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New fault location scheme for three-terminal untransposed parallel transmission lines

Ahmed Saber*, Ahmed Emam, Hany Elghazaly

ElectricPowerandMachineDepartment,CairoUniversity,Cairo,EgyptEgypt

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ABSTRACT

This paper proposes a new fault location scheme in the phase-domain for three-terminal untransposed double-circuit transmission lines utilizing synchronized voltage and current measurements obtained by GPS technique. The proposed scheme is derived taking into consideration the distributed line model and the mutual couplings effect between the parallel lines to obtain accurate results. The proposed scheme is derived based on the transmission line theory and Taylor series expansion of the distributed line model parameters. All fault types including normal shunt faults, evolving faults, and cross-country faults can be discriminated from each other and the fault location can be obtained for all fault types. The evolving faults include earth faults occurring at the same location in two phases of one circuit or two phases of different circuits at different fault inception time. While cross-country faults include earth faults occurring at different locations in two phases of one circuit or two phases of different circuits at same or different fault inception time. The proposed scheme is tested under different fault locations, different fault resistances, different fault inception angles, and all fault types including cross-country and evolving faults. Also, the effect of different sampling rate, measurement and synchronization errors, earth resistivity variations, and transmission line parameters errors on the proposed scheme is considered. Simulations studies conducted by MATLAB software demonstrate that the maximum estimation error in fault location does not exceed 3.06%.

1. Introduction

Transmission lines are very important for continuity of power supply. Since transmission lines are permanently exposed to different faults, the precise fault location is essential to repair the faulted line and minimize the outage time [1,2]. The transmission line faults include normal shunt faults (line to ground (LG), double line to ground (LLG), double line (LL), and three line (LLL)), evolving faults, and cross-country faults. Cross-country faults include earth faults occurring at different locations in two phases of one circuit or two phases of different circuits at same or different fault inception time. Cross-country faults which occur at same location between two different circuits are also defined as inter-circuit faults which appear in double-circuit transmission line. Inter-circuit faults are easily located because the inter-circuit faults occur at one location compared with the cross-country faults occurring at two different locations. Cross-country faults which include two phases in different locations at same or different fault inception time are very difficult to obtain their locations. While the evolving faults include earth faults occurring at the same location in two phases of one circuit or two phases of different circuits at different fault inception time. In other words, the evolving faults consist of primary earth fault which beginning in one line and secondary earth fault in another line at the same location. For single pole tripping function, the secondary faulted phase must be recognized. However, the faulty phase selector cannot easily recognize the secondary faulted phase because the evolving faults are more complex than normal shunt faults.

Generally, conventional fault location techniques can be divided into four main categories. The first category uses the fundamental frequency components measurements [3–8]. The second one includes techniques based on the fault generated traveling waves [9–14]. The third category applied soft computing methods such as artificial neural network [15,16], genetic algorithm [17], combined wavelet-fuzzy [18,19], and adaptive neuro-fuzzy [20] for transmission line fault location. The last category is based on fault-induced transient analysis for high frequency signals [21,22]. Moreover, the use of synchrophasor measurements for multi-terminal parallel transmission lines has been presented in open literature [23–29].

* Corresponding author.
E-mail address: a_saber_86@yahoo.com (A. Saber).

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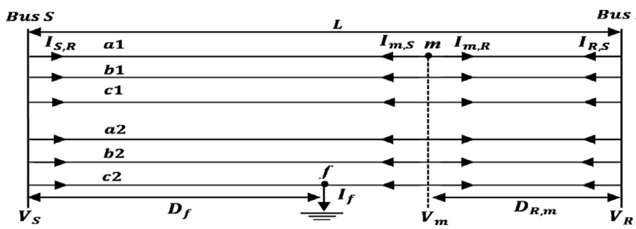

Fig. 1. Faulted two-terminal double-circuit transmission line.

However, in all these methods [3–29], the cross-country and evolving faults are not considered in power system simulation.

Detection and classification of evolving faults and cross-country faults have been presented in Refs. [30–33] and [32–35], respectively. However none of these methods [30–35] discussed fault location estimation. Only few research papers discussed fault location estimation for cross country faults [36–38] and evolving faults [38,39]. First-zone distance relaying techniques for parallel transmission lines utilizing only one end measurements have been proposed for cross-country non-ground faults [36] and cross-country ground faults [37]. In Ref. [38], discrete wavelet transform and back propagation neural network scheme have been incorporated to determine the fault location and identify the faulted phase of single-circuit transmission line during normal shunt faults and evolving faults, as well as cross-country faults. In this technique, neural network cannot be directly applied to new transmission line as manual retraining is required. In Ref. [39], a time-domain fault location scheme for evolving faults has been developed taking into account the influence of electric arc.

In this paper, a new fault location scheme is derived based on the transmission line theory and the truncated Taylor series is used to model the line. The proposed scheme can discriminate normal shunt and evolving faults from cross-country faults and obtain accurately locations of all fault types including evolving and cross-country faults.

2. Proposed fault location technique

The proposed scheme is developed considering that the three-terminal synchronized measurements and communication channels are available.

2.1. Review of two-terminal untransposed parallel transmission line fault location algorithm

The symmetrical components transformation is not applied for decoupling untransposed transmission lines due to the effect of mutual couplings. In Ref. [40], a fault location algorithm has been proposed for two-terminal single-circuit untransposed transmission line. Based on this work [40], the fault location scheme is extended to double-circuit untransposed transmission line and a new fault location scheme is proposed for evolving and cross-country faults.

Suppose that the parallel transmission line (S–R) depicted in Fig. 1 with length L. The voltage and current phasors in phase-domain at point m which is $D_{R,m}$ in per unit apart from bus R can be obtained as [41]:

$$\begin{bmatrix} V_m \\ I_{m,r} \end{bmatrix} = \begin{bmatrix} A\left(D_{R,m}L\right) & B\left(D_{R,m}L\right) \\ C\left(D_{R,m}L\right) & D\left(D_{R,m}L\right) \end{bmatrix} \begin{bmatrix} V_R \\ -I_{R,S} \end{bmatrix} \tag{1}$$

where V_m and V_R are 6×1 voltage phasors at point m and bus R, respectively. $I_{m,R}$ and $I_{R,S}$ are 6×1current phasors at point m and bus R, respectively. The A–D are 6×6 transmission line parameters matrices and they can be written in terms of infinite series as [40]:

$$A\left(D_{R,m}L\right) = 1 + \frac{(ZY)^1\left(D_{R,m}L\right)^2}{2!} + \frac{(ZY)^2\left(D_{R,m}L\right)^4}{4!} + \ldots \tag{2}$$

$$B\left(D_{R,m}L\right) = Z(D_{R,m}L) + \frac{(ZY)^1 Z\left(D_{R,m}L\right)^3}{3!} + \frac{(ZY)^2 Z\left(D_{R,m}L\right)^5}{5!} + \ldots \tag{3}$$

$$C\left(D_{R,m}L\right) = Z^{-1}(ZY)^1(D_{R,m}L) + \frac{Z^{-1}(ZY)^2\left(D_{R,m}L\right)^3}{3!} + \frac{Z^{-1}(ZY)^3\left(D_{R,m}L\right)^5}{5!} + \ldots \tag{4}$$

$$D\left(D_{R,m}L\right) = 1 + \frac{Z^{-1}(ZY)^1 Z\left(D_{R,m}L\right)^2}{2!} + \frac{Z^{-1}(ZY)^2 Z\left(D_{R,m}L\right)^4}{4!} + \ldots \tag{5}$$

where Z and Y are the series impedance and shunt admittance matrices per unit length, respectively. Suppose that a transmission line fault occurred at point f which is D_f in per unit apart from bus S. The voltage phasor at point f can be written from both ends of the line as:

$$V_f = [\, A(D_fL) \quad B(D_fL)\,]\begin{bmatrix} V_S \\ -I_{S,R} \end{bmatrix} = [\, A((1-D_f)L) \quad B((1-D_f)L)\,]\begin{bmatrix} V_R \\ -I_{R,S} \end{bmatrix} \tag{6}$$

where $V_f = [\, V_{f,a1} \quad V_{f,b1} \quad V_{f,c1} \quad V_{f,a2} \quad V_{f,b2} \quad V_{f,c2}\,]^T$. If the voltage and current phasors are given at the two ends of the line, the unknown variable in Eq. (6) would only be the fault distance (D_f). A and B are only expanded to three terms because the simulation results confirm that the fault location accuracy will not increase by expansion of more terms. By substituting Eqs. (2)–(5) into Eq. (6), the following equation is obtained:

$$\begin{aligned}&\left(1 + \frac{(ZY)^1L^2{D_f}^2}{2} + \frac{(ZY)^2L^4{D_f}^4}{24}\right)V_S - \left(ZLD_f + \frac{(ZY)^1\, Z\, L^3{D_f}^3}{6}\right.\\&\left.+\frac{(ZY)^2\, Z\, L^5\, {D_f}^5}{120}\right)I_{S,R} - \left(1 + \frac{(ZY)^1L^2(1-D_f)^2}{2}\right.\\&\left.+\frac{(ZY)^2L^4(1-D_f)^4}{24}\right)V_R + \left(ZLD_f + \frac{(ZY)^1 Z\, L^3(1-D_f)^3}{6}\right.\\&\left.+\frac{(ZY)^2 Z\, L^5(1-D_f)^5}{120}\right)I_{R,S} = 0\end{aligned} \tag{7}$$

Furthermore, Eq. (7) is rearranged and six polynomial equations are obtained:

$$\begin{aligned}&(V_S - [1 + \frac{(ZY)^1L^2}{2} + \frac{(ZY)^2L^4}{24}]\, V_R + [\frac{ZL}{1} + \frac{(ZY)^1ZL^3}{6} + \frac{(ZY)^2ZL^5}{120}]\, I_{R,S})+\\&([\frac{2(ZY)^1L^2}{2} + \frac{4(ZY)^2L^4}{24}]V_R - ZLI_{S,R} - [\frac{ZL}{1} + \frac{3(ZY)^1ZL^3}{6} + \frac{5(ZY)^2ZL^5}{120}]I_{R,S})D_f+\\&([\frac{(ZY)^1L^2}{2}]V_S - [\frac{(ZY)^1L^2}{2} + \frac{6(ZY)^2L^4}{24}]V_R + [\frac{3(ZY)^1ZL^3}{6} + \frac{10(ZY)^2ZL^5}{120}]I_{R,S})\, {D_f}^2+\\&([\frac{4(ZY)^2L^4}{24}]V_R - [\frac{(ZY)^1ZL^3}{6}]I_{S,R} - [\frac{(ZY)^1ZL^3}{6} + \frac{10(ZY)^2ZL^5}{120}]I_{R,S})\, {D_f}^3+\\&([\frac{(ZY)^2L^4}{24}]V_S - [\frac{(ZY)^2L^4}{24}]V_R + [\frac{5(ZY)^2ZL^5}{120}]I_{R,S})\, {D_f}^4+\\&(-[\frac{(ZY)^2ZL^5}{120}]I_{S,R} - [\frac{(ZY)^2ZL^5}{120}]I_{R,S})\, {D_f}^5 = 0\end{aligned} \tag{8}$$