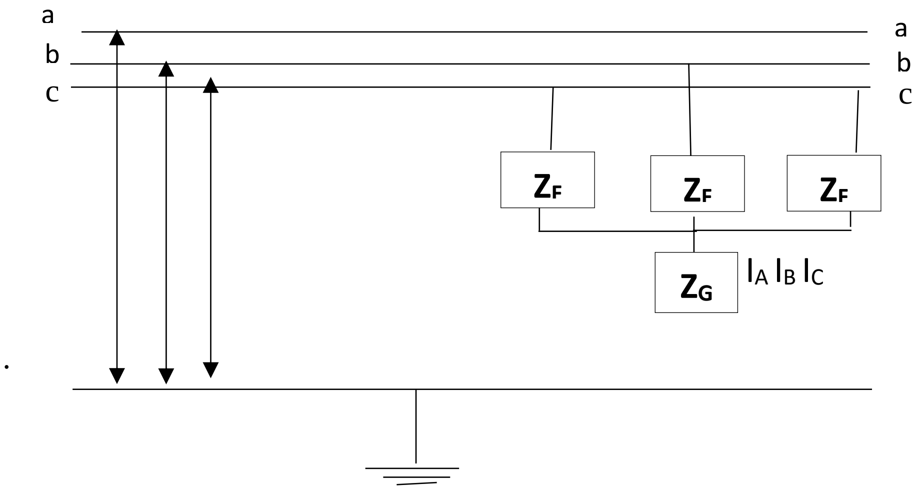

Figure 1.7: Three phase fault

A number of impedance-based fault location algorithms have been developed for transmission network applications. Fault locating algorithms using the data captured by IED device at one end of the line are commonly referred to as one-ended algorithm while those using data captured by IEDs at both end s of a transmission line are called two-ended algorithm each of them has definite input data requirements and makes certain assumptions when calculating the distance of the distance to a fault (Saha *et al* 2002, Zimmmerman and Costelto 2005).

II. MATERIALS AND METHOD

A) Impedance Based Technique

The method uses fault voltage and current from both terminal ends of transmission lines. Both ends are not synchronized. Fault currents and voltages are taken from fault recorder such as relays placed at the end of a transmission line

B) One—Edged Impedance-Based Fault Location Technique

Fault locations are estimated by looking into a transmission line from one end. Voltage and current waveforms captured by an intelligent electronic device (IED) at one end of the line can be used to find the apparent impedance between the IED device and the location of the short-circuit fault. This approach is straight forward to implement, yield reasonable locations estimates, and require data from only one end of a transmission line. The fact that there is no need for any communication channel or remote data is an added advantage.

C) Takagi Technique

The drawbacks suffered by one-edge impedance based location approach are corrected by this technique. The technique subtracts the load current from the total current using the superposition theorems to decompose the fault into a pre-fault and post-fault network. 3. 3.

D) Modified Takagi Technique

This is the modified version of the Takagi technique. It uses the zero sequence current for the system load during a single – line to ground fault to avoid the use of pre-fault current. The distance to fault is calculated from the following expression;

$$m = \frac{\mathrm{Img}(V_G \times 3I^*{}_{GO})}{\mathrm{Img}(Z_{L1} \times I_G \times 3I^*{}_{GO})} \quad (1)$$

The modified Takagi Method uses the zero sequence networks to compensate for a non-homogenous system,

E) Eriksson Technique

Source impedance parameters are used to overcome any reactance error caused by fault resistance, loads or system non-homogeneity in order to determine the distance to a fault.

The current distribution factor ds is directly substituted to give

$$V_G = mZ_{L1}I_G + R_F\left(\frac{Z_{G1}+Z_{L1}+Z_{H1}}{(1-m)Z_{L1}+Z_{H1}}\right)\Delta I_G \quad (2)$$

Simplifying and rearranging the terms result in the following expression:

$$m^2 - K_{1m} + K_2 - K_3R_F = 0 \quad (3)$$

The complex multiplications of voltage, current, line impedance, and source impedances are the constants *K1*, K_2, and K_3 and are defined as follows:

$$K_1 = a + jb = 1 + \frac{Z_{H1}}{Z_{L1}} + \left(\frac{V_G}{Z_{L1} \times I_G}\right) \quad (4)$$

$$K_2 = c + jd = \frac{V_G}{Z_{L1} \times I_G} + \left(1 + \frac{Z_{H1}}{Z_{L1}}\right) \quad (5)$$

$$K_3 = e + jf = \frac{\Delta I_G}{Z_{L1} \times I_G} + \left(1 + \frac{Z_{H1}+Z_{G1}}{Z_{L1}}\right) \quad (6)$$

Adequate Separation into real and imaginary parts enhances the solution of the distance to fault using the following quadratic equation

$$m = \frac{\left(a-\frac{eb}{f}\right) \pm \sqrt{\left(a-\frac{eb}{f}\right)^2 - 4\left(c-\frac{ed}{f}\right)}}{2} \tag{7}$$

The fault location estimate must be less than the total line length, the value of m that lies between 0 and 1 per unit should be chosen for accuracy.

The location estimate resistance can be calculated as:

$$R_F = \frac{d-mb}{f} \tag{8}$$

F) Novosel et. al., Technique

This approach is a modified version of the Eriksson and it is used for locating faults on a short radial transmission line. All loads served by the transmission lines and are lumped at the end of the feeder by estimating the load impedance from the pre fault voltage and current as

$$Z_{load} = R + jX = \frac{V_{G1\,R2}}{I_{G1\,R2}} - Z_{L1} \tag{9}$$

The per-unit distance to the fault can be obtained by using the quadratic equation in (7), where the constants are defined as:

$$K_1 = a + jb = 1 + \frac{Z_{load}}{Z_{L1}} + \left(\frac{V_G}{Z_{L1} \times I_G}\right) \tag{10}$$

$$K_2 = c + jd = \frac{V_G}{Z_{L1} \times I_G} + \left(1 + \frac{Z_{load}}{Z_{L1}}\right) \tag{11}$$

$$K_3 = e + jf = \frac{\Delta I_G}{Z_{L1} \times I_G} + \left(1 + \frac{Z_{load} + Z_{G1}}{Z_{L1}}\right) \tag{12}$$

The value of m which lies between 0 and 1 per-unit is chosen as the location estimate. The *Novosal et al* method is robust to any reactance error due to fault resistance and load.

G) Two-Edged Impedance Based Fault – Location Technique

Two-edged impedance-based technique uses waveform data captured at both ends of a transmission line to estimate the location of a fault. It uses the voltage and current during a fault to estimate the apparent impedance from the monitoring location to the fault. Any reactance error caused by fault resistance, load current, or system non-homogeneity are estimated using additional measurements from the remote end of a transmission line

H) Synchronised Two-Edged Technique

The technique utilises measurements from both ends of a transmission line to a common time reference via a global positioning system (GPS). Three symmetrical components can be used for fault location computation The negative-sequence components are are not affected by load current, zero-sequence method coupling, uncertainty in zero-sequence line impedance, or in feed from zero-sequence tapped loads

The zero-sequence, the positive and the negative sequence current can be expressed as:

$$I^0{}_a = \frac{1}{3}(I_a + I_b + I_c) \tag{13}$$

$$I^{+}_{a} = \frac{1}{3}(I_a + \alpha I_b + \alpha^2 I_c) \quad (14)$$

$$I^{-}_{a} = \frac{1}{3}(I_a + \alpha^2 I_b + \alpha I_c) \quad (15)$$

Summarily, the zero sequence, the positive sequence and the negative sequence voltages are expressed as

$$V^{0}_{a} = \frac{1}{3}(V_a + V_b + V_c) \quad (16)$$

$$V^{+}_{a} = \frac{1}{3}(V_a + \alpha V_b + \alpha^2 V_c) \quad (17)$$

$$V^{-}_{a} = \frac{1}{3}(V_a + \alpha^2 V_b + \alpha V_c) \quad (18)$$

The equations can be written in matrix form as

$$\begin{bmatrix} V^{0}_{a} \\ V^{+}_{a} \\ V^{-}_{a} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \end{bmatrix} \quad (19)$$

I) Unsynchronised Two-Edged Technique

Waveform captured by IED devices at both ends of a transmission line may not be synchronized with each other. The GPS device may be absent or not functioning correctly. Alternatively, IEDs have slightly different sampling rates or they may detect the fault at slightly different time instants. The communication channel which transfers data from one IED to the others, can also introduce a phase shift.

J) Unsynchronised Current-Only Two-Edged Technique

Due to limitations in data availability, suppose that only the current waveforms at terminals G and H are available for fault location purposes, Voltage phasors V_{G2} and V_{H2} are missing or supply not available. Using only the current and source impedance parameters. V_{F2} is calculated from either terminal as

Terminal G: $V_{F2} = -(Z_{G2} + mZ_{L2})I_{G2}$ (20)

Terminal H: $V_{F2} = -(Z_{H2} + (1-m)Z_{L2})I_{H2}$ (21)

Consider the absolute values as

$$|I_{H2}| = \left|\frac{Z_{G2}+mZ_{L2}}{Z_{H2}+(1-m)Z_{L2}} \times I_{G2}\right| \quad (22)$$

Squaring and rearranging the terms, the distance to fault m, can be solved by the quadratic, where the constants are defined as

$$a + jb = I_{G2}Z_{G2} \quad (23)$$

$$c + jd = Z_{L2}I_{G2}$$

(24)

$$e + jf = I_{H2}Z_{L2} \quad (25)$$

$$g + jh = Z_{L2} \quad (26)$$

$$A = |I_{H2}|^2 \times (g^2 + h^2) - (c^2 + d^2) \quad (27)$$

$$B = -2 \times |I_{H2}|^2(eg + fh) - 2(ac - bd) \quad (28)$$

$$C = |I_{H2}|^2 \times (e^2 + f^2) - (a^2 + b^2) \quad (29)$$

This method is applicable for locating unbalanced fault only. The accuracy of location estimates depends on accurately knowing the source impedance parameters.

III. CONCLUSION

An overview of impedance-based techniques in electrical power transmission network has been carried out. Impedance based techniques use the fundamental frequency of voltage and current phasors from installed transducers such as numerical relays and fault recorders. Under this technique, voltage and current phasors may be taken from both terminals or from a single terminal of a transmission line.

Two-edged impedance based fault location technique provides more accurate results compared to one-edged technique because the two-edged approach is not affected by fault resistance and reactance. Phasor voltage and current can be collected from two-edges of a transmission line by synchronized data.

Impedance based technique is widely used because of its simplicity and low cost. If the fault is underground, fault resistance will be small and it does not affect the precision of the fault location. In case of the grounded fault, fault resistance will be high and it will affect the fault location. Fault distance is calculated by measuring the reactance at one end of the line.

Conflict of Interest: The authors declare that they have no conflict of interest.

Ethical Statement: The authors declare that they have followed ethical responsibilities.

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