Accurate arcing fault location method for M-terminal transmission lines

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ABSTRACT

Arcing faults (AFs) are highly complex nonlinear phenomena which in turn cause voltages and currents of M-terminal transmission lines vary nonlinearly with time. So, the conventional fault location algorithms which use fundamental frequency of the signals, cannot locate the AFs, precisely. This paper proposes an accurate method to locate the AFs occurring on M-terminal transmission lines. The algorithm consists of two subroutines. In subroutine 1, the faulty section is determined; and in subroutine 2, the exact location of AF is calculated. The proposed method uses synchronized voltage and current measurements at all terminals and does not employ source impedances of the external networks. In addition, the proposed method takes advantage of distributed parameter line model in the time domain which accurately models the line. Since just one minimization problem is used for all AF types, classification of AF type and selection of faulty phase are not needed. An extensive series of simulations has been performed. The results, considering various AF conditions, show the high accuracy and efficiency of the offered method.

1. Introduction

Precise estimation of location of faults occurring on transmission lines is of a great significance for fast repair and reinforcement of damaged and weak parts. Various algorithms for fault location have been presented previously [1–24] which are using information of one terminal [1,2], two terminals [3–7], three terminals [8–13] and multi terminals [14–24] of the line. Conventional fault location algorithms which utilize one-terminal, two terminal and three terminal voltages and currents are difficult to apply to multi-terminal systems. Between the methods presented for multi-terminal transmission lines, the algorithms presented in [14–19] use lumped line model which have suitable accuracy for short lines. But, the accuracy of the methods is reduced for long transmission lines, since, the capacitive effect of the line is ignored in the lumped line model. Also, [17–19] assume the Thevenin impedances at terminals are known from the bus impedance matrix. But, it is difficult to obtain the precise value of the source impedances during faults, since they vary depending on the configuration of the external networks. For considering the capacitance effect of long transmission lines, the algorithm presented in [20] uses distributed parameter line model in the frequency domain, and is based on two-terminal fault location technique and synchronized PMUs, which uses a fault section selector. In [21], a two-stage fault-location method is suggested, which avoids iterative computations. A simple fault location method for multi-terminal transmission lines utilizing unsynchronized measurements is presented in [22]. A new fault location algorithm suitable for multi-terminal transmission lines that combines the advantages of both impedance and traveling wave based methods is developed in [23]. But, the methods proposed in [20–23] need filters to extract fundamental frequency components of the signals. Thus, the frequency response of the filter and dc-offset reduce the accuracy of the methods. In [24], a new fault location method for multi-terminal transmission lines based on current traveling waves is proposed. Generally, traveling wave based fault location methods need high sampling frequency which requires expensive instruments. For example, [23] and [24] need the sampling frequency of 1 MHz and 2 MHz, respectively.

Studies of arcing faults (AFs) have confirmed that they are highly complex nonlinear phenomena influenced by a number of factors, e.g. the path of arc, the geometry of arc-column, the cooling rate, etc [25]. AFs can be cleared by momentarily de-energizing the transmission lines. However, AFs are needed to be located, because:

1. Sometimes, AFs may be identified as permanent faults by protection system because of asynchronous and/or false performance of re-closures installed in the terminals of transmission lines.
2. AF location enables preventive maintenance, as a great number of transient faults may change to permanent faults.

The nonlinear variation of the arc manifests itself into generating high frequency components which in turn deform the arc voltage waveforms over the time [25–31]. Thus, when arcing faults occur on M-terminal transmission lines, the voltage and current of all terminals are
distorted, significantly. The level of the distortion is dependent upon the transmission line topology and parameters, the arc voltage and resistance, the dynamic changes in the AF length and the position of the AF on the line. Hence, fundamental frequency of voltages and currents recorded at all terminals of the line which are used by the previously presented methods for multi-terminal transmission lines, [14–23], are greatly affected. Therefore, calculation of the AF location is difficult to deal with, and [14–23] are not able to accurately estimate the AF location for multi-terminal transmission lines.

In this paper, an accurate fault location algorithm is discussed that is developed especially for AFs occurred on M-terminal transmission lines employing the distributed parameter line model in the time domain. The proposed method not only does not require classification of the AF-type, but also does not utilize the Thevenin impedances of the external networks. In addition, a faulty section selector is used for the proposed method in order to reduce the search space. To exactly locate the AF, the described method uses synchronized voltage and current measurements at all terminals. The analysis of the proposed algorithm is performed in the MATLAB/Simulink by using a 245-kV typical M-terminal transmission line and 500-kV, 50-Hz six-terminal transmission line used in [21], considering several AF distances in different sections and various AF types with different incidence angles.

The remainder of this paper is outlined as follows. The AF location method is detailed in Section 2. Arc characteristics considered in this paper, are illustrated in Section 3. Evaluation studies are reported in Section 4, followed by a conclusion.

2. Principle of distance estimation method

For simplicity, at first the proposed method is described for a single-phase M-terminal transmission line on which an AF has occurred. Then, it will be extended to three-phase M-terminal transmission lines as well.

2.1. Fault location for single-phase M-terminal transmission line

Consider an M-terminal (M > 2) single-phase power transmission line shown in Fig. 1. An AF has happened on point F. B0 and B\(_M-1\) symbolize the first and the last terminal of the line, respectively. Also, T\(_i\), B\(_i\), and S\(_i\) represent \(i\)th terminal, \(i\)th node, and \(i\)th section, correspondingly. This system consists of M terminals, M - 2 nodes, and 2 \(\times M - 3\) sections. Assume an AF has occurred on one of the sections of the transmission line, and the voltage and current samples are recorded at all terminals and are available for the fault locator, synchronously.

The proposed algorithm consists of two subroutines. The first one identifies the faulty section. In the second one, the location of AF is found based on the calculated voltages and currents of two ends of the faulty section. The presented method is described as follows.

![Fig. 1. Single line diagram of an M-terminal transmission line.](image-url)
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