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Study on Locating Techniques of Single-phase Grounding Fault in Distribution Network

Wang Jianmin[1], Shen Weiwei[2], Chen Yanping[2], Jin Xin[2], Shi Jidong*[3], Wang Dongju[3]
[1] State Grid JiaXing Power Supply Company, JiaXing, 314000, China
[2] State Grid Zhejiang Tongxiang Power Supply Company, Tongxiang, 314500, China
[3] College of Electrical Engineering, Zhejiang University, Hangzhou, 310027, China
*Corresponding author, e-mail: jidong_shi@163.com

Abstract

The single-phase grounding fault has great negative influence on neural ineffectively grounding system of distribution network. This article has illustrated and compared commonly used fault locating techniques including the impedance method, travelling wave method and signal injection method. The author has detailed how fault locating could be realized and merits and shortcoming of each method. It is shown that every method still has its own space of improvisation. And the rapid development of smart grid has given directions to further researches. On one hand the current problems of fault location have been revealed in this essay. One step further, this article has made expectations for achieving more accurate and timely fault locating methods.

Keywords: distribution network, neural ineffectively grounding system, fault location Introduction

1. Introduction

The neural ineffectively grounding system is widely used in distribution network of our country. The one special character of this kind of system is that there will be no short-circuited loop when single-phase grounding fault happens. The grounding current is only determined by system's distributed capacitance and very low. As the line voltage stays symmetrical, the distribution system could keep continuous operation for one or two hours after fault. However, the single-phase grounding fault could cause the earth voltage of healthy phases to rise. Without effective and timely actions, the single-phase ground fault could probably cause two-point or even multipoint grounding accidents, which means expansion of fault area and great danger to the power distribution network. The users' normal power consumption will also be affected. After all, the single-phase fault could possibly bring great damage to the power system. But the location of single-phase fault is a well known problem for its difficulties and complication because the grounding current is very small and hard to detect [1-3].

The diagnosis and location of single-phase grounding fault in distribution network is of great importance in improving operation reliability of power distribution system. The proper locating technique should give priority to accuracy with due consideration to efficiency. This article has introduced several common locating techniques and pointed out further direction of research on single-phase grounding fault.

2. Locating Techniques of Single-phase Grounding Fault

The locating techniques of single-phase grounding fault could be categorized as the impedance method, travelling wave method and signal injection method. Each method adopts its own theoretical methodology. More specifically, the signal injection method include the S injection method, impulse signal injection method, transfer function method and fault diagnosis method [4-11].

2.1. The Impedance Method

The impedance method needs to test and measure the voltage and current of the fault circuit. Then the impedance could be easily derived. Since the line length is directly proportional to the impedance, the fault location could be found according to the distance.

The impedance method is simple in theory and economic in investment. The disadvantage is that it is greatly affected by power load and power source parameters. And it is not applicable in lines mixed by overhead lines and electric cables because of its huge parameter difference. Apart from these, the multi-branch distribution lines don't possess the necessary characters for application of the method. Due to the complication of the line structure, the impedance method could not locate the fault just with the aid of the distance between fault location and the power source. Above all, the impedance method usually is not applied in direct locating fault simply. On more real occasions, it is used as an auxiliary locating technique.

2.2. Travelling Wave Method

The travelling wave theory indicates that all kinds of perturbation on power lines would cause electric parameter change and transfer it to the other parts of the system in the form of travelling wave. So theoretically the measured transient signal of travelling wave is useful for location of any kind of fault. Based on the time that takes to transmit the signal of voltage and current from fault location to the bus, the accurate fault position is within reach through calculation. Present travelling wave methods could be classified as three types of A, B, C.

a) A-Type travelling wave method

The A-type travelling wave method uses the travelling wave generated and transmitted from fault position to locate the fault. Theoretically, it takes a certain period of time for travelling wave to cover the distance between fault position and the measuring point. With consideration of the propagation speed, the fault area could be orientated and confirmed.
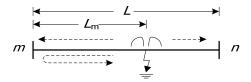

Figure 1. A-type Travelling Wave Method

Set the length of the line as L, the travelling wave propagation speed as v. The time that takes for the first travelling wave to travel from fault position to bus m is T1. The time for the reflected wave travelling from fault position to bus m is T2. Then it is known that the distance Lm between fault position and bus m could be calculated as following:

$$L_m = \frac{1}{2} v \left(T_2 - T_1 \right) \tag{1}$$

b) B-Type travelling wave method

The B-type travelling wave method is very similar to A type. The difference is that B type calculates the time that takes to travel from position to both sides of the line.
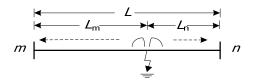

Figure 2. B-type Travelling Wave Method

The distance between the fault position and bus m is Lm and the travelling time is Tm. The distance between the fault position and bus n is Ln and the travelling time is Tn. Take Lm as an example:

$$L_m = \frac{v \left(T_m - T_n \right) + L}{2} \tag{2}$$

c) C-type travelling wave method

The C-type travelling wave method is different from former methods in basic theory. Other than travelling wave signal generated by system fault, the C-type method uses specific facilities to send high voltage and high frequency signal or direct current impulse signal. Based on the time that takes for the high frequency signal to travel from the facility to fault position and come back, the fault position is easy to be located.
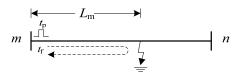

Figure 3. C-type Travelling Wave Method

The fault location facility is at bus m. At time tp the facility generates the impulse signal. Then at time tf the signal receiving end at bus m catches the reflected wave. So the distance Lm between fault position and bus m could be derived as following:

$$L_m = \frac{1}{2}v\left(t_f - t_p\right) \qquad\qquad (3)$$

d) Summarization of the travelling wave method

Among the all three types of travelling wave methods, A-type and C-type are single-ended fault location methods while the B-type is a two-terminal fault location method. The latter needs information exchange between both sides of the transmission line.

The A-type travelling wave method is applicable in distance measuring of simple network like high voltage transmission lines. However, the distribution network is multi-branched and in radiant structure. The complicated topological structure is a difficult problem for its application in distribution network. The B-type travelling wave method has two measuring terminals and uses only the first tip of the travelling wave. It will not be affected by the overlay of transmitted wave at fault position. The measuring signal is strong and easy to detect. On the other hand, this method needs detection device at both sides of the line and communication equipment to ensure clock synchronization. These conditions are rather harsh for distribution network. They make the B-type travelling wave method impractical in the area of fault location.

The C-type travelling wave method is an off-line ranging method. The signal intensity of the travelling wave doesn't affect the distance measuring because the locating process could be repeated. When the signal is not strong enough to be analyzed, the device could send another travelling wave and fulfill the locating process. Besides, this method is economically outstanding because of its low cost of equipment. It does not have to install high frequency data acquisition devices for every transmission line. Still this method has its own disadvantage. When high impedance grounding and flashover fault happens, the reflected signal from grounding spot is very weak and nearly to none. So a high voltage impulse generator is needed here to break down insulation with its strong signal. The highly qualified impulse generator has put up with more demands for the equipment.

2.3. Signal Injection Method

The signal injection method locates the specific fault position by injecting a certain kind of signal into the system. Depending on the signal, the current methods include S signal injection method, impulse signal injection method, transfer function method and port-fault diagnosis method.

a) S signal injection method

The core theory of the S signal injection method is to make use of the potential transformer injecting a special current signal. By detecting the specific signal the fault location can be realized.

When the fault happens, the busbar potential transformer injects current signals of specific frequency into the grounding line. The injected signal travels along the transmission line

and goes into ground through the fault location. With signal detectors at every branch point, the branch that has injected signal detected could be diagnosed as fault branch. Knowing the fault branch, we are able to locate accurate fault position with the fault detector by continuous observation of the signal along the fault branch. To avoid the interference of power frequency signal, the frequency of the injected signal is between power frequency multiplication and harmonic frequency. 220Hz is mostly used in current literature.

The 'DC open circuit, AC pursuit' offline fault location method is actually based on S signal injection method. It adds a constant DC high voltage on the fault phase after blackout accident. As the grounding spot remains the state of breakdown, the AC detecting signal would be injected into the system. Then follow the signal and locate the fault by recording where the signal vanishes.

Generally speaking, the S signal injection method has its advantages like not being affected by the arc suppression coil. It is applicable in overhead lines with current transformers installed on two phases. But its locating efficiency has a lot to do with the grounding resistance and distributed capacity of the transmission line. On the occasion of large grounding resistance like cement poles, or the fault position being far from the bus, the injected signal might be too weak to be detected. The fault location would fail to carry on. Besides, the single-phase intermittent electric arc grounding fault would lead to discontinuity of the injected signal, bringing new challenges for detection.

b) Impulse signal injection method

The impulse signal injection method appears in Japan in recent years. This method injects high voltage impulse into the fault phase. The voltage can be 5 or 10 or 15kV. The impulse period is 6 seconds. When fault happens, the staff can hold the impulse signal detector in his hand and travel along the line. The detector would beep if impulse signal is detected, which means the fault position is in downstream. Correspondingly, the fault position should be in upstream if the detector doesn't make a sound. At branch point, the sound of the detector indicates a fault branch, otherwise not. This method requires the staff to climb the pole and hang the detector on the transmission line. The length of the detector's insulation pod is about 2 meters.

The impulse signal injection method is also greatly affected by the grounding resistance and distributed capacity of the line. The effective detecting distance is about 5 kilometers. If the line is longer, the detector has to be moved forward. The impulse signal injection method is rather practical in fault location of the distribution network. On the other hand, it has its own disadvantages. The detection of the impulse signal brings a lot of work. The effective detecting area is not large enough to realize fault location in distribution network with long transmission lines.

c) Transfer function method

The transfer function method is based on spectrum analysis and distributed parameter model of the line. A square wave actuating signal source is installed at one side of the line. After fault the zero sequence voltage and current in time-domain would be measured. With calculation the transfer function in frequency-domain and transfer function spectrum at each branch terminal can be derived. According to frequency, phase angle and wave characters, the fault position can be found.

For the neural point ungrounded system, the transfer function method is not concerned about variation of power load. However, technical limits still restrain its practical application and popularization.

d) Port-fault diagnosis method

The port-fault diagnosis method applies the analog circuit fault diagnosis theory in fault diagnosis of distributed parameter network. It suggests that the characters of voltage and current after fault can be utilized to measure distance and locate. Starting from the port function, this method adds the audio frequency sinusoidal signal to the system. Compare the testing signal's change at every detecting port of the network before and after fault. The fault branch can be located online automatically.

The port-fault diagnosis method costs a small amount of work and fits for fault diagnosis of network in a large scale. Its deficiency would be fault location on the branch can only be considered as the connection point of main transmission line and the branch. While the exact fault position can not be verified. Apart from this, the instant information of the network is

needed but not easy to get. The real distribution network has difficulty realizing information updating at all time.

2.4. Other Methods

There are still many other techniques applied in location of single-phase grounding fault in distribution network like fifth harmonic method, medium resistance method and some artificial intelligence methods [12-16].

The resistance method adds an extra medium resistance to the neural point of the system after fault. The extra resistance would cause extra fault current flowing in fault phase and system bus. The artificial fault current can be detected at upstream of the fault position. Meanwhile the downstream and non-fault line would have none. The added power frequency current is the key of grounding fault location. This method is applicable in resonant earthed system. It overcomes the deficiency of low sensitivity of steady state methods. But it needs to change the neural point grounding mode of the system and brings certain additional investment.

The fifth harmonic method is focused on characters of zero sequence voltage and current of fault and non-fault branches. On premise of measuring space electric and magnetic field, the magnitude and phase angle can be used to locate fault position of small current grounding system. However, the fifth harmonic magnitude might not be large enough to be detected. How to improve the sensitivity and anti-interference quality of the detecting device would be the key of its broad application in future.

3. Retrospect and Prospect
3.1. Problems of Fault Location

a) Imperfect theory

For single-phase grounding fault in distribution network, the steady state fault current is usually less than 20A or even only several A. The extensive use of arc suppression coil has caused the amplitude and polarity of steady state zero sequence current not to have fault features any more. The traditional fault detecting method based on steady state zero sequence current is no long useful. As the arc grounding fault happens, especially intermittent arc grounding, there won't be any steady grounding current signal. The theoretical basis of locating method based on steady state signal has collapsed.

b) Having difficulties obtaining fault signal

The detecting techniques and devices used now mostly need to obtain system's zero sequence voltage or current signal. Currently this problem is solved by installing zero sequence current transformers in systems with cables and three-phase current transformers in systems with overhead lines. The zero sequence current signal would be available through calculation of three-phase current. The zero sequence voltage is derived by installing electromagnetic voltage transformers on the bus or lines. With the development of technology, the optical transformer has made progress but still not enough for practical application. If zero sequence of three-phase transformers were to be installed at every detecting point along the line, the economic cost would be huge and unacceptable. The inconvenience of installation and potential danger of ferromagnetic resonance has been obstacles for further application. Restricted by the level of facility, many effective fault locating techniques can not be applied in reality.

c) Data bulk transfer

Some locating methods need to use instant data of the network, which means the complete transient zero-module current signal has to be transferred to main station through communication network. The large amount of data has exceeded the capacity of data-delivering channel. The real time fault recorder might be blocked and delayed, disturbing the locating process.

d) Detecting device cannot report fault automatically

Current facilities have different kinds of defects in sensitivity, sampling frequency, reliability and data long distance transmitting. For example, the fault can be detected by means of the signal injection method but the data can not be uploaded. The staff will have to patrol along the line and climb the telegraph pole to confirm fault position, which takes a lot of energy and time. The fault area can't be found and isolated within the minimal period of time.

3.2. Prospects of New Fault Locating Techniques

a) Union of different methods

Up until now, no fault locating method is applicable under all kinds of circumstances. For real distribution network, application of these methods should be flexible. Depending on the network operation state, travelling wave method, signal injection method and other methods could be united and compensating each other to achieve higher quality of fault location.

b) Fault management system

The fault management system could make full use of fault information. With the aid of fault complaint system and information fusion technology the system can make optimal decision. Simultaneously the system keeps records of different locating methods' working history. Their efficiency and accuracy could be compared and analyzed, which provides evidence for further improvisation and exploitation.

c) Locating technology considering distributed generation

The rapid development of smart grid brings more and more distributed generation into power system. Distributed generation would affect the transient characters of small current grounding fault. The magnitude, phase angle, attenuation factor and main resonant frequency might change. Deep research into small current grounding fault that happens in network with distributed generation and exploration for a new grounding fault location technology is meaningful to improve the self-healing ability of power network.

4. Conclusion

This article has compared different techniques commonly used in single-phase grounding fault location of the distribution network. The study has analyzed advantages and disadvantages of current fault location methods and illustrated their characters and application fields. It is concluded that there hasn't been any general method that fits for most fault conditions. The selection of fault location method has to take into account the network structure and other conditions in reality.

The development of power network has put up with higher demands for reliability and fault elimination. Faults in distribution network happen frequently. Yet research on accurate and timely fault location could not meet our satisfaction. The author has prospects for future development of the fault location method and made suggestions for improving and creating the fault locating techniques.

Acknowledgements

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