Research on μPMU based fault location for active distribution network

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Abstract. Accurate fault location is helpful to improve the stability of power distribution network. With the integration of distributed generations and electric vehicles, the traditional distribution network gradually became the active distribution network, which requires new technologies for fault location. The arise of high-precision micro phasor measurement unit, termed μPMU, satisfies the need of active distribution network. In this paper, a new method based on μPMU is proposed to locate the fault in the active distribution network. The candidate faults are located by the voltage and current information of μPMU at one terminal. To get the actual fault location, the pseudo fault locations are eliminated by phase difference of μPMUs at two terminals. The simulation results show that the location method has high position accuracy, whether in traditional distribution network or in active distribution network, less than 1%. And can satisfy different types of fault with simply installing μPMUs at the two terminals of the active distribution network.

Introduction

Accurate fault location is helpful to repair fault, reduce outage duration and operating cost, expedite system restoration, and improve the stability of the distribution network. With the integration of distributed generations and electric vehicles, the traditional distribution network appeared some problems such as the overvoltage and the bidirectional flow. In order to deal with these problems, the traditional distribution network has gradually changed from passive mode to active mode, and gradually developed to active distribution network [1]. With these changes, the conventional overcurrent relays will be inadequate for active distribution networks and have been creating challenging needs and opportunities for new models, tools, and technologies for fault location.

Phasor measurement unit (PMU) is based on the global positioning system (GPS) and can provide voltage, current and frequency signal with high accuracy, high sampling rate and time scale. Because of its phasor characteristic, the synchronization of the clock and the real-time performance of data upload, it becomes the basic means for the dynamic monitoring of the power network and it is also widely used in the fault location of power transmission. But PMUs are almost exclusively used in high voltage power transmission. Compared with the power transmission, active distribution network has more challenging.

First, it has shorter line than power transmission, which requires much higher precision – meaning more precise time-stamping and shorter latencies in every step of the transfer of the measurement.

Second, its measurements will be fraught with much more noise from which the signal must be extracted. This is simply due to the proximity of a large number of different devices connected per mile of circuit at the distribution level, including loads as well as utility switchgear, transformers, capacitors, etc., that may introduce harmonic distortion and transients.

Third, the economic value of power transmission means that larger investments can be justified, with less pressure on the acceptable costs of instrumentation as well as data transmission and concentration, which is active distribution network unable to satisfy and requires lower cost.

With above reasons, PMU is unable to be directly applied to the active distribution network. Therefore, in fund of the United States energy support program (ARPA-E), the United States University of California in collaboration with the United States Power Standards Laboratory (PSL) and the United States Berkeley Laurence National Laboratory (LBNL) propose a high precision phasor measurement unit for active distribution network, termed μPMU [2]. Compared with PMU, it has higher phase resolution (Accuracies of PMUs can only vary by ±1˚, while the proposed μPMU can discern angle differences to an accuracy of better than ±0.05˚), function of power quality analyzer and lower cost, can be good to meet the requirements of fault location in the active distribution network.

On that basis this paper proposes a new method based on μPMU to locate the fault in the active distribution network. The candidate faults are located by the voltage and current information of μPMU at one terminal and the candidate faults location is determined by single terminal impedance based method. To get the actual fault location, the pseudo faults are eliminated by phase difference of μPMUs at two terminals. This method is simple, easily operated and can satisfy different types of fault with simply installing μPMUs at the two terminals of the active distribution network. It has a certain economy and practicability.

μPMU based fault location method

The proposed method consists of two steps to find the actual fault location [3]. In the first step, candidate locations are found using μPMU measured at one terminal by iterating every line segment. In the second step, the actual fault location is identified by the voltage phase difference, which is calculated using μPMUs measured from two terminals.

A 15-bus feeder system shown in Fig. 1 is used to illustrate this method. This feeder has a main circuit, five lateral branches, and one distributed generators (DGs) connected at bus-3. Two μPMUs, installed at bus-1 and bus-5, provide synchronized voltage and current phasor measurements. The knowledge of network topology, line parameters, and load models are known.

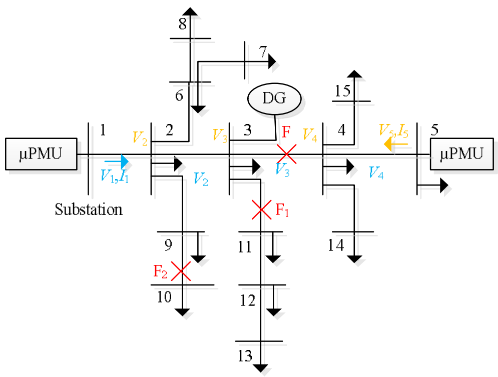

Fig. 1 One-line diagram for a 15-bus distribution feeder

Find candidate faults. For a fault at location “F” in Fig. 1, on line3–4, to find the candidate locations, the search starts from bus-1. First, the fault distance is calculated based on apparent impedance [4] to check if the fault is within the segment of line1–2. Next, if the fault is not on this line, the voltage phasor at bus-2 is calculated in terms of the voltage drop which includes the capacitance effect. Lateral branches, such as line2–6, line2-9 and line2–3, are handled by assuming one of them is faulted, and then the current flows on healthy lines are calculated using Thevenin equivalent circuits. For this case, the assumption is that line2–3 is faulted. The Thevenin equivalent circuit of lateral branches from bus-2 to bus-6 and bus-9 is then the self-impedance of the bus impedance matrix and open-circuit voltage at bus-2. For passive networks, only the equivalent impedance is utilized. The aforementioned procedures are repeated, iterating forward over every segment, until the calculated distance to the fault matches with a particular line segment. In this case, three candidate locations, designated as F, F1, and F2 on line3–4, 3–11 and 9–10, respectively, are found.

Eliminate pseudo faults. To eliminate the nonfaulted lines, voltage and current phasors measured at bus-1 and bus-5 are used. Using the superposition principle, the network during a fault can be decomposed into a prefault and "pure fault" network [4], as shown in Fig. 2. So, we can calculate the voltage phasors ΔV_G and ΔV_H in "pure fault" network from µPMUs at two terminals. Using the voltage phase difference (the distance of one cycle 2π is vT = v/f) of µPMUs at two terminals bus-1 and bus -5, we can get the actual fault location and eliminate the pseudo faults.

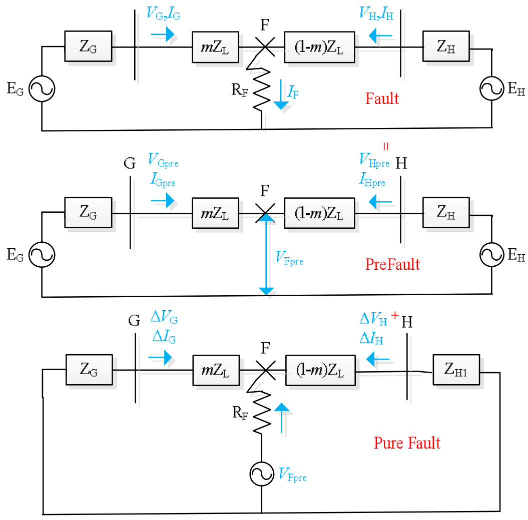

Fig. 2 Decompose of the fault circuit

For a fault on the main circuit covered by two measurement points, for example, line1–2, 2–3, 3–4, and 4–5 in Fig. 1, the value of the fault impedance has no impact on the calculated location's accuracy. This is because of the availability of remote current measurements. When given one-terminal measurement for a line segment (e.g., a fault occurring on line6–9), an iterative method is used to eliminate the effect of fault resistance.

A sensitivity analysis is conducted. The results indicate that the impact of resistive uncertainties of line parameters on estimated distance is in the range of 0.01. The measurement error has a linear impact on estimated distance. For example, a 1% TVE in voltage and current phasors can result in up to 2% error in estimated distance.

Modeling and method validation

The 15 bus feeder system, shown in Fig. 1, is used to demonstrate the efficacy of the proposed fault-location method. The distribution network is an 11kV/3MVA rural power distribution network, the DG capacity is 0.6MVA [5].

It is modeled with MATLAB/Simulink, in which DG is a 0.6MW wind farm using asynchronous generators and exporting power to an 11-kV distribution feeder. A six-cycle three-phase fault is programmed on line3-4. µPMU is simulated with "zero crossing" detection method to achieve synchronous measurement of frequency and phase and use the peak-to-peak detection to determine amplitude change, when the change of value in peak-to-peak is large, we think there is a change in the amplitude and use FFT in an entire cycle to calculate the amplitude and the real time change of phase. The model is discretized using a 50µs sample time. Simulation time is 0.1s and fault happens at 0.06s-0.07s.

From the model simulated, we can get the µPMU data in CSV file format. And then fault is located by the µPMU based fault location method mentioned above. Fault distance m is calculated and then we can get the location accuracy Er using the formula as Eq. 1 shown. Simulation result of location accuracy with different fault types is shown in Table 1.

$$E_r = \left| \frac{m - m_{real}}{L} \right| \times 100\% \quad (1)$$

In which, m is the calculated fault distance; m_{real} is the real fault distance; L is the length of fault line.

Table 1 Simulation result of location accuracy with different fault types

	Fault type	Location accuracy E_r(%)		Fault type	Location accuracy E_r(%)
Traditional distribution network without DG	Single phase to earth	0.32	Active distribution network with 0.6MW wind farm	Single phase to earth	0.43
	double phase to earth	0.37		double phase to earth	0.44
	double phase short	0.55		double phase short	0.86
	three phase to earth	0.46		three phase to earth	0.66

The simulation results show that the location method has high position accuracy, whether in the traditional distribution network or in the active distribution network, less than 1%. And can satisfy different types of fault with simply installing µPMUs only at the two terminals of the active distribution network.

Conclusions

In this paper, the high-precision micro phasor measurement unit, µPMU, is applied to the fault location in the active distribution network, which is the future of distribution network. Compared with PMU, it has higher phase resolution, function of power quality analyzer and lower cost, which is suit for active distribution network.

A new method based on µPMU is proposed. The proposed method consists of two steps to find the actual fault location. In the first step, candidate locations are found using synchrophasors measured by µPMU at one terminal by iterating every line segment. In the second step, the actual fault location is identified by comparing the voltage phase difference from µPMU at two terminals.

The simulation results show that the location method has high position accuracy, whether in the traditional distribution network or in the active distribution network, less than 1%. And can satisfy different types of fault with simply installing µPMUs only at the two terminals of the active distribution network.

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