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A new single ended fault location algorithm for combined transmission line considering fault clearing transients without using line parameters

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ABSTRACT

In this paper a new single ended fault location method is proposed for underground cable combined with overhead lines. In this algorithm fault clearing high frequency transients are used instead of fault-generated transients and the line parameters are not needed. In the proposed algorithm, samples just from voltage transients generated by fault clearing action of circuit breaker are taken from the sending end of the cable line. Applying wavelet transform, the first three inceptions of traveling waves to the fault locator are detected. Using these, the proposed algorithm at first identifies fault section, overhead or cable, and then wave speed is calculated and at last location of fault is determined accurately. Because of using only voltage samples taken from one terminal, it is simple and economic and does not need to GPS and data communication and synchronization. Extensive simulations carried out using SimPowerSystem toolbox of MATLAB, confirm the capabilities and high accuracy of the proposed method under different system and fault conditions.

1. Introduction

Use of cable lines and combined overhead transmission lines with underground power cable are expanding due to safety considerations and enhanced reliability in the distribution and transmission systems [1,2]. Precise fault locating reduces time and costs related to the dispatched crews searching to find the fault location. Providing customers and feeding the consumers with minimal interruption improve the performance of the power system and identifies weak and vulnerable points [3,4]. In addition, accurate fault location improves the availability and reliability of the system [5]. Existing fault location methods, which are used to find location of fault in the overhead lines and underground cables, can be classified into two general categories [6]: impedance-based methods [7–9] and traveling waves-based methods [10–16].

Use of traveling waves-based algorithm is developed because they are more precise compare to impedance-based algorithms and are not influenced by source impedance, fault resistance and power flow [11]. In the majority of traveling waves methods, fault generated high frequency transients are utilized to determine fault location. Theses algorithms, despite the mentioned advantages, are sensitive to noises and faults occurred on the other lines, fault inception angle, reflected waves from other terminals and equipments, which are outside from the relay and fault point [12]. In addition, these methods suffer from faults occurred close to the relay [13]. So, Refs. [12–15] propose utilizing high frequency fault-clearing transients instead of the fault-generated transients to use advantages of the traveling wave methods whilst avoid their problems.

Locating fault point in the combined transmission line due to different wave speeds and different impedance sequences of positive and zero in overhead and cable sections is subject to complexity. Ref. [1] offers a fault location algorithm for locating single phase to ground faults in combined transmission lines using Neuro-Fuzzy approach. In [16] a traveling wave based method, which uses samples from high frequency fault generated voltage transients in two terminals, is introduced. This method is based on the wavelet analysis and is independent of the wave speed. In [17] an algorithm for fault location in combined transmission lines is proposed that uses adaptive network-based fuzzy inference system and samples of voltage and current.

Traveling wave based fault location algorithms for combined transmission lines, which use data sampled only from one terminal, need cable and overhead line parameters. The cable parameters and so, wave speed in cable changes over time, climate and humidity variations [16], therefore, algorithms based on utilizing line and cable parameters will have computational error.

In this paper, a novel single-ended fault location algorithm for combined transmission lines is proposed. The proposed algorithm uses transients caused by opening of circuit breaker instead of using transients generated by fault. In addition, it does not utilize the overhead line and the cable parameters. Suggested algorithm in compare to the double-ended algorithms has the advantage that

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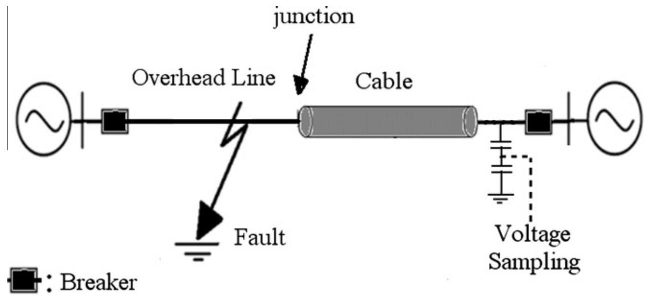

Fig. 1. View of combined line with three-phase to ground fault in the overhead line section.

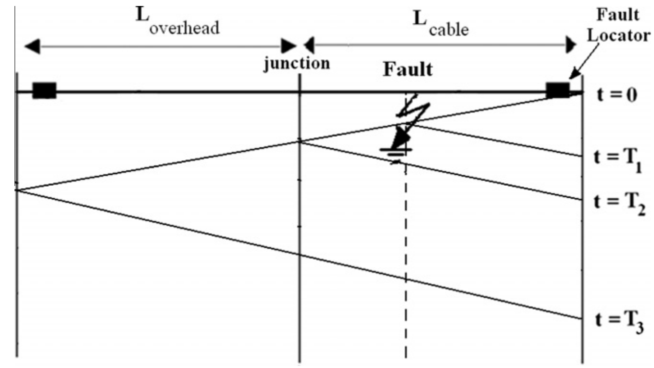

Fig. 2. Lattice diagram for fault occurred in the cable section.

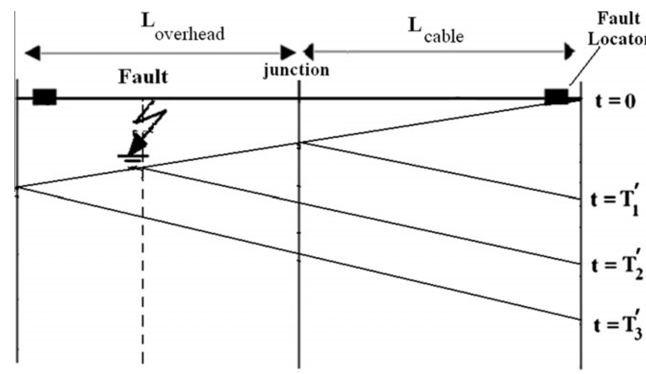

Fig. 3. Lattice diagram for fault occurred in the overhead line section.

does not need to communication equipments, Global Positioning System (GPS) and synchronization of data. Because of using fault-clearing transients instead of the fault-generated transients, the common problems of the traveling wave methods are removed. In addition, because of using only voltage samples, it has less instrumental error compare to the algorithms, which use both voltage and current samples.

In the proposed algorithm, using modal transform, three-phase voltages are transformed into a ground and two aerial modes. Then utilizing wavelet transform the first, second and third inceptions of voltage traveling wave to the fault locator are detected and then by comparing the polarities of the inception and incident waves, fault section is identified. After fault section identification, actual speed of traveling wave in the cable and overhead line sections are calculated without using their parameters. Finally, using arrival times of traveling waves the location of fault is calculated accurately. The algorithm is capable to determine the location of fault for different fault types, single-phase, double-phase and three-phase to ground faults and double-phase and three-phase together faults. It should be noted that the accuracy of the proposed algorithm is not sensitive to the fault resistance, the fault inception angle, the fault type, the distance of the fault from the fault locator and the section of fault, cable section or overhead section. In spite of using single terminal data, the accuracy of proposed method is comparable to the double-ended traveling wave-based methods.

2. Proposed fault location algorithm for combined lines

Fig. 1 illustrates a schematic view of an overhead line combined with a power cable in which a three-phase fault occurred on the overhead section. In the following subsections, the proposed method is explained based on this figure.

2.1. Modal transform

Every sudden change such as fault occurrence on the power system generates current and voltage traveling waves, which propagate away from the fault point in both directions over the transmission line to arrive discontinuity points such as terminals and junctions. In these points, a part of the wave is let through and a part of the wave is reflected and travels back. This phenomenon continues to wave attenuate and damp. The voltage and current waves in the distance of x, for the time of t in the lossless line can be expressed in two forward and backward waves [18]:

$$u(x,t) = F_1(x - vt) + F_2(x + vt) \tag{1}$$

$$i(x,t) = \frac{1}{Z_0}[F_1(x - vt) - F_2(x + vt)] \tag{2}$$

where Z_0 and v are characteristic impedance and wave speed, respectively and F_1 and F_2 are forward and backward waves.

Three-phase lines have significant electromagnetic coupling between conductors. By means of modal decomposition, the coupled voltages and currents are decomposed into a new set of modal voltages and currents, which each can be treated independently in a similar manner to the single-phase line. The relation between modal components and phase components of the voltage and current signals are as below:

$$U_m = T^{-1} \times U_p \tag{3}$$

$$I_m = T^{-1} \times I_p \tag{4}$$

where U and I are the voltages and currents and m and p subscripts are related to the modal and phase quantities, respectively, and T is the transformation matrix. For three-phase fully transposed line assumed in this paper, the Clarke's transformation matrix can be used to obtain the ground and aerial mode signals from the three-phase transients [15]:

$$\begin{bmatrix} U_0 \\ U_\alpha \\ U_\beta \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 1 & 1 \\ \sqrt{2} & -1/\sqrt{2} & -1/\sqrt{2} \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} U_a \\ U_b \\ U_c \end{bmatrix} \tag{5}$$

where U_0 is the ground mode voltage component, and U_α and U_β are known as the aerial mode voltage components for transposed lines. After transforming the phase voltages to modal components, it is possible to detect the first, second and third inceptions of voltage traveling waves to fault locator point using wavelet transform. In this paper db4 wavelet is used for this purpose [19]. In wavelet decomposition, original signal is decomposed into two approximation and detail, and each part can be decomposed into two others with more resolution. In this paper, details of first decomposition