A New Single Phase Fault Location Method Of Noneffectively Grounded Networks for DA systems

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ABSTRACT

The paper presents a new small current grounding fault location method applicable to distribution automation systems (DASs) using fault transient currents. The faulty section is identified by comparing the degree of similarity of transient currents of feeder terminal units (FTUs) (including faulty line selection device) at adjacent switches. If both transient currents are highly similar, then the section is regarded as the sound section, otherwise as the faulty section. The paper also analyzes the adaptability of the transient localization algorithm on DAS, as well as other key technologies such as time synchronization for FTUs, software and hardware processing ability, etc. The prototype system was installed in a typical distribution system in Xiamen Power Supply Bureau, State Grid Company of China. Dozens of grounding fault transients were captured with correct faulty line identification and faulty section localization. The method is reliable, free from the influence of arc suppression coil and easy to be implemented. It makes DASs function more complete, and helps to improve its overall performances.

Keywords: distribution automation systems (DASs), small current grounding, fault location, transient current

0、Introduction

Fault location, isolation and restoration are critical functions of distribution automation system (DASs), which can improve power supply reliability by narrowing the range of outage, speeding troubleshooting, shortening fault clearing time[1,2].

Single-phase to ground faults account for about 80% of the total number of faults in medium-voltage distribution networks. However, the existing distribution automation systems (DASs) can't provide fault location information of single phase to ground faults (small current grounding faults) of non-effective networks, which has become one of the key factors of restricting the development of DA and FA technique and needs to be solved urgently.

Recently, small current grounding fault line selection techniques based on fault transient information has been successfully applied[3-5], which establishes a good foundation for the small current grounding fault location. The paper presents a new small current grounding fault location method applicable to DASs using fault transient currents. The paper also describes the necessary of fault line selection accessing to DASs, introduces fault location process in DASs. Field test and operation verify the effectiveness of location algorithm and location system.

1、Small Current Grounding Fault Transient Current Distribution Feature

For both non-grounding system and the grounded system via arc suppression coil, the distribution of transient zero-sequence current within the system is shown in Figure 1-1 and the rules of the distribution are:

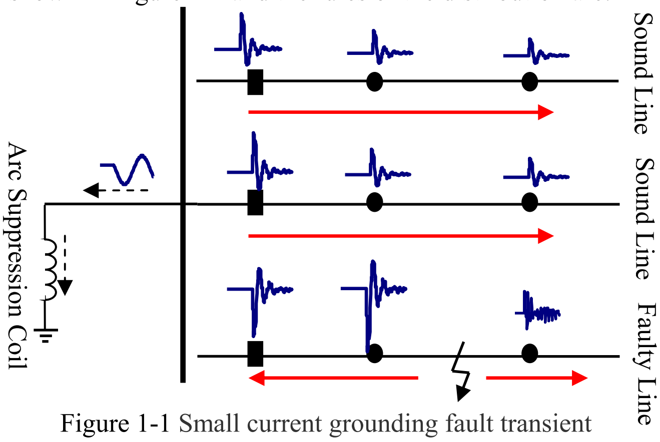

Figure 1-1 Small current grounding fault transient current distribution rules

For small current grounding fault, the amplitude of transient current through fault point upstream line is large, and the current flows from line to bus; the amplitude of transient current through fault point downstream line is small, the current flows from bus to line. The amplitude of transient current is close at the same side of fault point and has a high degree of similarity, however, the frequency of transient current is different from both sides of fault point, the direction of which is contrary and has a low degree of similarity, which can be used for fault location.

2、The Location Principle Based on Transient Current Similarity

The similarity of two waveforms can be described by the correlation coefficient[6], therefore, whether two waveforms are similar can be identified by calculating the correlation coefficient ρ of transient zero mode current at adjacent switches and the equation is as follows:

$$\rho = \frac{\sum_{n=1}^{N} i_{01}(n) i_{02}(n)}{\sqrt{\sum_{n=1}^{N} i_{01}^{2}(n) \sum_{n=1}^{N} i_{02}^{2}(n)}} \quad (1)$$

Where i_{01} and i_{02} is respectively transient zero mode current at adjacent test point; n is sampling sequence, and when the first sampling point n=1 means the time of fault occurring; N is data length of zero mode current signal.

In practical, the faulty section is identified by calculating the correlation coefficient ρ of transient currents of FTUs (including faulty line selection device) at adjacent switches:

If $\rho > \theta$ (θ is a threshold value between 0.5 and 0.8), that means transient current waveform at both sides of this section has a high degree of similarity and this section is not a faulty section. If $\rho < \theta$, then this section is a faulty section.

3、Transient Location Challenges for DASs

Taking advantage of DASs to realize ground fault transient location should take all kinds of limitation into consideration.

3.1 FTU Signal Acquisition

In substations, the desired voltage and current signal can be easily obtained, but in DASs, signals obtained by FTU are restricted.

In distribution network, current transformers (TAs) integrated on load switches and breakers are generally divided into two kinds: three-phase TA and two-phase TA with zero sequence TA used for protection.

For the kind of three-phase TA, zero sequence current signals can be synthesized by three-phase TA. And unbalanced current (fundamental frequency component) produced because of different TA parameters is eliminated by using break variable theory. During normal operation, there is no transient component, and transient current is much larger than power frequency current, so fault transient current can be reliably obtained by three-phase TA synthesis method.

For the kind of configuration with zero sequence TA, zero sequence current signals can be directly obtained.

If no external power, circuit switches are generally mounted with one or two voltage transformers (TV) to supply power for the primary and secondary equipments. That means FTU can obtain one or two line voltage signals and be unable to obtain phase voltage or zero sequence voltage signals.

So, as far as ground fault, zero sequence current signals can be achieved by FTUs; line voltage signals can be achieved by part of FTUs; but three-phase voltage or zero sequence voltage signals cannot be achieved.

3.2 FTU Clock Synchronization

Arc grounding and intermittent grounding account for a fairly large proportion in ground faults, and this kind of faults will continue to produce transient current. The calculation of the correlation coefficient of transient zero mode current signals acquired by FTUs at both sides of the calculated section needs the higher time synchronization capacity (error < 1ms).

Under the situation of the existing equipments failing to provide more precise time setting, the error produced by asynchrony will be reduced by mathematical method to meet the calculation requirements of correlation coefficient algorithm.

For two signals with similar waveforms, by fixing one of signals as reference signal and forward and backward translation of data window of another signal, their correlation coefficient is calculated at the same time. The points that have the best overlapping, their correlation coefficient is the highest, which can be approximately regarded as synchronization. The equation is:

$$\rho_{\max} = \max[\rho(m)] = \frac{\sum_{n=1}^{N} i_{01}(n) i_{02}(n+m)}{\sqrt{\sum_{n=1}^{N} i_{01}^2(n) \sum_{n=1}^{N} i_{02}^2(n+m)}} \quad (2)$$

Where i_{01} and i_{02} is respectively transient zero mode current at adjacent test point; n is sampling sequence, and when the first sampling point n=1 means the time of fault occurring; N is data length of zero mode current signal; m is translation point number of zero mode current signal, m=1,2,3,⋯,M; M is the maximum length. Because time setting error is a few milliseconds, generally M is set by 1ms-3ms according to the master station time setting precision. For transient zero mode current signals at both sides of the fault section, with less correlation, even the maximum correlation coefficient is calculated, the value is close to 0, which still meets correlation location principle.

3.3 FTU Software and Hardware Processing Capability

The dominant frequency of ground fault transient signals is between several hundred and 2 kHz. A high requirement is proposed to FTU sampling frequency, generally is greater than 6 kHz.

Because of transient signal record and processing requirement in the event of failure, FTU is also required to have a strong software and hardware processing capability.

3.4 The acquisition of fault information at feeder breakers

In the process of short circuit fault location, DASs need to collect fault information from feeder circuit breakers in substation. The monitoring scope of most of DASs doesn't contain feeder switches, it needs the cooperation of regional dispatching automation system or substation integrated automation system to obtain the desired information.

Different from short circuit fault that produces fault current only in faulty line, during small current grounding fault, fault signals can be detected on all feeders and at all test points in system. Protection devices of feeder breaker generally can't provide the required ground fault information. Only relying on the fault information from FTUs, faulty line should be identified and then location. Limited by access signal and software and hardware processing capability, detection reliability of FTU is relatively poor, mistakes may be made in the phase of line selection. On the other hand, lack of outlet fault information, location blind area is existed (the section between bus and the first FTU).

3.5 The Adaptability of Master Station Algorithm

In centralized fault processing mode that is the most widely used[7,8], FTU is responsible for fault information acquisition, master station is responsible for fault location. In general DASs, products about master station and terminal are from a number of manufacturers. For convenience, the simpler the algorithm is, the better it is, or the specific location software owned by terminal manufacturer should be implanted into master station.

4、Introduction of DASs with Location Function

4.1 The Necessary of DASs Access Fault Line Selection Device

In order to solve the problem of ground fault information acquirement at feeder breaker and improve location reliability, line selection device with high reliability can be installed in substation. In addition to achieve the conventional line selection function, the device produces all kinds of fault information required by location, and let information access to DAS. Its main function is:

1) Identify faulty line, improve location reliability. Selecting faulty line is the first step of location. Compared with FTU, line selection device can obtain all kinds of desired signals with stronger software and hardware processing capability and a higher reliability.

2) Provide outlet fault information, eliminate location blind area. Line selection device can provide all kinds of fault information as transient current records and transient current approximate entropy at faulty line outlet, having a function of outlet protection device during short fault, which can eliminate location blind area between the first FTU and bus.

3) Improve the ability of anti-interference. Line selection device can distinguish transient process caused by lightning, closing, etc, and fault transient process according to three-phase voltage/zero sequence characteristics. For ground fault, the device can tell fault type (stable fault, arc fault or intermittent fault, etc) and identify the fault duration. By reporting this information to DA mater station, anti-interference ability of fault detection can be improved.

The amplitude of small current grounding fault transient current is far greater than that of fundamental frequency steady state current. Generally, the value is hundreds of A, guaranteeing the reliability of fault detection effectively.

4.2 Field Operation of DASs Structure

Field operation system is 10kV-I bus and 10kV- IV bus in TY substation in Xiamen Power Supply Bureau, Fujian province, China. Each bus respectively has 11 feeders and 5 feeders and both grounded by automatic tuning arc suppression coil. The 911 Tingxi line at I bus and the 946 Silin line at IV bus were monitored. Two lines were installed two FTUs respectively (the line is divided into three sections). The improved line selection devices based on transient theory were installed in TY substation and location master station was installed in dispatch department. FTUs, line selection devices and location master station communicate through GPRS. The system structure is shown in figure 4-1.

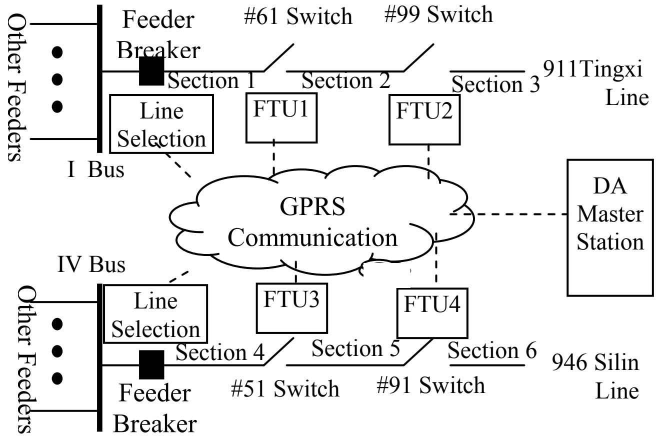

Fig. 4-1. Field location system

4.3 Ground Fault Location Process for DASs

Distribution network allows running with ground fault for a period of time, no strict requirements on the detection time. The centralized fault processing mode can be adopted, which is the master station collecting different FTU fault information to realize location, the dispatcher carrying out remote control according to requirements to isolate fault. Ground fault location process for DASs is:

1) During grounding, line selection devices start to select faulty lines according to the zero sequence voltage changes, and report information such as the fault line with time label, outlet transient current wave records and power frequency voltage, etc to master station.

2) During grounding, FTUs start according to transient current changes, and report information such as transient current wave records with time label, etc to master station.

3) After master station collect the information from line selection devices in substation and each FTU, whether ground fault occurring can be confirmed by voltage information of line selection devices. For disturbance, the devices exit.

4) When identifying ground fault, the faulty line is examined according to the result of line selection achieved by line selection devices.

5) According to the information from line selection devices in substation and FTUs on faulty line, the fault section can be identified by transient current correlation theory.

6) According to voltage information from line selection devices, the duration of fault can be confirmed. For permanent faults, the result of location is proposed and acousto-optic alarm information is given; for instantaneous fault, the result of location is saved and only text alarm information is given.

5、Field Experiment and Operation

The small current grounding fault transient location function developed on the platform of DAS had completed static simulation experiment, and field artificial grounding tests and operation were carried out.

5.1 Field Experiment

In order to verify the efficiency of transient current similarity location principle and DAS location function, field artificial single-phase grounding tests were carried out in Xiamen Power Supply Bureau. Two artificial grounding points were set and the types of ground fault involved metal grounding and grounding via resistance to observe the location results given by location master station in the event of ground fault.

There were 16 times artificial grounding tests carried out at two grounding points, 15 location results were given by the system. The first grounding test for No. 1 grounding point failed to give reliable location results due to FTU1 delay start phenomenon. Figure 5-1 is the sixth grounding test record waveform for No.1 grounding point.

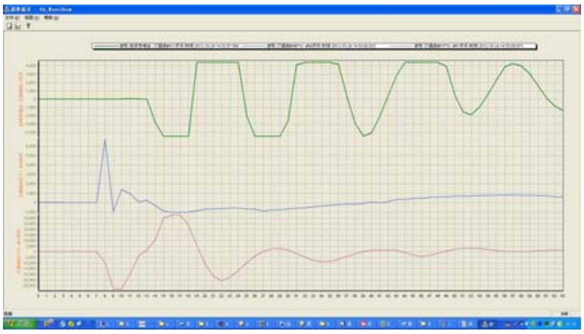

Fig. 5-1. The grounding test record waveform for No.1 grounding point

5.2 Site Operation

From July 26th to October 6th, 2012, location system recorded 21 actual faults, 20 times location results were given by the system. The fault occurring on October 6th didn't realize location because FTU1 on Tingxi line didn't receive fault information, and FTU2 recorded small fault current value. Figure 5-2 is the fault current waveform recorded by line selection device and each FTU when the fault occurred at section 3 (each current occurred different degree of saturation).

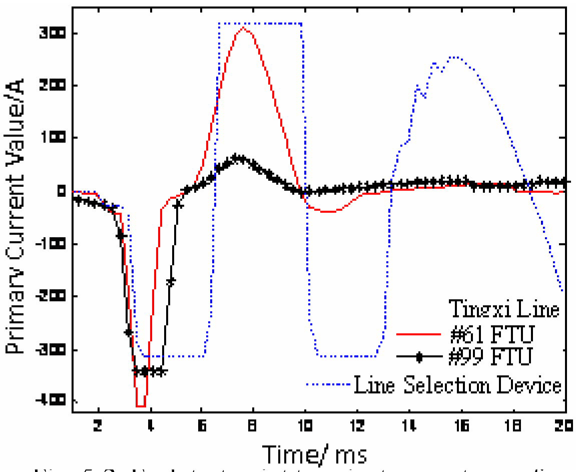

Fig. 5-2. Each test point transient current waveform when the fault occurred at section 3

In addition to the actual fault, each FTU also recorded 2000 times disturbance data. That means FTU is easy to be disturbed and misoperation occurs only using the current variation start, but the disturbance can be distinguished by the line selection device information.

6、Conclusion

Small current grounding fault location has become one of the key factors of restricting the development of DA and FA technique and needs to be solved urgently. The location principle and technique must be adapted to the limited conditions such as voltage signal access to DASs and the problem of time setting, etc. That fault line selection device installed in substation accessing to DASs can improve the reliability of ground fault location and eliminate the blind area.

The paper presents a new small current grounding fault location algorithm based on zero mode current correlation. The faulty section is identified by comparing the degree of similarity of transient currents of FTUs (including faulty line selection device) at adjacent switches. The algorithm is not affected by neutral grounding mode and has strong applicability.

Field operation and experiment verify the effectiveness of location algorithm and location system. The method is reliable, no need to install the parallel resistance with arc suppression coil. The system cost is low and easy to be implemented. It makes DASs function more complete, and helps to improve its overall performances.

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