Single-phase ground fault location technology research and application based on transient recording wave

YIN Hui¹, SHI Changkai¹, LI Baikui¹, GUAN Shilei¹ and Liu Yue²

¹China Electric Power Research Institute, Beijing, China
²Tianjin Haoyuan Huineng Technology Co., Ltd., Tianjin, China
E-mail: 2034946676@qq.com

Abstract. Fault location is an important part of distribution automation. Aiming at the problem of single-phase grounding fault detection, a fault location system based on transient recording technology is proposed. Compared with the advantages and disadvantages of the traditional single-phase ground fault detection method, the single-phase ground fault location application based on transient recording is proposed. The proposed method is not only theoretically verified in the simulation of the distribution network system, but also applied to the operation of fault location network in the true test field, which verifies the effectiveness of the proposed method.

1. Introduction
The distribution network is at the end of power system, which plays an important role in the transmission of electric energy. Whether the whole power system can run stably and safely depends on its operation condition. Most of the 6 ~ 35 kV distribution systems in China are small current grounding systems, and the neutral point is grounded by arc suppression coil or ungrounded. About 80% of the total faults are single-phase grounding faults [1]. When grounding occurs, because the system still maintains the three-phase symmetrical characteristic and can continuously supply power to users, so the power grid is allowed to continue to operate within 2 hours even if single-phase grounding occurs. However, if the power grid runs for a long time after the fault, it will lead to the damage of substation equipment, and may result in personal and property losses. In addition, the non-fault voltage rises after the fault, which may break through the insulation protection layer and even cause short circuit fault [2], seriously affecting the safe operation of the distribution network. The types of single-phase ground fault are complex and varied, because the steady-state current of the fault is very small, the arc is unstable, and the noise interference in the field, the detection is very difficult [3]. Therefore, the accurate and fast location of fault points, shortening the outage time, affects the power supply quality of users and affects the reliability of distribution network operation. The demand of social development must be to improve the reliability of single-phase grounding fault detection. Therefore, combined with signal processing, wireless information communication and artificial intelligence technology, this paper proposes a single-phase ground fault location system based on transient wave recording technology. The method can accurately reflect the current amplitude of the line and the transient changes of current and voltage, provide rich operation data for ground fault analysis, and can also provide early warning for abnormal state of the line, carry out inversion for complex fault process, and effectively improve the automation level of the distribution network.

2. Traditional detection method of grounding fault
Fault indicator technology (abbreviated as indicator) is widely used in fault location system, bringing revolutionary changes. At present, there are mainly three types of single-phase grounding detection methods for fault indicators: transient method, steady-state method and signal injection method [4].

2.1. Steady state method
The indicator of zero sequence current method locates the faulty line by collecting the zero sequence current of the line current signal to be greater than the set value, and the direction of the current flowing through the indicator is opposite to the direction of other lines [5], thereby locating the faulty line. This method is commonly used in neutral point ungrounded systems, but in actual operation, when the three-phase asymmetry of the line brings a large zero-sequence current, the method will also cause misjudgment. Different from the zero sequence method, the principle of the fifth harmonic method indicator is mainly based on the same characteristics as the fundamental waves of power frequency in the ungrounded system [6]. The method reduces the compensation effect of arc suppression coil to a minimum, but it is affected by uncertain factors in actual operation, such as the position of nonlinear load, the line impedance, etc.

2.2. Transient method
The indicator of first half wave method uses the fault transient information to judge the ground fault. Find out the line where the transient current and the transient voltage are opposite in the direction of the first half of the wave when single-phase grounding occurs, and locate the line as the fault line for alarm indication. The method can detect a single fault point and a relatively simple ground fault process. However, the criterion is based on the assumption that the fault occurs at a phase voltage of 90 degrees. The current and voltage characteristics are very short and affected by the line parameters [7]. In practical application, this method is not suitable for locating the fault point.

2.3. Signal injection method
The indicator of the signal injection method mainly detects the line characteristic coded signal according to the change of the induced electric field. The signal source judge the ground fault and inputs a specific coded signal to the bus after the ground fault occurs [8]. For the small current grounding system, the method is relatively stable and is a common grounding detection scheme. However, in practical applications, the injected signal strength is limited by the capacity of the voltage transformer. When the operation mode of the distribution network changes, it is also possible for multiple signal sources to input signals at the same time, resulting in long voltage fluctuation at the neutral point and even causing phase-to-phase short circuit fault [9].

3. Transient recording fault location system

3.1. Transient wave recording technology
Transient wave recording technology is a combination of fault indicator technology, signal processing, wireless information communication and artificial intelligence technology. Through indicator, it carries out high-precision sampling of line current and ground electric field, tracks load current trend and ground electric field change, and monitors the running state of line in real-time. When the line state changes abnormally, the high-frequency sampling and recording is automatically triggered, which is not less than 4kHz. With the help of high-precision wireless synchronization technology, the synchronization time of three-phase recorded data is guaranteed to be less than 100μs, providing rich and accurate transient information for ground fault detection. The intelligent analysis will be carried out by three-phase waveform data of the line or the change of the synthesized zero sequence current. The ground fault line is positioned such that the induced electric field of the line drops obviously while the zero sequence current has obvious mutation and is larger than a certain value.

3.2. Transient recording fault locating system
The transient wave recording fault location system consists of indicator and power distribution master station. The indicator includes acquisition unit equipment and collection unit equipment. The positioning schematic diagram is shown in figure 1. The acquisition unit is the core sensing part of the system. According to the distribution network wiring diagram, the acquisition unit is installed on the branch line of the distribution line and coded address, which is used for labeling in the geographic information system (GIS) of distribution master station. The collection unit serving as a bridge between the collection unit and the distribution master station is correspondingly installed on the telegraph pole at the branch, and receives the state information, fault, recorded wave data and other information from collection through a short-distance wireless communication mode. The use of the general packet radio service (GPRS) technology facilitates the communication between the collection unit and the distribution master station, and uploads recorded wave files including synthesized transient zero sequence current, electric field waveform and other information. The master station constructs a network model according to the coded information of the installed monitoring points, and detects the state information array of each node. In case of fault or abnormal state, each monitoring point will actively send a recording file. The master station will firstly analyze the characteristics of zero sequence current of each monitoring point according to the zero sequence current method, and select the network nodes with large zero sequence current to locate the fault lines. According to the network model comparison table, the entire network topology is simplified to the network model of the fault line, and then the nodes in the simplified model are analyzed in detail for single-phase current waveform, and the fault phase is determined according to the characteristics of the electric field waveform that the electric field of the fault phase drops and the electric field of the normal phase rises. Because the zero sequence current increment at the position before the fault point is larger than that after the fault point, the zero sequence current change critical point is finally screened out from the indicator of the fault phase, and the precise location of the fault point is displayed on the geographic background of GIS. According to this information, the maintenance personnel can quickly get to the fault area for troubleshooting.

![Figure 1. Schematic diagram of fault location system.](image)

4. System verification
In order to verify the effectiveness of the proposed fault location system in single-phase grounding fault detection, the power system simulation software platform and the actual field line operation are respectively used for verification.

With the help of electromagnetic transient simulation software (PSCAD), several distribution network models with different neutral grounding modes are built to simulate and monitor the transient waveforms before/after the ground fault line, normal line and fault point. By modifying the grounding resistance parameters, the simulation of metallic, small resistance and high resistance ground fault is realized. Taking a single radiation grid structure as an example, the simulation model is shown in figure2, and a 10kV neutral point ungrounded system model with three outgoing lines L1-L3
is designed. Among them, the transmission line coupling model (PI) is used for short line simulation, and the model at the end of the line is used for load simulation. Ground fault simulation test of 800 ohm grounding resistance is carried out for phase A of L3 line. As shown in figure 3, it can be seen from the L3 electric field waveform diagram in part (a) that the fault occurs at the moment when the phase A voltage is 45 degrees, the phase A electric field $U_a$ decreases, and the electric fields of the normal phases $U_b$ and $U_c$ increase. In part (b), the zero sequence current $I_0$ of the normal line L2 and the fault line L3 both have abrupt changes at the time of fault, and the zero sequence current of L3 is greater than L2’s, while the abrupt changes of $I_0$ are in opposite directions. The waveform directions of L3’s zero sequence voltage $U_0$ and zero sequence current $I_0$ are also opposite. Similarly, comparing and analyzing the transient output results of simulation waveforms of other grounding resistances and angles, it is found that the current and voltage of the fault phase have the above obvious transient characteristics in the ground fault is different from the non-fault line. Therefore, it is theoretically feasible to detect ground detection by wave recording.

![Figure 2. PSCAD simulation model.](image)

![Figure 3. Waveform of line.](image)

The system is also used in the real test field of the small current grounding system to verify the fault location system. As shown in figure 4, indicators are respectively installed on the three lines of 10kV ungrounded system, i.e. No.43 indicator is installed on No.1 pole of zhenpei line I, No.42 indicator is installed on No.1 pole of zhenpei line II, No.45 indicator is installed on No.5 pole, and No.40 indicator is installed on zhenpei line III. After the line is running normally, a ground fault experiment with a grounding resistance of 3kΩ is carried out on phase A of the line through switch control at the
experimental grounding point of Zhenpei II line. When a ground fault occurs, the indicator starts recording according to the sudden change of the induced electric field, synthesizes the three-phase current data into a zero sequence waveform, and uploads it to the distribution master station. The distribution master station receives the waveform files uploaded by all line indicators and analysis the waveforms. The waveforms of zero sequence current \( I_0 \) and zero sequence voltage \( U_0 \) are shown in figure 5. It can be seen that the zero sequence currents waveforms of No.42 indicators in part (a), No. 45’sin part (b), No. 43’sin part (c) and No. 40’sin part (d). The waveforms of No.42 and No.45 have obvious abrupt changes compared with the waveforms of other indicators, and the directions are opposite. In addition, the zero sequence current of No.42 is greater than No.45’s. The master station gives an alarm prompt for ground fault through complex network topology analysis, and locates the fault area between No.42 and No.45 indicators of Zhenpei II line. It can be seen that the position result of the operation test is consistent with the theoretical verification of the simulation software platform, and the fault zone can be determined by comparing the direction and magnitude of zero sequence current of each line through various algorithms and combining the change of electric field.

5. The end
The requirement of high reliability of power supply will surely bring users' attention to single-phase grounding fault location technology. According to the characteristics of the grid structure in our country, after analyzing various ground fault detection principles and comparing their respective advantages and disadvantages, this paper proposes a single-phase ground fault location method based
on transient wave recording technology. This method can obtain accurate line operation parameters and fault transient informations, restore the change process of current and electric field, not only realize ground fault judgment and rapid fault location, but also can carry out early warning for abnormal states. As a new method of ground fault detection, the relation criterion of current and voltage transient waveforms under different grounding conditions still needs to be improved and optimized by on-site measured.

6. References
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