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Transmission lines fault location using transient signal spectrum

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ABSTRACT

This paper proposes a method for fault location on transmission lines, which is based on time to frequency domain transformation of transient signals of the fault instant measured at one end. Fast Fourier Transform (FFT) is used for time to frequency domain transformation and frequency of the first fault generated harmonic is utilised for determination of the fault location using the travelling wave theory of the transmission line. The accuracy of the method has been tested using the simulations carried out in Alternative Transients Program (ATP/EMTP) with frequency-dependent distributed parameter transmission line model by considering several cases and various types of faults, different values of fault resistance and phase angle at fault instant. The method has good accuracy and the simulation results show that the accuracy of the method is insensitive to the fault resistance and phase angle of the fault instant. Reactive elements may affect the resolution but, it can be removed by applying the correction procedure proposed.

1. Introduction

Power outages lead to loss of manpower and resources in industrial plants; on the other hand reliability and continuity of electrical energy has gained more importance in last decades due to enhanced competition and limited resources. The most important cause of disturbances in the power systems is unexpected failures, and within them, short circuit faults are more common, which are arisen due to lightning surges, usage of defective materials, improper system operation, human error, overloading and aging. Besides the economical losses in industry, a fault may cause loss of system stability, failure of transformers, generators and transmission lines and therefore, fast clearing of faults is greatly significant. First condition for clearing a fault in a short time is to estimate the fault location quickly and precisely. This subject gained more importance in last decades and advance in the computer technology allows development of new algorithms for determination of fault location. In recent years several methods have been proposed for fault location in power systems, which may be classified into two categories; the methods which employ electric quantities and the methods based on the travelling wave theory. In some of the first category methods, fault distance is estimated from the information received from one end of the transmission line [1–4], usually by using fundamental frequency voltages and currents measured at one terminal [1,2] or by measuring impedance from measuring terminal to the fault point [3,4]. However, some of these methods require accurate modelling of both the faulted transmission line and the power system in which the line is embedded and some others cannot be used to locate symmetrical faults. In addition, for short lines, the equivalent impedance variation can have a higher influence in method precision. Also unknown fault impedance affects the accuracy and some methods are sensitive to errors in the value of the local bus impedance. Due to these restrictions, two- or multi-ended fault location techniques have been proposed [5–8]. However, measurement from two ends is expensive and synchronised sampling of the voltage and current data from two ends of the line are usually required.

In the travelling wave based methods [9,10] on the other hand, time-space analysis have been used for fault location. Short and open circuit faults on transmission lines cause sudden changes in the distribution of electric and magnetic energy which result travelling waves. In order to determine the fault distance, the analysis of wave time-position graphs are employed. In recent years, many studies have been devoted to develop different methods based on wavelet transform to determine the fault type and location [10,11]. Wavelet transform (WT) is a recently developed mathematical tool, which is used to capture the dynamic characteristics of unstable signals using short data windows. Depending on the direction in the protection of transmission lines, fault classification and fault distance identification using wavelet transform was carried out by separating the necessary information from the short circuit transient behaviour. The most important limitation of the existing methods based on the wavelet transformation is the low degree of accuracy in the prediction fault points near the busbar in general. In addition, there are other techniques, which use elements

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of artificial intelligence in the form of artificial neural networks (ANN's) [12,13] and support vector machine approach [14].

Using the theory of travelling waves, transient signal spectrum can also be used for determination of fault distance. This method has been applied for fault location estimation in single-phase transmission lines and satisfactory results have been obtained [15]. In this study, using modal transformations, the method is extended for three-phase transmission lines. Frequency spectrum which is obtained by Fast Fourier Transform (FFT) of the transient signals measured on one terminal of the transmission line is used to detect the travel time of the fault generated wave, which makes available the fault distance. The proposed method is applied to the simulations carried out in Alternative Transients Program (ATP). A two-terminal three phase system with distributed and frequency dependent parameters is considered. The effects of phase angle, fault resistance and source parameters are also investigated.

The organisation of the paper is as follows: After this introductory section, the theory of fault distance calculation using travelling wave theory of the distributed parameter transmission line is introduced in Section 2. In Section 3 the simulation model is given. In Section 4 application results are introduced; the effect of fault resistance, the affect of phase angle and the effect of source inductance is investigated.

2. Fault distance calculation using travelling waves

Voltage and current phasors **V** and **I** at any point on the line with per unit length series impedance $\mathbf{z} = r + j\omega l$ and shunt admittance $\mathbf{y} = g + j\omega c$ are determined as [16]

$$\mathbf{V} = C_1 e^{\gamma x} + C_2 e^{-\gamma x} \tag{1}$$

$$\mathbf{I} = \frac{1}{z_0} C_1 e^{\gamma x} - \frac{1}{z_0} C_2 e^{-\lambda x} \tag{2}$$

where r, l, g and c are resistance, inductance, conductance and capacitance of transmission line per unit length, respectively; and $\gamma = \sqrt{zy}$ is the propagation constant, $z_0 = \sqrt{z/y}$ is the characteristic impedance of the line. The constants C_1 and C_2 can be evaluated by using the boundary conditions at terminals of transmission line. Propagation constant of a transmission line can be written as $\boldsymbol{\gamma} = \alpha + j\beta$, where attenuation constant α measured nepers per unit length and phase constant β radians per unit length. A wavelength λ is the distance along a line between two points of a wave which differ in phase by 360°, or 2π rad. If β is the phase shift in radians per km, the wavelength in km is

$$\lambda = \frac{2\pi}{\beta} \tag{3}$$

The velocity of propagation of a wave in km per second is

$$v = f\lambda \tag{4}$$

where f is frequency in Hz and λ is wavelength in km. The velocity of propagation in terms of line parameters can be simply obtained as

$$v \approx \frac{1}{\sqrt{lc}} \tag{5}$$

Let τ_f is travel time from fault point to measuring point which has theoretical value calculated as

$$\tau_f = \frac{x}{v} \tag{6}$$

where x is the distance between the fault point to the measuring point. Each 2τ generates a period and it has been observed from the simulation results that the frequencies of the voltage and current harmonics generated after the fault are proportional to the travel time as

$$f_1 = \frac{1}{2\tau_f}, f_2 = \frac{1}{\tau_f}, \cdots f_i = \frac{i}{2\tau_f} \tag{7}$$

Hence, if the wave speed and frequency of ith harmonic f_i is known, the fault distance can be found from the following equation:

$$x = v\tau_f = \frac{iv}{2f_i} \tag{8}$$

The frequency of the fault related harmonics of the voltage and current signals can be obtained by transforming transient signals into frequency domain. FFT is used for this purpose.

3. Simulation model

In this study a 240 km 400 kV fully transposed three phase line shown in Fig. 1 is considered in the computer simulations to verify the accuracy of the proposed algorithm. Tower configuration of the system is illustrated in Fig. 2 and physical parameters of the transmission line are given in Table 1.

Marti frequency dependent transmission line model [17,18] is used in ATP simulations. ATPDraw file of the test system is illustrated in Fig. 3. Sequence current and voltage waveforms obtained by ATP simulation are transformed into frequency domain using FFT. As the positive sequence inductance of overhead lines is practically constant, wave speed is not affected from the frequency dependence of the line; hence the positive sequence voltage and current data are used. The voltage and current waveforms in time domain are transformed to modal quantities by using the following transformation:

$$\begin{aligned} \mathbf{I}_m &= \mathbf{T}^{-1}\mathbf{I}_p \\ \mathbf{V}_m &= \mathbf{T}^{-1}\mathbf{V}_p \end{aligned} \tag{9}$$

where subscript p and m denotes the phase and modal quantities, respectively. Modal transformation is not unique and for a transposed three-phase transmission line the following transformation matrix may be used:

$$\mathbf{T} = \begin{bmatrix} 1 & 1 & 0 \\ 1 & 0 & 1 \\ 1 & -1 & -1 \end{bmatrix} \quad \text{and} \quad \mathbf{T}^{-1} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 2 & -1 & -1 \\ -1 & 2 & -1 \end{bmatrix} \tag{10}$$

Positive sequence transmission line parameters at power frequency are used to calculate the wave speed from the following equations [19]:

$$l_{pos} = 10^{-7} \ln \frac{2d_m h_m}{GMR_{eq} D_m} \quad \text{H/m} \tag{11}$$

$$c_{pos} = \frac{2\pi\varepsilon_0}{\ln \frac{2d_m h_m}{r_{eq} D_m}} \quad \text{F/m} \tag{12}$$

where h_m is geometric mean height, d_m is geometric mean distance, D_m is geometric mean distance to images, r_{eq} is equivalent radius of sub-conductor and GMR_{eq} equivalent geometric mean radius of conductor.

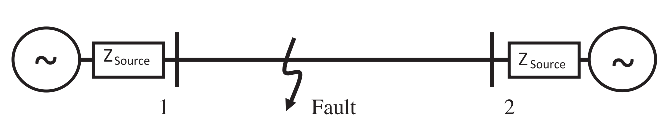

Fig. 1. Two-terminal power network.