Research on Fault Waveform Recording Testing of Single Phase to Earth for Distribution Line Fault Indicator

Hui Yin*, Baikui Li, Jie Chen, Lingyun Gu, Zhe Wang and Jingjing Bao

China Electric Power Research Institute, Beijing, China
*E-mail: yinhui@epri.sgcc.com.cn

Abstract. To evaluate the recognitional capacity of single-phase grounding fault based on transient recording method in distribution system, the corresponding test method about fault waveform recording is presented for distribution line fault indication. The principle and implementation process of transient recording method is introduced. Ten 10 key indexes are selected from typical characteristic signals of earth fault, and a similarity comparison method of fault waveforms is designed. The proposed method is verified by laboratory tests, which shows its feasibility and effectiveness for test of the recognitional capacity of single phase to earth fault.

Keywords: distribution line fault indicator; fault waveform recording; performance testing; single phase to earth fault

1. Introduction

Distribution network is the end of the power system, the stability and safety of the whole power system depends on its operation [1-2]. Distribution network fault location is an important part of distribution automation, which affects the reliable operation of distribution network [3-4]. From the initial rely on relay protection device to determine the fault location, to the use of circuit breakers, load switches, boundary switches and fault indicator for fault isolation [5], and then to the wide application of distribution line fault indicator, promote the development of distribution network fault location technology [6]. According to statistics, single-phase grounding fault accounts for about 60% ~ 80% of the total faults in 10kV distribution network [7-8]. Due to the single-phase grounding fault in non-effectively grounded system, the steady-state current signal is very small, the fault arc is unstable and other factors. Moreover, the fault indicator is affected by the power grid operation, environmental electric field, noise and other interference factors, so it is very difficult to accurately detect the grounding fault [9-10]. For this reason, domestic and foreign researchers for this technical problem, according to the use of different signal is divided into passive and active two kinds [11]. The former mainly uses the fault characteristics of distribution line operation signal after single-phase grounding, while the latter, by increasing the fault current, is easy to monitor and collect the fault signal to complete fault detection and location.

At present, transient recording is mainly used in distribution line fault indicator which is known as transient record type fault indicator (TRTFI) to realize single-phase grounding fault detection. Compared with the traditional distribution line fault indicator using applied signal method, transient characteristic method and steady-state characteristic method, it has the characteristics of high measurement accuracy, accurate fault identification, fault process traceability, etc. it has been widely concerned by power supply companies, and has been widely installed and applied in distribution lines, which improves the distribution automation coverage and reduces the operation and maintenance...
workload of distribution network [12].

Due to transient recording can collect and record the correct discriminant single-phase grounding fault and fault waveform is directly related to the quality, to ensure the product quality based on the detection method of TRTFI qualified and reliable performance, this article through the analysis based on the transient recording of single-phase grounding fault detection principle and function realization process, selection of 10 fault wave record accuracy key indicators, this paper discusses the fault waveform similarity comparison method, this paper put forward a system based on fault indicator of single-phase grounding fault identification capability test method. The feasibility and effectiveness of this method are proved by practical test and application.

2. Analysis of distribution line fault indicator

2.1. Principle of single-phase grounding fault identification

The transient record type fault indicator is installed on the distribution overhead line and consists of three acquisition units and collection units. It has the functions of monitoring the line operation parameters, detecting and indicating all kinds of grounding and short trouble, etc., and supports sending the line operation information and waveform to the main distribution station.

Fig. 1 is the schematic diagram of single-phase grounding fault detection based on transient recording. Combined with the line topology, the detection and location of single-phase grounding faults are realized by comparing the difference of transient characteristics of zero-sequence current waveforms on different lines, that is, the waveforms of fault lines and non-fault lines are in opposite directions, the waveforms before and after the fault points are not similar, and the waveforms between non-fault lines and before and after the fault points are similar [7]. Based on wireless synchronization timing and fault trigger sampling wave record technology, each phase sequence acquisition unit will be collected on the fault signal to the collection unit, the latter waveform and waveform synthesis of transient zero-sequence current, is converted into a standard wave record file far to the distribution center, by comparing with the busbar fault indicator which record waveform, judge the fault section, then sends a command to the fault point upstream of fault indicator which indicates a fault in the form of flash.

2.2. Single-phase grounding identification process

Fig. 2 shows the realization process of ground identification by transient recording. When TRTFI collects a sudden change in line current or phase electric field intensity, and the sudden change value is greater than the set threshold value, the collection unit of the same group can be triggered synchronically to start fault recording. Collection unit receives the uploading of the fault line and waveform, synthesis of zero-sequence current waveform, and gave the distribution main station through wireless communication mode, the latter according to the identification algorithm to identify ground fault, combined with the network topology to realize fault location, the fault point upstream acquisition unit flash alarm in situ indicates a fault, and downstream of the acquisition unit without...
flash action, convenient patrol personnel find point of failure.

**Figure 2.** Flow chart of fault identification.

### 3. Method for measuring fault recording performance

#### 3.1. Fault recording performance requirements

| Index name           | Index requirements                                                                                                                                 |
|----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|
| File format          | There are only two files, CFG and DAT, and the binary format is adopted. The uploaded recording data conforms to the requirements of Comtrade1999 standard file format. |
| Content of the waveform | At least ABC three-phase electric field, three-phase current and zero-sequence current. The number of cycles before the start of recording is ≥4 cycles, and the number of cycles after the start is not less than 8 cycles, and the number of sampling points of the maximum cycle is not less than 80 points. |
| Record the wave range | The recorded waveforms have the same transient polarity as the actual waveforms.                                                                   |
| Steady state polarity | The recorded waveforms are consistent with the actual waveforms in the initial steady-state polarity.                                               |
| Waveform trend       | The changing trend of recorded waveform is consistent with the steady amplitude of actual waveform.                                                 |
| Steady current       | When 0≤I < 300, the relative error of the effective value of the phase current is not more than ±3A, and when 300≤I < 600, the relative error of the effective value of the phase current is not more than ±1%. |
| Transient current    | The relative error of maximum instantaneous phase current amplitude should not be more than 10%.                                                    |
| Time error           | The time difference between fault occurrence and recording start is no more than 20ms.                                                             |
| Synchro error        | The three-phase synchronization error of each collection unit is no more than 100μs.                                                               |
Waveform quality of fault record affects seriously the single-phase grounding recognition accuracy. Therefore, to judge fault wave record performance for TRTFI, this paper selects the 10 parameters as the evaluation criterion, which comes from the wave record file format specification and content integrity, waveform information reflect the characteristics of the ground fault typicality, wave record data reliability dimension precision, see Table 1 for detailed requirements.

The first three indicators in Table 1 mainly require fault recording duration, recording content and storage file format. The last seven indicators evaluate the consistency between the transient signal, steady-state signal, variation trend and time difference of recording waveform and actual fault waveform from both quantitative and qualitative aspects. Among them, waveform trend refers to the change of the effective value of the cycle current before and after the occurrence of the fault, and the synchronization error is used to ensure the synchronization of the three-phase synthesis zero-sequence current waveform of each collection unit. Indicator weight is used to measure the importance of an indicator relative to the evaluation target. To evaluate the performance of power distribution terminals, it is necessary to first calculate the weight value of the lowest index in the evaluation system, then convert the detection results of each index into corresponding score value according to the scoring criteria, and finally get the comprehensive performance score of equipment by weighting sum layer by layer.

### 3.2. Fault recording similarity comparison

The core of TRTFI fault identification ability test is to judge whether the fault indicator recorded waveform is consistent with the standard waveform. Usually, the sampling rate of standard waveform is different from that of the measured sample, so waveform preprocessing is required before fault waveform comparison. In this paper, by putting the standard waveform and the recorded waveform of the measured sample in the same coordinate, the sudden change points of the two groups of waveforms are selected first, and then aligned with the sudden change points as the center, and the comprehensive average value of the amplitude error of each data point in the sample waveform is calculated. Then, in the center of the mutation point, the standard waveform is parallel moved to both ends, and the comprehensive average value of the data error of each point of the sample waveform after each movement and alignment is obtained. Finally, through comparative analysis, the minimum comprehensive mean value is taken as the alignment condition of the two groups of waveforms. The processed waveform reference fault waveform feature index starts to compare waveform features and determine waveform similarity.

Specific comparison methods are as follows: Firstly, the waveform is qualitatively evaluated by the characteristic indexes such as the number of wave sampling points per week, the number of cycles before the fault point, the three-phase synchronous sampling and the fault time. Then, the characteristic physical quantity is extracted from the products that meet the requirements of the indicators for waveform comparison. Including the initial angle $\phi$ and amplitude $A$ of the steady state signal, the maximum value of the zero-sequence transient signal $M_t$, the polarity $P_t$, the frequency of the high-frequency and low-frequency parts of the signal are respectively $F_h$, $F_l$, and the amplitude ratio $K_f$. Finally, the maximum polarity of the zero-sequence transient signal is verified. If it means that the polarity of the recorded wave shape is opposite to that of the standard waveform, then the waveform similarity is zero. If they are the same, then continue to judge the sum of parameter errors of other characteristic indicators, as shown in Formula (1) below.

$$
E_r = \frac{|\Phi_\alpha - \Phi_\beta|}{\Phi_\alpha} + \frac{|\Phi_\beta - \Phi_\gamma|}{\Phi_\beta} + \frac{|\Phi_\gamma - \Phi_\delta|}{\Phi_\gamma}
+ \frac{|A_\alpha - A_\beta|}{A_\alpha} + \frac{|A_\beta - A_\gamma|}{A_\beta} + \frac{|A_\gamma - A_\delta|}{A_\gamma}
+ \frac{|M_t - M_s|}{M_s} + \frac{|F_\alpha - F_\beta|}{F_\alpha} + \frac{|F_\beta - F_\gamma|}{F_\beta} + \frac{|F_\gamma - F_\delta|}{F_\gamma}
+ \frac{|F_\alpha - F_\beta|}{F_\alpha} + \frac{|F_\beta - F_\gamma|}{F_\beta} + \frac{|F_\gamma - F_\delta|}{F_\gamma}
+ \frac{100\%}{16}
$$
3.3. Accuracy test of fault waveform identification
The specific process steps are shown in Figure 3. (1) according to the neutral point grounding mode, fault type, fault parameters and other conditions, to select the same number of grounding fault waveform files from the grounding fault waveform library to form test cases; (2) to relay protection testing device replays and reproduces the operating signal of the grounding fault on the analog coil; (3) to collect analog output fault information and waveform, and as the standard value, and indicator collection for the measured value. (4) to judge the accuracy of fault recording according to the extracted indexes and requirements in Section 3.1 of this paper; (5) According to the method proposed in Section 3.2 of this paper, the similarity of fault recorded wave is compared; (6) to use equation (2) to calculate the single-phase grounding fault recognition rate, where n is the number of correct fault identification and N is the number of tests.

\[ \alpha = \left( \frac{n}{N} \right) \times 100\% \] (2)

Figure 3. Flow chart of fault identification

4. Test application and validation
In order to verify the validity of the test method of single-phase grounding fault record performance for TRTFI, ground fault playback output waveform can be divided into small resistance grounding, grounding, high resistance grounding, four categories of arc light earthing, and further subdivided into neutral point grounding, the arc suppression coil and small resistance grounding 3 items. A kinds of labels, for example fault initial Angle, fault location, fault occurring and so on, is used to identify the ground fault waveform information. The initial phase angles of fault occurrence are divided into [0°, 30°], [30°, 60°] and [60°, 90°]. The positions of fault points include before and after the fault point. The fault lines are divided into cable lines, overhead lines and mixed cable overhead lines. Test cases with similar degree of difficulty were formed by means of differential grouping of labels and random sampling of various groups of waveform files, covering single-phase grounding fault waveforms of various label contents, with a total number of 50 groups, which ensured the objective and accurate test results. The single-phase grounding identification ability test was carried out for two sets of recorded-type fault indicators from different manufacturers, and the test results are shown in Table 2.
Table 2. Testing situations of single phase grounding

| Grounding type          | Single phase grounding fault identification accuracy (%) |
|-------------------------|--------------------------------------------------------|
| Metallic grounding      | Sample 1: 92, Sample 2: 90                           |
| Low resistance grounding| Sample 1: 90, Sample 2: 86                           |
| High resistance grounding| Sample 1: 74, Sample 2: 72                           |
| Arc grounding           | Sample 1: 86, Sample 2: 88                           |

By comparing the recorded waveform of the test sample with the playback output waveform recorded by the recording unit, it is found that the reasons for the identification error of the test sample mainly include: The recording file format and data do not meet the requirements, the recording content is incomplete, the recorded waveform has no fault point, the waveform transient polarity is reversed, the three-phase time synchronization or the fault recording accuracy is poor, as shown in Figure 4 to Figure 6 below.

![Figure 4](image1.png) Lack of recorded current data for phase B.

![Figure 5](image2.png) Fault point information missing.

![Figure 6](image3.png) Transient polarity reversal.
5. Conclusion
The application of fault indicators of distribution lines based on transient recording is more and more widely, which ensures the reliability and sensitivity of fault recording performance and helps to improve the accuracy of single-phase grounding fault detection and location of distribution network. Based on the technical characteristics of transient recording, 10 key indexes are selected and a method of waveform similarity comparison for single-phase grounding fault is proposed. At the same time, the effectiveness and accuracy of the proposed method are demonstrated through a large number of examples, and several reasons for the fault indicator recording function not meeting the standard requirements are summarized, which provides a strong support for strengthening the fault recording function of equipment and fault identification.

Reference
[1] XU Zai-de, Xin Jian-bo, PAN Jian-bing, et al. Research and Application of New Fault Indicator Test Platform[J]. Electrical Measurement & Instrumentation, 2019, 56(5): 124-129.
[2] Pang Yuji, Jiang Bo, Luo Ruixi. The distribution network selectric energy metering influence of the single-phase earth fault[J]. Electrical Measurement & Instrumentation, 2019, 56(16): 67-72.
[3] O. Siirto, J. Kuru, and M. Lehtonen, “Fault location, isolation and restoration in a city distribution network,” 9th Int. 2014 Electr. Power Qual. Supply Reliab. Conf. PQ 2014 - Proc. pp. 367–370, 2014.
[4] A. Salazar, G. Zapata, and R. Garcia, “A Fault - Indicator - Based Methodology for Distribution Power Systems Fault Location,” Aceptado para SICEL 2013, no. 1, 2013.
[5] R. Dashti and J. Sadeh, “Fault Indicator Allocation in Power Distribution Network for Improving Reliability and Fault Section Estimation.”
[6] E. Koreneva, “Evaluation of practical experience of fault indicator performance in medium voltage networks,” CIRED - Open Access Proc. J. vol. 2017, no. 1, pp. 1117–1119, 2017.
[7] SONG Hongtian, XIAO Xia, XU Yan, et al. Research on Voltage Measurement in the Field of Fault Indicator[J]. Electrical Measurement & Instrumentation, 2020, 57(3): 110-115.
[8] LIU Jian, ZHANG Xiaoping, SHEN Wei, et al. Performance Testing of Single Phase to Earth Fault Location for Distribution Network with Neutral Point Non-effectively Grounded Systems
[9] LI Tianyou, XU Bingyin, XUE Yongdian. High-impedance Fault Protection of Distribution Networks and Its Developments[J]. Distribution & Utilization, 2018, 35 (05): 2-6+24.
[10] QIU Jin, CUI Xin, TIAN Ye, et al. Analysis of the arc high impedance grounding faults voltage characteristics in non-effective grounding feeders[J]. Power System Protection and Control, 2019, 47(16): 115-121.
[11] YANG Fan, JIN Xin, SHEN Yu, et al. Simulation test and characteristic analysis of grounding fault causes of 10 kV overhead distribution network [J]. Distribution & Utilization, 2019, 36(3): 37-43.
[12] WANG Qin, QIU Hui, LI Dawu. Application of Line Fault On-Line Monitoring System Based on Transient Recording Technology in Distribution Network [J]. Power & Energy, 2018, 39(03):23-25.

Acknowledgments
This work is supported by China Electric Power Research Institute science and technology project (research on the linkage test technology of local type feeder automation, No. PD83-20-001)