ELSEVIER

Electrical Power and Energy Systems 22 (2000) 147–153

ELECTRICAL POWER & ENERGY SYSTEMS

www.elsevier.com/locate/ijepes

Sensitivity analysis of fault quantities

Parmod Kumar[a,*], Majid Jamil[b], Mini S. Thomas[b], A. Moinuddin[b]

[a]*Department of Electrical Engineering, Delhi College of Engineering, New Campus Badli, New Delhi 110042, India*
[b]*Department of Electrical Engineering, Faculty of Engineering and Technology, Jamia Millia Islamia, University, New Delhi 110025, India*

Received 8 April 1998; accepted 3 September 1998

Abstract

In this paper, a method for the sensitivity analysis of sequence fault currents and voltages in an unloaded overhead transmission line for perturbation in line parameters is described. The sensitivity of these quantities with respect to conductor radius, spacing between conductors, earth resistivity, height of conductor and frequency are evaluated for an overhead transmission line. The sensitivity predicts the effect of each parameter on fault currents and voltages, which help in tap setting of the relays for protecting the transmission line against faults. To demonstrate the potential of the proposed scheme, the sensitivity of fault currents and voltages for a three phase, 220 kV line has been studied and the results are presented. © 1998 Published by Elsevier Science Ltd. All rights reserved.

Keywords: Overhead line; Sensitivity analysis; Fault current; Fault voltages; Symmetrical components

1. Introduction

Faults on an overhead transmission line can never be ruled out in-spite of the best transmission system design. Symmetrical components method is commonly employed for computing the currents, voltages and power during fault condition. Here, the unbalanced currents and voltages are resolved into symmetrical components viz positive, negative and zero sequence components. These fault quantities are computed and predicted based on the fixed line parameters such as conductor size, configuration of line, frequency and earth resistivity. Accordingly, the relay settings are made for isolating the faulty transmission line to keep the system stable. The sequence voltages and currents depend upon the impedance of the line, which can be derived from self and mutual impedance of transmission line. During a fault, the capacitance and the inductance of the transmission line change due to charging and discharging of electromagnetic and electrostatic circuits. Also, the line parameters such as radius of the conductor, height, spacing between conductors, frequency and resistivity may vary considerably along the line due to manufacturing defects, stringing, fault current etc. Thus, for a transmission line with known sending end voltage, it is of considerable interest to evaluate the sensitivity of fault quantities with respect to different line parameters. The motivation for this study has arisen from the working experience of authors related to malfunctioning of protective relays [1, 2].

In this paper, the authors have carried out sensitivity analysis of fault current and voltage considering a 220 kV transmission line for perturbations in frequency, resistivity of earth, height, radius of conductor and spacing between conductors. The results of this study should be of interest to protection engineers and transmission system design engineers.

2. Parameter sensitivity model

The sequence impedance in terms of self and mutual impedances of a three-phase transmission system is given by the following equations [4].Zero sequence impedance

$$Z_0 = j(X_s + 2X_m) \tag{1}$$

Positive sequence impedance

$$Z_1 = j(X_s - X_m) \tag{2}$$

Negative sequence impedance

$$Z_2 = j - (X_s - X_m) \tag{3}$$

where, X_s, self reactance of transmission line; and X_m, mutual reactance of transmission line neglecting the resistance during fault.

* Corresponding author.

PII: S0142-0615(98)00053-2

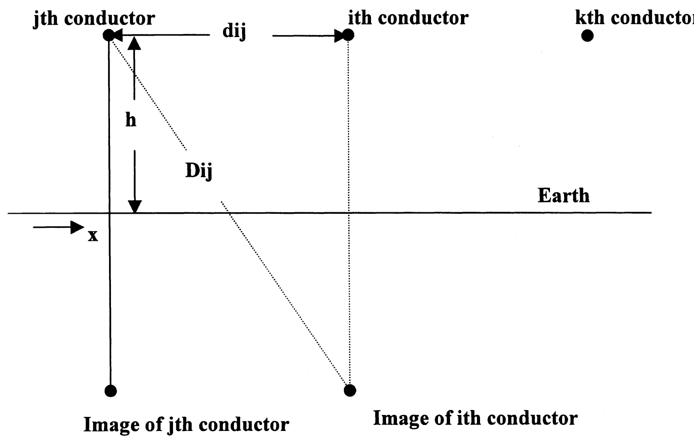

Fig. 1. Sensitivity analysis of a 220 kV overhead transmission line.

The self and mutual reactance are computed using Eq. (4)

$$X = \begin{bmatrix} X_s & X_m \\ X_m & X_s \end{bmatrix} = [X_g] + [X_c] + [X_e] \tag{4}$$

where X_g, the contribution of reactance due to physical geometry of the conductors; X_c, the contribution of reactance due to the conductor; and X_c, the contribution of reactance due to the earth path.

$$X_g = \frac{\omega\mu B}{2\pi}, \text{ where } B = \log_e\left(\frac{Dij}{dij}\right) \tag{5}$$

dij, distance between the ith conductor and the jth conductor for $i \neq j$ and radius of ith conductor for $i = j$; and Dij, distance between ith conductor and image of jth conductor

$$X_c = \frac{K\rho m}{2\frac{1}{2}r(n+2)\pi}, \text{ here } m = \sqrt{\left(\frac{j\omega\mu}{\rho}\right)} \tag{6}$$

where $K = 2.25$ is a factor due to conductor stranding; ρ, conductor resistivity; r, radius of each outer strand; and n, number of strands in the outer layer

The value of X_e at 50 Hz frequency is quite small in comparison to X_g and X_c, hence X_e has not been taken into account in our present study for computing ^{X}.

The mutual impedance of any one of the conductor with respect to other conductors are considered to be equal. The self and mutual impedance matrices state the electromagnetic performance of the line and depend on the physical and electrical characteristics of the line, the geometrical arrangement and height of conductors above the ground plane. Thus, the general fault current and voltage equations can be written as: [6]

$$I_f = \frac{V_f}{(Z_f + Z_{0,1,2})} \tag{7}$$

$$V_f^0 = -Z_0 I_f^0 \tag{8}$$

$$V_f^1 = V_K - Z_1 I_f^1 \tag{9}$$

$$V_f^2 = -Z_2 I_f^2 \tag{10}$$

Where V_K, pre-fault voltage at the fault point; $Z_{0,1,2}$, zero, positive and negative Thevenin sequence impedances between fault point and reference; $V_f^{0,1,2}$,zero, positive and negative sequence fault voltage between fault point and reference; Z_f, shunt fault impedance.

The detailed expression of sequence currents are given in Appendix A

3. Parameter sensitivity functions

Sensitivity in general is expressed in terms of ratio of the percentage change in the system function of interest to the percentage change in a parameter of the system. To determine the sensitivity $S_x^{I_f}$ of the fault current I_f with respect to a parameter 'x' of the transmission line, we differentiate Eq. (11), and the normalised sensitivities, given by Eq. (13)

$$I_f = \frac{V_f}{Z_f + Z_0 + Z_1 + Z_2} \tag{11}$$

$$S_x^{I_f} = \frac{\partial I_f}{\partial x} = -V_f\left[\frac{\frac{\partial Z_f}{\partial x} + \frac{\partial Z_{0,1,2}}{\partial x}}{(Z_f + Z_{0,1,2})^2}\right] \tag{12}$$

$$\hat{S}_x^{I_f} = \frac{x}{I_f}\left(\frac{\partial I_f}{\partial x}\right) = -x\left[\frac{\frac{\partial Z_f}{\partial x} + \frac{\partial Z_{0,1,2}}{\partial x}}{(Z_f + Z_{0,1,2})}\right] \tag{13}$$

The sensitivity functions for parameters such as radius 'r', resistivity 'ρ', spacing between conductors 'd', height of the conductor 'h' and frequency 'f' were evaluated for an overhead line with a horizontal configuration and are presented in Appendix B.