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Methodology for testing a parameter-free fault locator for transmission lines

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ABSTRACT

This paper presents a comparison between two different approaches to fault location both with and without utilising transmission line parameters. Firstly, an impedance-based parameter-dependent algorithm, derived by using modal transformation theory and fast Fourier transform is presented. The methodology is able to locate the fault whether it is on an overhead line or on an underground power cable. The second algorithm is a parameter-free fault location method that uses time synchronised data. Here, the unknown fault location is determined from voltage and current phasors, synchronously measured at both line terminals. This approach to fault location avoids the requirement for prior knowledge of line parameters, which is advantageous as line parameters are not always known precisely. This paper presents the results of algorithm testing through the use of ATPDraw simulations and MATLAB. The results were validated through laboratory experiments. The results of the line parameter-free model are compared with those from the parameter-dependent model. Both algorithms were tested for single line to ground faults.

1. Introduction

Electric power is generated by diverse and dispersed sources, which are often remote from load centres. Transmission lines are essential for transporting the generated power to load centres, and their routes can be very long and through inhospitable terrain. Should a fault occur that cannot be cleared through auto-reclosure, then service crews must be sent to repair the fault; knowledge of where exactly the fault has occurred expedites this process and helps to improve the security and quality of the energy supply [1]. Thus, fault location algorithms have become a very important part of transmission line protection schemes [2–4].

FLAs are a means to accurately determining the distance to a fault on a transmission line from a set reference point, which is usually one of the line terminals.

Whilst there are very many different methods of fault location discussed in the literature, FLAs can be broadly classified into two main types [3]:

- methods based upon travelling wave technology [5–7];
- methods based upon the transmission line impedance and voltage and current measurements [8–11].

Impedance-based FLAs measure take voltage and current measurements from one or both ends of the transmission line and utilise suitable circuit analysis techniques to calculate the distance to the fault from the reference point as a function of the transmission line parameters (resistance R, inductance L, and capacitance C per unit length) [12]. However, these parameters may not be known precisely and they can change with different line loading and weather conditions, which may adversely impact the accuracy of the fault location calculations. In recent years, several papers have been published in which methods of eliminating the negative impact of the line parameters on fault location calculations have

Abbreviations: OHL, overhead line; EMTP, Electro Magnetic Transients Programme; ATP, Alternate Transients Programme; FLA, fault location algorithm; SMT, synchronized measurement technology; PMU, phasor measurement units; SLG, single line to ground.

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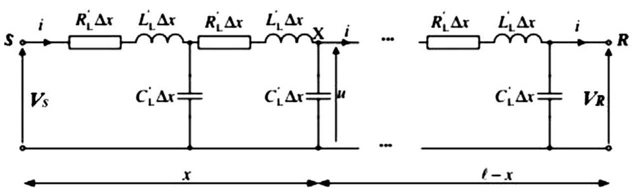

Fig. 1. Schematic representation of a transmission line.

been investigated [13–18]. In each of these cases, the authors developed parameter-free fault location algorithms that were found to deliver accurate calculations of the fault distance when tested with computer simulations.

In this paper, the performance and accuracy of the parameter-free FLAs presented in [13–15] are compared with those of a more conventional parameter-dependent FLA. Both fault locators were assessed through computer simulations using EMTP-ATP [19] and MATLAB [20], and the results were validated through laboratory experiments. The results from both algorithms were compared to assess their accuracy.

Section 2 gives detailed derivations of the two FLAs used for this paper; details of the computer simulation testing are given in Section 3; Section 4 presents the results of the laboratory tests; and, finally, the conclusions drawn from this work are given in Section 5.

2. Fault location algorithms

2.1. Parameter-dependent algorithm

In this subsection, the derivation of an impedance-based parameter-dependent FLA is given. Transmission feeders commonly comprise a combination of overhead lines and underground cables; this FLA can locate faults on both. Using Telegraphers' equations, from a single-line representation of a two terminal transmission line model as shown in Fig. 1, voltages and currents on a transmission line can be defined with respect to distance and time. Clarke's transformation is applied to convert the original set of phase variables into a set of 0, α, and β variables. This algorithm uses the work established in [21,22].

Telegraphers' equations are given as:

$$\frac{\partial v}{\partial x} + L\frac{\partial i}{\partial t} = -Ri \tag{1}$$

$$C\frac{\partial v}{\partial t} + \frac{\partial i}{\partial x} = -Gv \tag{2}$$

where R, L, C, and G are the resistance, inductance, capacitance, and conductance of the line/cable per unit length, respectively.

Fig. 2 shows a schematic diagram of three-phase transmission line, with a phase to ground fault at point F. D is the total length of the transmission line and ℓ is the distance at which fault F occurs from the sending-end terminal (S) of the line. The same F can also be located at a distance $(D - \ell)$ from the receiving end terminal (R) of the line.

The propagation constant γ and the characteristic impedance of the line Z_c are given as:

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)} \tag{3}$$

$$Z_c = \sqrt{\frac{(R + j\omega L)}{(G + j\omega C)}} \tag{4}$$

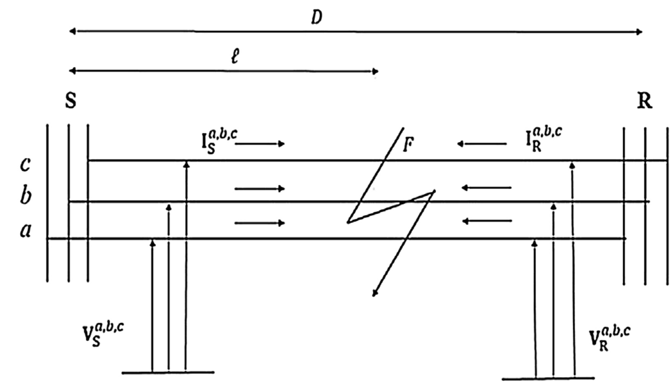

Fig. 2. Three-phase representation of a faulted line.

Telegraphers' equations (1) and (2) for a single-line can be represented as:

$$\begin{bmatrix} V_x \\ I_x \end{bmatrix} = \begin{bmatrix} \cosh(\gamma x) & Z_C \sinh(\gamma x) \\ \dfrac{\sinh(\gamma x)}{Z_C} & \cosh(\gamma x) \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \tag{5}$$

where V_x, I_x are the voltage and current at any point x from the sending end of the line terminal and V_R, I_R are the voltage and current at the receiving-end. Eq. (3) can also be re-written to express V_x, I_x by the sending-end voltages and currents V_S, I_S for a single phase line as:

$$\begin{bmatrix} V_x \\ I_x \end{bmatrix} = \begin{bmatrix} \cosh(\gamma(D-x)) & -Z_C \sinh(\gamma(D-x)) \\ -\dfrac{\sinh(\gamma(D-x))}{Z_C} & \cosh(\gamma(D-x)) \end{bmatrix} \begin{bmatrix} V_S \\ I_S \end{bmatrix} \tag{6}$$

where D is the total line length and x is any point on the line, which can also be represented by the fault point F.

When a fault occurs ℓ km away from the sending end, by making use of above equations, the distance to the fault can be determined by:

$$\ell = \frac{1}{\gamma}\tanh^{-1}\left(\frac{A}{B}\right) \tag{7}$$

Here, the constants A and B are given as:

$$A = V_S \cosh(\gamma D) - Z_C I_S \sinh(\gamma D) - V_R \tag{8}$$

$$B = V_S \sinh(\gamma D) - Z_C I_S \cosh(\gamma D) + Z_C I_R \tag{9}$$

By making use of the Clarke's transformation, the single-phase solution can be extended to a three-phase solution:

$$\begin{bmatrix} V_0 \\ V_\alpha \\ V_\beta \end{bmatrix} = T \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{10}$$

$$\begin{bmatrix} I_0 \\ I_\alpha \\ I_\beta \end{bmatrix} = T \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \tag{11}$$

where $T = 1/3 \begin{bmatrix} 1 & 1 & 1 \\ 2 & -1 & -1 \\ 0 & \sqrt{3} & -\sqrt{3} \end{bmatrix}$ is Clarkes transformation.

Hence, the distance to fault in a three-phase system can be shown as:

$$\ell_{0,\alpha,\beta} = \frac{1}{\gamma_i}\tanh^{-1}\left(\frac{A_i}{B_i}\right) \tag{12}$$