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Fault location scheme for a multi-terminal transmission line based on current traveling waves

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ABSTRACT

As very little research on the fault location for multi-terminal transmission lines based on current traveling waves only has been done, a new fault location scheme on this is proposed. The proposed scheme is different from the traditional ones based on fundamental impedance. Fast Intrinsic Mode Decomposition (FIMD) and Teager Energy Operator (TEO) are combined (FIMD&TEO) to detect the arrival time of the traveling wave at each terminal. Fault Distance Ratio Matrix (FDRM) and rules for identifying faulted sections of a multi-terminal transmission line are proposed and the method for building FDRM is presented in this paper. After several couples of local and remote terminals connecting through the faulted section are got, their fault distances are calculated by means of a two-ended traveling wave method, and then the fault point can be located by averaging the fault distances. Many simulations under various fault conditions have been done, and the results show that the proposed scheme can locate faults more accurately than existing impedance-based methods.

1. Introduction

The fault location for transmission lines is of great significance to help power line maintenance crews search for fault points and restore the lines' transmission service without too much delay. The existing fault location schemes are mainly for two-terminal transmission lines. However, there are some multi-terminal lines in a transmission or subtransmission network. Therefore, it is of practical significance to find out a more accurate fault location scheme for multi-terminal transmission lines.

It is more difficult to locate a fault in a multi-terminal transmission line than a two-terminal one. At present, almost all the fault location schemes for a multi-terminal transmission line are based on fundamental frequency components, i.e. voltages and currents [1–5] which are mainly determined by the fault impedance from a power source to the fault point. However, the fault impedance may change with the variation of power frequency, the line's connected system operation mode, and the arcing resistances of the fault point. Therefore, large enough deviation for the voltage and current may inevitably be produced, so the accuracy of the fault locating cannot be guaranteed. Up to now, finding an accurate fault location scheme for a multi-terminal transmission line is still a challenge.

At present traveling wave based methods are thought as the most accurate fault location schemes for transmission lines because they are immune to transmission power swings, are insensitive to fault types, fault grounding resistances, the system impedance and the saturation of current transformers in a transmission line [6]. However, they are mainly for two/three-terminal transmission lines [6,7]. Very few traveling wave based fault location schemes have been proposed for multi-terminal transmission lines. In [6], the traveling wave based fault location scheme combining the fundamental frequency components is applied to the fault location for three-terminal lines. However, it could not be extended to multi-terminal transmission lines. In [8], a single-ended traveling wave based method is used for computing the fault distance for multi-terminal transmission lines, and the fundamental frequency components are also needed, so it has the similar disadvantages to the ones in [1–5]. Furthermore, the two-ended traveling wave based method is more accurate and reliable than the single-ended traveling wave based one [7], and current traveling waves are more effective than voltage waves [9]. Considering the recent advancements in real-time data acquisition, GPS time synchronization, communication networks and signal de-noising, the authors try to use two-ended current traveling wave scheme for the fault location in a multi-terminal transmission line.

The exact arrival time detection for an initial traveling wave is the key factor for the two-ended traveling wave based method. Hilbert–Huang Transform [10–12] (HHT) overcomes the shortcomings of Wavelet Transform [13–15] (WT), so it has better effect in fault location [16]. However, Empirical Mode Decomposition (EMD) as a main step in HHT still has defects, such as the overshoot or undershoot phenomenon, in theory. A different stopping

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condition for the EMD calculation loop may produce a different set of Intrinsic Mode Functions (IMFs), and the resulting IMF may not accurately reflect the true physical nature of the analyzed data because the EMD tends to miss some riding wave on steep edge of the IMF. At the same time, Hilbert Transform may result in a negative frequency at times, which is extremely hard to interpret and is of debatable physical significance [17]. In 2008, a new adaptive time–frequency analysis method – Fast Intrinsic Mode Decomposition (FIMD) is proposed by Louis Yu Lu [17]. The FIMD method can overcome the disadvantages of EMD, and it has higher computational efficiency as well [17]. At the same time, Teager Energy Operator (TEO) can effectively reflect changes in the amplitude and frequency of the analyzed signals [18,19], and its computational efficiency is higher than Hilbert Transform. Therefore, FIMD and TEO are combined, called FIMD&TEO, in this paper, to detect the arrival time of the initial traveling wave in a faulted transmission line.

To locate a fault in a multi-terminal transmission line, the key step is to identify the faulted section which is certain in the area surrounded by the wave receiving terminals of the line. The possible faulted sections include a branch line, a *T* node or a line section between two adjacent *T* nodes. Each fault distance of a fictitious two-terminal line formed by any couple of the terminals is calculated. To reduce the possible faulted section range, the ratio of the fault distance to the line length from the local terminal to a *T* node should be calculated. If the ratio is less than 1, the fault should be in the section from the local terminal to the *T* node, otherwise it is not. A Fault Distance Ratio Matrix (FDRM) is set up to store all the ratios, and it is used to determine the faulted section. After the faulted section is identified, the fault point can be located by averaging the calculated distances which are described in Section 3.4 in this paper.

2. The new traveling wave detection method based on fast intrinsic mode decomposition and teager energy operator

2.1. Traveling wave detection method based on FIMD&TEO

The acquisition costs of current are lower than voltage, and current traveling waves are more effective than voltage waves [9]. Hence, the current traveling waves are employed for fault location in this paper. The current data are decomposed into modal components by Karrenbauer Transform, and then the aerial mode current traveling waves are used for fault location. To show the principle of the proposed current wave detection method, a single-phase grounding fault on a typical transmission line is simulated by PSCAD, and the α-mode fault current I_α is calculated from the phase current in a quarter of fundamental cycle. I_α is illustrated in Fig. 1a, and decomposed by means of FIMD. The results are also illustrated in Fig. 1a, and the instantaneous teager energy curve of the IMF1, calculated by TEO, is shown in Fig. 1b.

In Fig. 1a, I_α has a sharp change at the 203rd sampling point due to the arrival of the traveling wave, and it should have maximum energy at this point. With refracting and reflecting between the terminals and the fault point in the transmission line, the energy of the detected current wave will gradually become weaker. An obvious pulse appears on the instantaneous teager energy curve in Fig. 1b at the 203rd sampling point, which is similar to the sharp change in I_α. Therefore, the arrival time of initial traveling wave can be detected according to the first energy pulse on the instantaneous energy curve of IMF1 obtained by FIMD, and the appearance of the first energy pulse whose amplitude is larger than a preset threshold can be considered as the occurrence of a fault in a transmission line. Many simulations are also done and the wave detection method based on FIMD&TEO is workable.

2.2. Computational efficiency comparison of FIMD&TEO and HHT

FIMD can offer higher computational efficiency while it overcomes the disadvantages of EMD [17]. Because TEO does not need complex operation compared with Hilbert Transform, the FIMD&TEO method has better performance.

To investigate the computational efficiency of the FIMD&TEO method, the same α-mode fault current data used in Section 2.1 are calculated for 1000 times by FIMD&TEO and HHT respectively. The average time consumed by FIMD&TEO is 8.2063 ms, while the average time consumed by HHT is 81.7562 ms. So the efficiency of the FIMD&TEO method is almost 10 times higher than the HHT method.

3. Fault location scheme for multi-terminal transmission lines based on two-ended traveling waves

3.1. Faulted section identification rules for three-terminal transmission lines

A three-terminal transmission line is depicted in Fig. 2. After a fault occurs in the line, it is assumed that the arrival times of the initial traveling waves detected by FIMD&TEO at Terminal M1,

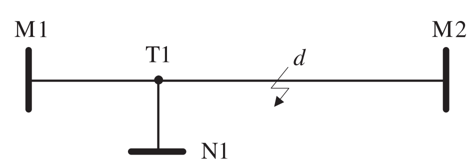

Fig. 2. Diagram of a three-terminal transmission line.

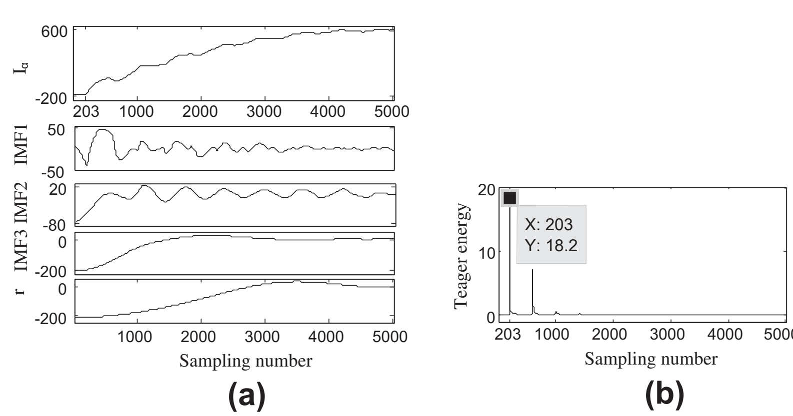

Fig. 1. (a) α-Mode current and the fast intrinsic mode decomposition results and (b) the teager energy curve of IMF1.