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Automated double-ended traveling wave record correlation for transmission line disturbance analysis

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ABSTRACT

Automating analysis and correlation of traveling wave data of the same fault event from two terminals of a transmission line is essential for automated double-ended traveling wave based fault location and disturbance analysis. This paper presents a traveling wave data detection and correlation matching method. This method is capable of detecting disturbance events on transmission lines obtained at different terminals based on synchronized data. The traveling waves caused by the same disturbance tend to be captured by multiple recording devices at different observation points, resulting in a significant change in only a few channels for each captured record. The waveform pixel ratio and the featured line of waveforms are extracted based on the possible disturbances that can be identified and recorded at a local database. The correlated searching and feature matching is executed for the remote record database. The correlated traveling wave data for disturbance events can be acquired and then used for locating the event and further analysis. The proposed method is able to extract the effective traveling wave segment corresponding to the same disturbance event from the database at different observation points. This facilitates the automated double-end location. Test results based on field data have demonstrated the effectiveness of the proposed method.

1. Introduction

Automated transmission line fault location speeds up the identification and repair of faulted components, and expedites the system restoration process [1–3]. Fault location can be based on voltage and current phasors, or voltage and current traveling waves initiated by faults [4,5].

Traveling wave based fault location is an important technique used to accurately pinpoint faults on transmission lines. It has the advantage of high accuracy, immunity to power swings and CT saturation, and insensitivity to various fault conditions such as fault type, fault inception moment, and fault resistance. Therefore, it attracts the increasing interests of researchers and engineers within the field [4,6,7].

Compared with single-ended traveling wave fault location method, the double-ended method is usually more reliable and more widely applied in AC transmission networks and in HVDC systems because it merely needs the initial surge generated by the fault. This essentially avoids the difficulty in recognizing the subsequence traveling waves [8]. The double-ended method also has the potential to locate many forms of disturbances besides the usual lightning strike occurrence [9].

Much research has been done related to the traditional double-ended traveling wave fault location in the following aspects: (1) Determining the arrival time of the initial surge [10–12]; (2) Extending the application of the traditional two-terminal method to new types of lines such as underground cables [13–15], teed circuit lines [16] and multi-terminal DC lines [17–19]; (3) Wide-area traveling wave fault location and optimal placement for achieving observability [20–23]; (4) The utilization of two-ended unsynchronized data [24]. These methods have greatly improved the traveling wave fault location technique. However, all of the above methods run on the precondition that the records containing the initial traveling waves induced by the same fault have already been selected and paired correctly.

In practice, traveling wave recorders are usually set with a low threshold to capture as many fault traveling waves as possible for an event analysis. This reduces the chance of missing true fault events, but also increases the amount of unwanted noise-triggered data to be recorded. Due to the vast volume of data, it is challenging to automatically identify the records from the two terminals,

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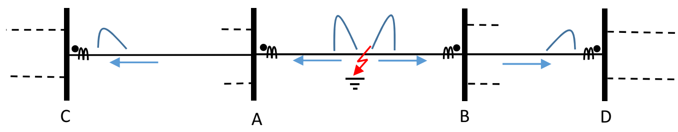

Fig. 1. Diagram of wide area double-ended traveling wave fault location.

which include the initial traveling waves related to the same fault [1]. Although the information provided by protective relay devices provides some clues to the approximate fault inception time, the initial traveling wave records cannot be simply determined by the earliest timestamp for two reasons. First, a fault usually includes a series of sub-events including fault occurrence, fault clearance, and autoreclosure. It is possible for the recording devices to miss the fault occurrence sub-event. Second, non-fault triggered data may be recorded just before the fault occurrence. Moreover, the acquired position of non-fault lightning strikes is extremely helpful for inspection and maintenance. The traveling waves caused by lightning strokes, if captured, should be used for event locating. However, the location process cannot be implemented automatically at this time because of their reliance on tripping of protective relays, which cannot detect this kind of event. Therefore, it is necessary to explore the active and effective double-ended traveling wave data identification and correlation matching method.

Communication networks and global positioning systems based time synchronizations are increasingly deployed at modern transmission substations, and thus more and more double-ended traveling wave systems have been put into practice. Massive field data can be acquired and used to investigate the data extraction method according to the features of actual data. In this paper, by analyzing the features of actual field data, a waveform feature based double-ended traveling wave data correlation approach is proposed. The method can initially identify true fault and disturbance records at one substation and directionally search and extract the correlated record data from the remote substation, both of which are necessary for the application of double-ended location for fault and disturbance events without protection information.

The paper is structured as follows: the traveling wave records of disturbances are introduced and their features are analyzed in Section 2. Based on the obtained features, a novel double-ended traveling wave data correlation approach is proposed in Section 3. Section 4 presents test results based on field record data and discussions about the feasibility of the proposed method in various scenarios. The conclusion is made in Section 5.

2. Disturbance events observed by traveling wave fault location devices and their feature analysis

2.1. Disturbance events observed by traveling wave fault location devices

Traveling waves are generated by many kinds of disturbances such as faults, lightning strikes, and the operations of circuit breakers on lines. They propagate toward the two terminals along the line at a constant velocity. The disturbance location can be calculated by double-ended locating methods, as long as the initial traveling waves and their arrival times are captured and determined by traveling wave recorders at both sides. Furthermore, wide area double-ended location can be implemented if the initial traveling waves are strong enough to be captured by the recorders on the end of the adjacent lines [21]. As shown in Fig. 1, fault location may be calculated based on records obtained at observation points A and B, or C and D, where using data at C and D is termed wide-area double-ended traveling wave fault location.

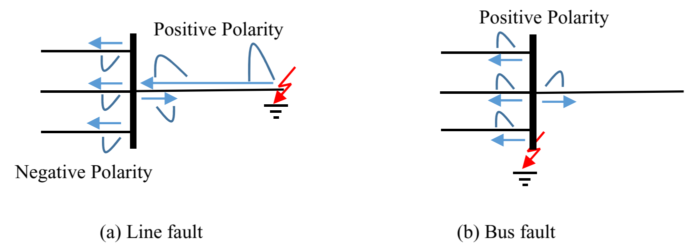

Fig. 2. Amplitude and phase currents traveling waves of faults.

This paper focuses on analysis of current traveling waves. From the perspective of traveling wave recorders, any unplanned incidents on transmission lines that are able to trigger traveling wave recorders and have the practical need of locating the traveling wave source will be referred to as disturbance events in this paper. Faults and lightning strikes on the monitored lines and adjacent lines all belong to disturbance events.

2.2. Feature analysis for observed traveling waves caused by disturbances

A recording device at a substation commonly has a number of channels for monitoring the multiple lines connected to the substation. A disturbance such as a fault usually occurs on an individual line, and has the characteristics of short duration and fast attenuation, which causes a rapid change in the waveform shape on only a small number of channels in a short period of time. Suppose a three-phase fault occurs on one line of the substation. Then, only three channels will see rapid change in waveforms. Moreover, the feature of the traveling waves for the same disturbance event observed at different points should satisfy the principle of traveling wave propagation.

For convenience of illustration, the transmission line along which the traveling wave caused by the disturbance propagates to the bus of the monitored substation is called dominant line. And, the phases on which the disturbance occurs is called the feature phase. The polarity is defined as positive if the rapid change of the traveling wave's wavefront is upward, and vice versa. If a disturbance occurs on a line, on the premise of consistent wiring polarities of CTs, the incident and reflected current traveling waves of the dominant line will be superimposed with same polarity at the monitored bus. This makes the amplitude larger, while the amplitude of traveling wave currents transmitting to the other lines remains low and with the opposite polarity [25], as is shown in Fig. 2(a). Therefore, the dominant line can be identified based on this characteristic. If a disturbance occurs on the bus, the amplitude and polarity of the traveling waves on all the lines are consistent, as is shown in Fig. 2(b). Bus fault can be identified according to this feature.

In summation, the traveling waves caused by the disturbance tend to be captured at multiple observation points within a certain range. At each observation point there is a significant change of short duration in waveforms on a few channels. The current traveling waves captured at different observation points contain information on the direction and position of the disturbance. These characteristics enable extraction of the correlated disturbance records from massive datasets observed at different points, and further the analysis and location of the disturbance.

3. Proposed method

Based on the above analysis, this section presents a data correlation method for identification of the disturbance events from different observation points. The method first detects the candidate disturbance data in the local database according to characteristics