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Wide area traveling wave based power grid fault network location method

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ABSTRACT

Traditional fault traveling wave location schemes, which are based on the fault information of only one line, have lower sensitivity and reliability, especially when one or more traveling wave fault location devices (TWFLD) break down, startup fails or an incorrect arrival time of the initial traveling wave is recorded, this will result in the failure of the fault location. Based on the analysis of the propagation characteristics of the fault traveling wave in power grid, a novel power grid fault traveling wave network location method is proposed in this paper. Firstly, the topology of a power grid is analyzed, and the installation principle of TWFLD is presented. Secondly, when the fault occurs on one transmission line, the fault traveling waves travel from the fault point to the whole power grid, and the values of the arrival time of the initial traveling wave is recorded in the substations where the TWFLD are installed. Then the values of the arrival time are analyzed with the information fusion and the fault point is located by using the power grid fault traveling wave network location method. Compared to the existing fault traveling wave location schemes those are based on the fault information of only one line, all correct time information of the whole power grid has been used to calculate the fault distance in this method. Therefore, this method can achieve reliable fault location even when one or more TWFLD break down, startup fails or an incorrect arrival time of the initial traveling wave is recorded. The simulation results match the theoretical analysis well and show that the proposed location method provides not only high accuracy and reliability, but also good economy. These characteristics are beneficial to further enhancement of the practicability of the traveling wave location.

Introduction

With the expansion of power systems, rising voltage levels and increased power demands from the customers, fast fault clearing has become an important measurement to enhance the transient stability of power systems and improve the capacity of transmission lines [1,2]. Many algorithms for the traveling wave fault location have been previously investigated [3–7,1,8]. However, these methods only target single transmission line throughout the whole power grid. When one traveling wave fault location device (TWFLD) 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 communication technology of power systems, the fault location methods based on a single transmission line are not satisfied with the needs for power operation. Therefore, the construction of the fault location network, and the improvement of traveling wave fault location algorithms based on the network become increasingly important [9–11].

To solve the above problems, this paper proposes a fault traveling wave network location method based on the whole power grid. When the fault occurs on a certain transmission line, the fault traveling waves travel from the fault point to the whole power grid, and the values of the arrival time of the initial traveling wave are recorded in all substations where the fault location devices are installed. Then the values of the arrival times in different locations are analyzed according to the information fusion, and thus the fault point is located. Theoretical analysis and simulation results show that this location method provides high accuracy and reliability, even when one or more TWFLDs break down, startup fails, or an incorrect arrival time of the initial traveling wave is recorded. The method can also calculate the location of the fault point.

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Principle of traveling wave network location

Analysis of traveling wave propagation characteristics in power network

A short circuit fault on a power transmission line can generate the transient voltage and current signals over a wide frequency range. These signals travel away from the fault point in both directions along the transmission system at a velocity close to the speed of light [12,10,13]. It has been long recognized that the actual fault position could be calculated on-line if the transient signals could be time tagged at the key points on the traveling wave propagation network. The arrival times recorded at the different substations are highly correlated to the propagation time of the interconnecting transmission lines.

The TWFLDs installed in all substations can be used to detect the traveling wave and record the values of the arrival time of the initial traveling wave. The Global Positioning System (GPS), with its ability to provide time synchronization with an accuracy of 20 ns over a wide area, acts as an ideal tool for TWFLD to produce a time stamp on the reception of a traveling wave.

Principle of fault location

After collecting information on the state of the circuit breaker and recording the values of the arrival time of the initial traveling wave, the selected fault location master station firstly determines the fault line and eliminates incorrect arrival times of the initial traveling wave. This is followed by using all the correct values of arrival times of the initial traveling wave to calculate the fault location. The detailed procedure is shown as follows:

(1) Install TWFLDs at various substations in the whole power grid, and set the fault location master station (selected randomly and usually the substation with more adjacent substations).
(2) After a fault occurs, the TWFLD detects the transient signal of traveling waves, records the state of the circuit breaker and the values of the arrival time of the initial traveling wave, and then sends the fault information to the fault location master station.
(3) According to the state of circuit breaker and the arrival time of the initial traveling wave, the fault location master station determines the fault line, and eliminates all the incorrect arrival times of the initial traveling wave.
(4) The fault location master station takes one end of the fault line as the reference end, and divides all the correct values of the arrival times of the initial traveling wave that were recorded at both ends of the fault line into two arrays. Then the fault location master station takes one arrival time from each of the two arrays respectively: t_i and t_j. It then calculates the distance from the fault point to the reference end, and saves the distance as d^*_{ij}.
(5) The fault location master station calculates the weight (R_i) of d^*_{ij}, and the fault distance as in formula (1).

$$d_c = \frac{\sum_i (R_i \cdot d^*_{ij})}{\sum_i R_i} \qquad (1)$$

Determining the fault line

When a fault occurs, circuit breakers at both ends of the fault line will trip, whereas circuit breakers on other lines do not trip. According to the state of circuit breakers detected by TWFLDs, the fault line can be identified. Moreover, since the initial traveling wave travels from fault point to the whole power grid, the TWFLDs at two ends of the fault line will be the first to detect the initial traveling wave signal. Based on the arrival order of the initial traveling wave at different substations, the fault line can be identified. If the state of circuit breaker is wrongly detected or the arriving time is recorded incorrectly, the fault line identification can be realized by combined using of arrival time of initial traveling wave and state of circuit breakers.

Eliminates incorrect time values

Considering the existence of high frequency interference signals and switching operation wave, some TWFLDs may record the incorrect value of the arrival time of the initial traveling wave. Therefore, it is necessary to distinguish and eliminate the incorrect traveling wave arrival time from all the time information recorded by TWFLDs.

Assuming that the arrival time recorded at substation i is t_i, and the arrival time recorded at adjacent substation j is t_j. The differential value between t_i and t_j can be calculated as formula (2).

$$t_{ij} = |t_i - t_j| \qquad (2)$$

Assuming the number of substations connected to substation i is Z_i, and the number of substations, whose time meets formula (3), is more than $Z_i/2$, then the value of the arrival time recorded at substation i can be assumed to be correct. When the number is less than $Z_i/2$, if t_j is correct arrival time, t_i is also correct arrival time on condition that formula (3) is right; or t_i is incorrect arrival time.

$$\left| t_{ij} - \frac{l_{ij}}{v} \right| < t_{set} \qquad (3)$$

In the above formula, l_{ij} is length of transmission line between substation i and substation j, v is the speed of traveling wave, t_{set} is time error allowance, whose value is $0 < t_{set} < 1$ μs.

Calculating fault distance d^*_{ij}

All the correct arrival time of initial traveling wave recorded at two ends of fault line are divided into two arrays. Taking arrival time from the two arrays respectively, one is t_i, and the other is t_j. The master station calculates the distance of fault point according to double terminal method of traveling wave fault location.

$$d_{ij} = [(t_i - t_j) \cdot v + L_{ij}]/2 \qquad (4)$$

In the above formula, d_{ij} is the distance of fault point to substation i, L_{ij} is the shortest distance through fault line from substation i to substation j. The shortest path between substation i and substation N (one end of fault line) is L_{in}, and then d_{ij} can be converted into d^*_{ij}, which is the distance of substation N from fault point:

$$d^*_{ij} = |d_{ij} - L_{in}| \qquad (5)$$

Setting weight of d^*_{ij}

Assumed that the number of substations between substation i and substation j in the shortest distance is n (including substation i and substation j), then the master station sets the weight R_i for d^*_{ij} is $1/(n-1)$.

Installation principle of TWFLDs

Fault locating method based on the whole power grid traveling wave information has high fault-tolerance performance, but all substations installed TWFLDs is not economic. So, part of substations can be selected to install TWFLDs on condition that it does