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Techniques for Location of Fault on Transmission Lines in Power System

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Abstract— In Power System, high voltage transmission and distribution lines are vital links that achieve the essential continuity of service from the generating plants to the end users. The service continuity is one of the important concerns to the utility, but a fault is inevitable often resulting in power interruption. This is more prominent in the transmission systems, because most of lines are exposed to air and spread over a wide area. Electric power transmission systems are susceptible to faults caused by a variety of situations such as adverse weather conditions, equipment failure, traffic accidents, etc. When a fault occurs on a transmission line, it is very important for the electrical utility to identify the fault location as quickly as possible for improving the service reliability. In this paper, some techniques for location of fault on transmission line in power system are discussed.

Keywords— *transmission system; fault location; generating plants; distributed generation*

INTRODUCTION

Fault detection/location on transmission lines is a widely known problem that has been studied for a long time. An accurate fault location technique is of great importance in improving systems' reliability including relaying, analysis for line inspection, and routine maintenance [1]. The growing complexity of power systems, along with increased consumption and quality energy demand require an increasingly safe and reliable protection system [2]. The development of fault in transmission line often give rise to some severe economic losses and social problems, such as producing a lots of toxic pollution in an emergency shutdown of semiconductor production line, etc. [3]. The rapid removal of transmission lines' faults is one of the best measures to improve power systems stability. Decreasing the protection operation time is the simplest method for fast fault clearance. In the same time, in a competitive electricity market, the rapid fault restoration on transmission lines is faced with the quality of utility's power service. Following the occurrence of a fault, the utility tries to restore power as quickly as possible because rapid restoration of service reduces customer complaints, outage time, etc. To aid rapid and efficient service restorations, an accurate fault location estimation and fault discrimination technique are needed [4].

Without neglecting the severe economic losses induced by a fault occurrence, the increased accuracy into the fault's detection and location estimation make an easier task for inspection, maintenance and repair. For the transmission lines, an error into the fault's location of a few kilometers may still be acceptable for impedance relays decision but would represent a hard work for maintenance teams. When a fault occurs on a transmission line, the responsible utility must identify the fault location as fast and accurate as possible for restoring the line, improving the service reliability and avoiding severe economic loss [5]. For that, there are many researches done to date and different fault location algorithms were developed, among which stand out here [6]:

- Digital fault recorder and short circuit data match;
- Traveling wave methods;
- One-ended impedance-based methods, with or without using source impedance data;
- Two-ended methods.

This paper focus on techniques for location of fault which are: one-ended and two-ended techniques. According to [7], a correct fault location estimate can be affected by many factors, such as:

- Inaccurate fault type identification;
- Presence of shunt reactors and capacitors;

- Measurement errors, current and voltage transformer errors;
- If the fault voltages and currents do not reach steady state value or if it is cleared before the filter nominal
- response time;
- Uncertainty about the line parameters.

In this paper, three one-ended techniques and a two-ended technique which are impedance based fault location techniques are discussed.

II. PROBLEM DEFINITION

In electrical power systems, transmission lines form the backbone of the systems. So, when a fault occurs on transmission line i.e. when two or more conductors come in contact with each other or ground in three phase systems, the power system components are subjected to the greatest stresses from excessive currents. These faults give rise to serious damage on power system equipment. Fault occurs on transmission lines not only affects the equipment but also the power quality. So, it is necessary to determine the fault type and location of fault on the line and clear the fault as soon as possible in order not to cause such damages. Therefore, there is a need for some techniques to solve this problem.

I. ONE-ENDED IMPEDANCE-BASED FAULT LOCATION

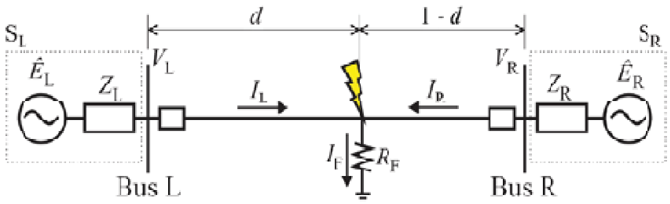

Fig.1 Single-line diagram of a two-terminal transmission line

The problem of fault location using one-end data is described considering the single-line diagram of a simple homogeneous Transmission line of length "l" illustrated in Fig.1. The local and remote terminals are represented by the letters L and R, respectively. The terminal voltages are V_L and V_R. When a fault with resistance R_F occurs at a distance of "d" per unit from the bus L, the currents from both ends, I_L and I_R, contribute to the total fault current I_F. The Transmission line has a positive-sequence impedance of Z_{TL1} between terminals L and R. The Thevenin equivalent circuits S_L and S_R represent the power systems connected at each end of the line.

Table1: Phasors used for each fault type

Fault Type	V_L	I_L
A-G	V_A	$I_a + k^a I_0{}^b$
B-G	V_B	$I_b + kI_0$
C-G	V_C	$I_c + kI_0$
AB, AB-G, ABC	V_{AB}	I_{AB}
BC, BC-G, ABC	V_{BC}	I_{BC}
AC, AC-G, ABC	V_{AC}	I_{AC}

According to the specialized literature [7], the voltage drop from terminal L is given by:

$$V_L = dZ_{TL1} + R_F I_F \quad (1)$$

Where the voltage V_L and current I_L depend on the fault type and are replaced according to table1. The value of the apparent impedance measured at terminal L is found dividing "(1)" by the measured current I_L.

$$Z_{app} = \frac{V_L}{I_L} = dZ_{TL1} + \frac{I_F R_F}{I_L} \quad (2)$$

Since the only available information is from one end of the Transmission line, R_F and I_F are not known. In order to eliminate those two unknown variables, several one-ended algorithms have been developed by using following techniques:

A. Simple Reactance Method

The Simple Reactance method (SR) ignores the $R_F I_F / I_L$ term in "(2)". To do so, it assumes that the current through the fault resistance is in phase with the current at the measurement point, and there is no load prior to the fault. In addition, the algorithm considers only the imaginary part of the apparent impedance. The per unit distance d to the fault is computed according to:

$$d = \frac{Im(V_L/I_L)}{Im(Z_{TL1})} \quad (3)$$

Where V_L and I_L depend on the fault type and are defined in Table.1

This method has the advantage of being easily implemented. However, its accuracy is very susceptible to the alignment of I_F and I_L. The error is zero if only the fault resistance is zero or if I_F and I_L are in phase, otherwise, R_F introduces an additional reactance to the fault. The reactance effect increases or decreases the apparent line reactance to the fault, creating to an error in apparent fault location.

B. Takagi Method

This method eliminates the influence of load current by determining the change in current on occurrence of a fault, i.e. it subtracts out the load current from the total fault current. The per unit distance d to the fault is computed according to:

$$d = \frac{Im(V_L \Delta I_L^*)}{Im(Z_{TL1} I_L \Delta I_L^*)} \quad (4)$$

where V_L and I_L depend on the fault type and are defined in table and ΔI_L^* is the complex conjugate of the current difference between pre-fault and post-fault.

Errors caused by load flow, fault resistance and the unsymmetrical arrangement of the Transmission line are automatically corrected. However, if the system is non-homogeneous, there is a reactance error in the distance estimation.

C. Eriksson Method

The main feature of the method presented is that it considers the influence of the remote-end data of the transmission line by using a complete network model. It uses a positive-sequence model of the transmission line and source impedance at both ends of the line (Z_{L1} and Z_{R1}). The remote source impedance Z_{R1} must be accurately known. If the local impedance Z_{TL1} is not available, it can be calculated using the following equation:

$$Z_{L1} = -\frac{V_{L1} - V_{L1-pre}}{I_{L1} - I_{L1-pre}} \quad (5)$$

Where V_{L1-pre} and I_{L1-pre} are the pre-fault voltage and current measured at the local terminal.

Pre-fault load-current samples are stored and used for compensation to eliminate a substantial effect on accuracy. Also, representative values for the source impedances are stored to compensate for variations in impedance angles [8].

The per unit distance d to the fault is computed according to:

$$d^2 - K_1 d + K_2 - K_3 R_F = 0 \quad (6)$$

Where K1, K2 and K3 are defined as follows:

$$K_1 = 1 + \frac{Z_{L1}}{Z_{TL1}} + \frac{V_L}{Z_{L1} * I_L} = m + jn$$

$$K_2 = \left(1 + \frac{Z_{R1}}{Z_{TL1}}\right) * \left(\frac{V_L}{Z_{L1} * I_L}\right) = o + jp$$

$$K_3 = \left(1 + \frac{Z_{L1} + Z_{R1}}{Z_{TL1}}\right) * \left(\frac{\Delta I_L}{Z_{TL1} * I_L}\right) = q + jr$$

There are two possible values for d. The correct per unit distance is the value that lies between 0 and 1, since it has to be less than the total line length.

II. TWO-ENDED IMPEDANCE-BASED FAULT LOCATION

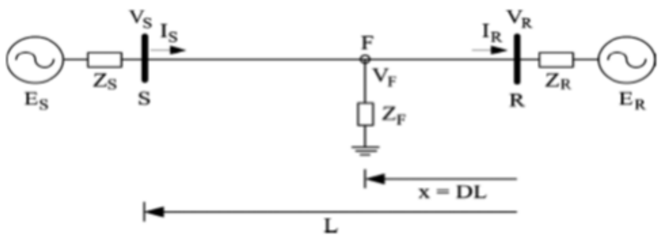

Fig.2 One line view of a single circuit transposed transmission line with a fault at a distance x = DL away from the bus R

Fig.2 shows a single-circuit transposed transmission line. Total line length is assumed to be L, and the synchronized voltage and current phasor measured on buses S and R are V_S, I_S, V_R and I_R respectively. Using symmetrical components transformation to decouple three phase quantities and to consider only the variation of a distance variable (km), the relation between the voltages and currents at a distance x away from bus R can be expressed by the following sequence equations,

$$\frac{dV}{dX} = ZI \quad (7)$$

$$\frac{dI}{dX} = YV \quad (8)$$

Where, Z and Y are the per-unit length sequence impedance (Ohm/km) and admittance (Mho/km) of the transmission line, respectively. The matrices of Z and Y are all diagonal matrices, and the diagonal entries of matrices Z and Y are (Z_0, Z_1, Z_2) and (Y_0, Y_1, Y_2) respectively. The variables with the subscripts 0, 1, 2 denote the zero, positive and negative sequence variables, respectively.

The solutions of voltages and currents of the three decoupled sequence systems can be written as [9],

$$V_{xi} = [A_i exp(\gamma_i x) + B_i exp(-\gamma_i x)] \quad (9)$$

$$I_{xi} = \frac{1}{Z_{Ci}}[A_i exp(\gamma_i x) - B_i exp(-\gamma_i x)] \quad (10)$$

Where the subscript denotes 0, 1, and 2 sequence variables, $Z_{Ci} = \sqrt{\frac{Z_i}{Y_i}}$ denotes the characteristic impedance and $\gamma_i = \sqrt{Z_i Y_i}$ is the propagation constant. The constants A_i and B_i can be obtained by the boundary conditions of voltages and currents measured at bus R and bus S, respectively.

A fault is assumed to occur at point F with a distance x = DL km away from the receiving end R on a transmission line shown in Fig.2, where D is termed as the per-unit fault location index. Using the relationship $V_{F,R} = V_{F,S}$ the index can be solved as follows,

$$D = \frac{ln\frac{N}{M}}{2\gamma L}$$

$$M = \frac{1}{2}(V_S + Z_C I_S)e^{-\gamma L} - \frac{1}{2}(V_R + Z_C I_R)$$

$$N = \frac{1}{2}(V_R - Z_C I_R) - \frac{1}{2}(V_R - Z_C I_S)e^{-\gamma L}$$

When a fault occurs between buses S and R, the obtained value of D is between 0 and 1. When no fault or an external fault occurs, the value of D is indefinite. It is worth mentioning that there is no assumption made in the procedure of derivation for the fault location index D. Thus, the index D is unaffected by the variations in source impedance, loading change, fault impedance, fault inception angle, and fault type. The performance index in terms of the error percentage is defined as follows:

$$\text{Error}(\%) = \frac{|(\text{Estimated location in km}) - (\text{Actual location in km})|}{(\text{Total line length in km})} * 100$$

V. CONCLUSION

In this paper, various techniques for location of fault on transmission line which are one-ended techniques and both-ended techniques are discussed. As compared to other fault location technique indices, the both-ended fault location technique index does not need any assumption, so it is a very robust index. With the advent of both-ended fault location technique we can achieve an excellent performance for locating the fault on transmission line.

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