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A general fault location method in complex power grid based on wide-area traveling wave data acquisition

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ABSTRACT

With the development of wide-area measurement technology, it is possible to obtain the fault-originated traveling wave synchronously in a complex power grid. Based on the specialized deployment of the monitoring points and arrival time of initial traveling wave-front acquired by phase-mode transformation and wavelet transformation, this paper proposes a general method for fault-location in complex power grid. Manhattan distance is adopted to find out the accurate measuring combinations, by which the preliminary fault location is calculated. Then the accuracy and robustness of the results can be improved by the fault-occurrence time which is calculated by the information of monitoring points and grid topology relationship. All simulations are carried out in PSCAD and the IEEE 30-bus system is built in order to obtain the synchronization fault signals. The simulation result proves that the proposed method has high accuracy. The uncertainty of the measurement errors is also included in the simulation and shows that the algorithm has high robustness.

Introduction

Fault location is still being a challenging problem which related to reliability of power supply [1]. Rationally, fault location technology can be classified into two categories: (1) impedance-based method; and (2) traveling-wave-based method. The former is widely used by devices requiring low computational efforts, while the latter require accurate analysis in time-domain or frequency-domain. At present, massive proposals have been developed by many scholars according to impedance-based method: an innovative two-terminal impedance-based fault location algorithm is proposed taken into shunt capacitance effect in [2]; Chaiwan delivers a new accurate fault location algorithm for parallel transmission lines based on the distributed parameter line model, which is also a single-end method [3]. Studies on the traveling-wave-based method are increasing rapidly [4], due to the availability of synchronization measurement and high-frequency sampling: Online traveling-wave method for fault location on a cross bonded cable system using sheath currents is proposed in [5]; a universal wave-front positioning correction method on traveling-wave-based fault location algorithms is described in [6]. Synthetical utilization of impedance and transient-based spectral analysis technique is also studied in [7,8]. With the advance of communication technology, double-end fault location methods utilizing synchronized or unsynchronized measurements at both terminals of the faulted line have been employed in [9–12].

However, these methods only target on single transmission line throughout the whole power grid. TWR (Traveling Wave Recorder) is used to accurately detect the arrival time of initial traveling wave-front originated by the fault point. When one TWR breaks down, startup fails, or an incorrect arrival time of the initial traveling wave is recorded, the reliability and precision of the fault location can hardly be guaranteed. On the other hand, with the development of the Global Positioning System (GPS) technology and the Wide Area Measurement System (WAMS), fault location methods are not limited using local measurements but data acquisition over the whole network. Among research on traveling wave fault location method in wide-area system, authors of [13] have proposed the algorithm based on multi-end information. But it is not applicable in loop network. Authors of [14,15] have proposed the fault location method based on optimal deployment scheme, which has blind zone.

This paper proposes a novel wide-area traveling wave method on the basis of few TWRs deployed in the power grid. The method is applicable in complex power grid based on measurement and integration of wide-area network information. Wherever fault occurs, the general method could be realized on the basis of

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information of monitoring points and grid topology relationship. Meanwhile, fast and accuracy fault location is guaranteed and the proposed method strives to improve the accuracy and robustness.

The remainder of this paper is organized as follows: section 'Basic theory of travelling wave fault location' introduces the basic theory of traveling wave fault location; section 'Proposed fault location method' describes the proposed fault location algorithm; section 'Simulation results' presents the simulation results based on the selected deployment scheme; Finally, section 'Conclusion' concludes the paper.

Basic theory of traveling wave fault location

Traveling wave data acquisition in power grid

If the arrival time of the traveling wave can be acquired accurately in power grid already running, the fault location method could be realized further. However, two main aspects which affect the precise directly and significantly need to be considered. The first is the data synchronized sampling. The other is the arrival time detection technology. Data synchronized sampling can be obtained by using the GPS which can provide time synchronization up to 1 µs accuracy over a wide-area; TWR installed in buses can be used to detect the traveling wave and record the value of the arrival time of the initial traveling wave by the following signal processing technique [16]. Finally, date acquisition is achieved by incorporating GPS data with voltage measurements from TWRs installed at buses.

Wavelet transform is utilized in detecting arrival time of fault traveling wave. In three phase transmission lines, the traveling waves are mutually coupled and therefore a single traveling wave velocity does not exist. In order to implement the traveling wave method in three phase systems, the phase domain signals are first decomposed into their modal components by means of the Clarke's modal transformation matrices. Generally, the fault location problem is formulated based essentially on the aerial mode traveling wave. By comparing detection effect of several wavelet bases, db6 is adopted to carry out the DWT (Discrete Wavelet Transform). Arrival time of initial traveling wave-front is captured according to singularity spot time which corresponds to modulus maximum of the wavelet transform. The processing flow of the fault-originated signal is pictured in Fig. 1.

By using db6 wavelet base to decompose the fault-originated aerial mode voltage traveling wave, wavelet coefficient (WC) of level d_1 is obtained. Finally, modulus maximum of level d_1 in Fig. 2 is used to get the arrival time of initial traveling wave-front.

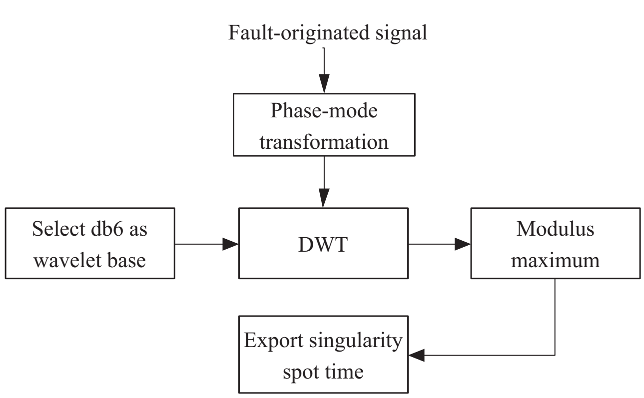

Fig. 1. Processing flow of fault-originated signal.

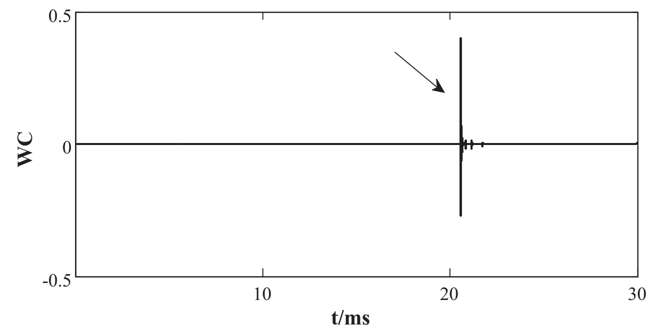

Fig. 2. Wavelet coefficient of level d_1.

Implementation of extended double-end fault location

Double-end fault location method that utilizes synchronously acquired transient signals of both ends of transmission line can locate the fault precisely. To solve the limitation that both ends of transmission lines shall deploy TWRs in application, the extended double-end fault location method is proposed [17]. As pictured in Fig. 3, TWRs are deployed at Bus X and Y, rather than Bus M and N. If fault occurs at point *f* on Line MN, the initial traveling wave will arrive at Bus X and Y, and the arrival time is t_X and t_Y. The distance from point *f* to Bus M is:

$$L_{fX} = \frac{1}{2}[L_{XY} + (t_X - t_Y)c_a] \quad (1)$$

$$L_{fM} = L_{fX} - L_{XM} \quad (2)$$

Here, c_a is the velocity of the traveling wave.

Wherever fault occurs, the formulas above could be applied as long as at least two TWRs ('a combination') contribute a shortest path that contains both ends of this fault-line.

However, the challenge is when fault is occurred close to the monitoring point n in Fig. 4, where one end of the fault line is not equipped with TWR. For such a situation, L_{fp} (the distance between fault point *f* and monitoring point p) is less than L_{fm} and n, p are utilized as the double-end of the above traditional fault location method. Obviously, blind zone exists and wrong fault location result f'' is calculated. The advantages over traditional approaches in solving blind zone, when fault is occurred close to monitoring point, are shown in section 'Calculate preliminary fault position f''.

Proposed fault location method

Calculate preliminary fault position f'

In the power grid which uses distributed parameter line model, fault-originated traveling wave transmit from fault point to monitoring points along shortest path between them. Dijkstra algorithm is adopted to calculate shortest distance between any two points in

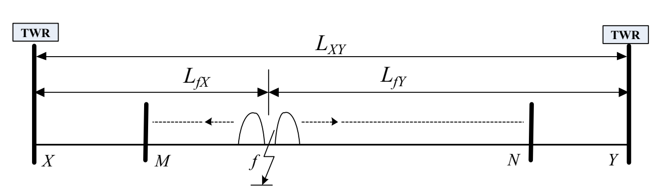

Fig. 3. Schematic of the extended double-end fault location method.