Fault Location in Self-Healing Distribution Networks

Qi Yin and Rui Ding
State Grid Deyang Power Supply Co. Ltd., Sichuan, 61800, China
Email: yinqi_dy@sc.sgcc.com.cn, raydean@163.com

***Abstract*—Research on fault location in self-healing distribution system has been conducted for decades. However, a complete solution has not yet been found. This paper reviews the existed fault location methods in distribution system, except the SLG (Single-line-to-ground) fault in NUGS (Neutral un-effectively grounded system). The discussed faults in this paper are the short circuit faults which would cause large fault current and could be detected by over-current relay in substation. The principles and developments of several typical fault location methods are introduced in the paper. At last, possible improvements are proposed at the end of the paper.**

***Index Terms*—fault location, self-healing, distribution networks**

I. Introduction

Fault location in self-healing distribution systems is an important function for improving customer Average Interruption Duration Index (CAIDI) and System Average Interruption Duration Index (SAIDI). Also it is the premium of realization self-healing of networks, one of the most important and attractive features of smart grid. The fault is inevitable in distribution system. There are many possible reasons could cause fault, including lighting, animal/tree contact the line, overloading, equipment failure, human intended or unintended actions and so on. The protection in distribution system is over-current relay which would operate system when a fault caused large fault current. It can point out the fault feeder but cannot point out the fault position. Then an accurate fault location method is needed to locate the fault.

This paper introduces the fault location methods in self-healing distribution system. It is suit for the shunt faults in NEGS(neutral effectively grounded system) which is widely used in North-American and some Asia and Europe countries and phase-to-phase fault in NUGS(neutral un-effectively grounded system) which is widely used in Northern Europe and China. The paper is organized as follows: Section 2 introduces the requirements of fault location in distribution system. Section3 review the existed fault location methods. Section4 summary the existed methods and propose some viewpoints for fault location.

Manuscript received February 15, 2016; revised November 2, 2016.

II. The Requirements of the Fault Location in Self-Healing Distribution System

There are some differences between fault location methods in transmission system and distribution system for distribution system structure is more complex. The most important aspects considered by fault location methods are directly related to the characteristics of distribution systems [1]: (a) Heterogeneity of feeders given by different size and length of cables, presence of overhead and underground lines, etc. (b) Unbalance due to the un-transposed lines and by the presence of single, double and three phase loads. (c) Presence of laterals along the main feeder. (d) Presence of load taps along the main feeder and laterals. The fault location in distribution system is that point out the accurate fault position or fault section which has been detected by relay. The accurate fault position location includes two parts: one is the fault distance calculation and another is fault branch identification. It is note that the distribution system considered in the report is radial structure.

In the past two decades, many fault location algorithms for distribution system have been proposed. But the fault location in distribution system is still a world-wide problem. The methods can be divided into fundamental signal based and high frequency signal based, single ended method and multiple measurements based, and so on. Ref. [1] reviewed the fault location in distribution system before 2009 and divided the methods into three types: Impedance and other fundamental frequency component based methods, high frequency components and traveling wave based methods and knowledge-based methods. But it doesn't introduce the principle of the methods and there are some new methods have been proposed in recent years. This report divides the fault location methods in detail based on the principle of the methods, as shown in Fig. 1.

The most typical method is impedance based which is similar to the principle of impedance protection in transmission system. It is also the most economical method which needs only one measurement in substation and lower sample frequency. With the development of hardware of signal sampling, the traveling wave based method is proposed in 90s which is used for fault distance calculation in transmission line. It is high cost for the high sample frequency (MHz). In recent years, it was introduced for distribution system fault location, but it is

doi: 10.18178/ijoee.4.4.217-220

still in theoretical analysis because the distribution system is too complex.

With the development of computation speed, the methods proposed recent years, such as data match based and voltage distribution based methods, rely on the massive simulation. Although many new methods are proposed, most of them are theoretical analyses which haven't been in field test. The principle and the development of the methods are introduced in the following sections separately.

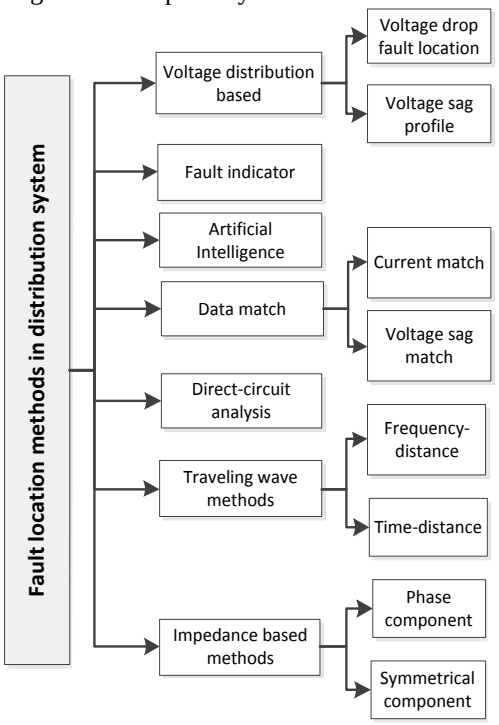

Figure 1. Fault location methods in distribution systems

III. The Fault Location Methods in Distribution System

A. Impedance Based Methods

Impedance focused methods, either symmetrical component or phase component based, generally estimate the distance to fault as a function of total line impedance using fundamental voltage and current measured from single end. It is the most economy fault location method for only needs one measure point at substation and doesn't need high sample frequency. The drawback of the method is multiple estimation results due to the large number of branches in distribution system and reliance solely on measured voltage and current signals at substation.

The simplest approach is reactance-based method which measures the apparent impedance ignoring fault resistance and effect of load current. Then the modified methods are proposed to enhance the accuracy in different assumption to eliminate the effect of fault resistance and load current. In recent ten years, much more researchers utilize the phase component for fault distance computation to reduce the effect of the three phase unbalance and un-transposed lines. Also the iterative calculation is introduced to fault analysis for an accurate result. It is a trend of impedance based fault location in distribution system. The classification and development of impedance based method are shown in Fig. 2. And the comparison of impedance based method proposed before 2004 is introduced in [2].

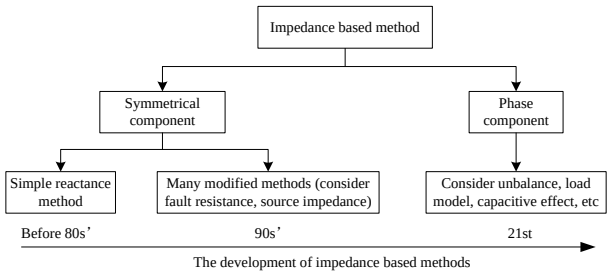

Figure 2. The classification and development of impedance based methods

B. Travelling Wave Based Methods

Traveling waves (also called surges) on power lines arise from a number of causes, of which the most common are faults, switching operations, and lighting. Surges on overhead power lines travel at the speed of light, approximately 3×108 m/sec, and consist of a voltage wave and a current wave related through the surge impedance of the line [3]. There are two types of traveling wave based methods, first one utilizes the traveling wave propagates time from fault point to substation combine with traveling wave speed for calculation, it can be subdivided into A, B, C, D and E five types; another one is based on the traveling wave frequency for calculation.

1) Time-distance based methods

The traditional traveling wave based method in distribution system is the single-ended method using the time difference between the first arrival of an incident traveling wave generated by a fault and corresponding reflected wave reflected from point. We nominated this type method time-distance based traveling wave method in this report. Knowing this time delay and traveling wave velocity the place of fault is determined. In three-phase networks, the traveling waves are mutually coupled which means a single traveling wave velocity does not exist. Therefore, the phase domain signals are first decomposed into their modal components by means of the modal transformation matrices and each node is treated separately. The most critical issue in these methods is detecting and extracting desired part of the signal, which indicates the traveling of the waves. There are many methods have been proposed to identify the reflected wave, including cross-correlation, wavelet transform and so on. In recent year, the accurate traveling wave velocity is considered. It is found that traveling wave velocity is related to traveling wave frequency. Ref. [4] proposed and modified algorithm to enhance the accuracy considering the relationship between the velocity and frequency of traveling wave.

2) Frequency-distance based methods

Another type of traveling wave based method is emerged in recent years which utilize the relationship between specific paths in the network and traveling wave frequency [5]. Fault-originated traveling waves propagate along the network and reflect at line terminations, junctions between feeders, and the fault location. The characteristic frequency of the path is determined by the length and structure of the system.

C. Direct Circuit Analysis Based Methods

The traditional impedance based methods mainly using the sequence component for calculation, generate three independent sequence networks only in the case of the balanced systems. If the network is not balanced, for example mutual impedance between different phases are not equal, it is not possible to draw three independent sequence networks and each sequence is coupled with others. So a fault location algorithm in [6] based on direct circuit analysis is suggested. The fault location equation has been derived by applying matrix inverse lemma and is relatively simple and easy to apply for any system regardless of a phase balance condition.

D. Data Match Based Methods

The data match based methods locates the fault by comparing the measured parameters (voltage or current) with the simulation results when they are best matched. The fault is presupposed to happen in the system. Then the method can be divided into current match based and voltage sag match based methods. The assumptions made by this method are that the accurate system typology and load parameters should be known in advance or can be get when the fault happened. The idea of the methods would be introduced as follows.

1) Voltage sag match based methods

The earliest voltage sag match based fault location is proposed in [7] which is used in transmission system. There are two types of voltage sag match based method applied in distribution system; one is based on only one measurement point in substation and another one is based on several measurement points distributed in the system. A brief comparison of two methods is shown in Fig. 3.

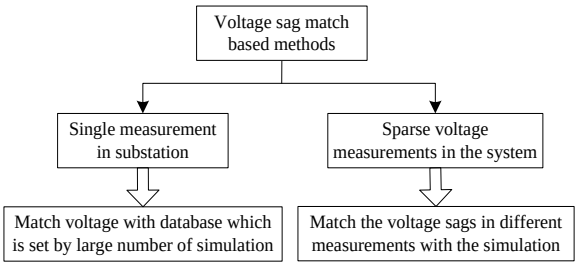

Figure 3. The classification of voltage sag match based method

2) Current match based methods

Ref. [8] utilized current measurements captured from power quality monitoring devices to locate faults. The method attempts to match pre-calculated current at the monitoring site under different fault locations with the measured current. Rather than using a simplified feeder model, the authors proposed to use a short circuit analysis program to pre-calculate fault current magnitudes of different types at every feeder section. The calculated fault currents are then compared with the actual fault current to estimate the fault location of the fault. The main disadvantage of the method is that it uses a simplified feeder model, as it ignores all the laterals, and neglects the mutual couplings between the phases. Also, the shot current database should be re-built when the topology or the operation mode changed.

E. Voltage Sag Distribution Based Methods

The fault location methods witch utilize the voltage sag distribution features in the system would be introduced in this section. There are two methods: one is based on the single ended voltage measurement which utilize non-linear voltage sag profile equations, the possible fault location is estimated by incorporating the measured voltage magnitude and its corresponding phase angle into equation of voltage sag as a function of fault distance; the other one utilize distributed voltage measurements which is called VDFL (Voltage drop fault location) proposed by Hydro-Quebec. The two methods would be introduced in detail as follows.

F. Fault Indicator Based Methods

The fault indicator based methods use large number of measurements (current measurement) in the system to identify the fault section. The fault section is identified by comparing the current or some other features measured along the distribution line. It is widely used in DA (distribution automation) system which contain many FTU (feeder terminal unit) in the system. Ref. [9] proposed using symbolic method for detection of short circuit fault and open conductor fault in automated distribution system. This type of method needs large number of current measurements in system, it is high cost and maintenance workload. It's an optional choice to identify the fault branch when utilizing single-ended method.

G. Artificial Intelligence Based Methods

There are several artificial intelligent methods such as ANN (artificial neural network), Fuzzy logic, Expert System and Genetic Algorithm, etc., with the development of computers emerged. In [10], faulted area is detected by training an ANFIS (Adaptive Neuro-Fuzzy Inference system) net with extracted features based on knowledge about protective device settings. This method requires a large number of history statics or simulation data for training and a re-training subsequent to a change in power system structure.

IV. Conclusion

There are many methods have been introduced in the paper. Some of them are in theoretical analysis, such as traveling wave based methods and AI based methods; some of them have been used in field test and would be spread in the future, such as DA (distribution automation) based method and VDFL. But the requirements of the

methods are different which need high investment, such as DA based method. Also the VDFL is just utilized in distribution system with simple structure. The calculation is very complex when the distribution system contains large number of branches. The following problem could be considered in the future fault location methods: (1) the development of distribution system is different in different countries or different areas. The different fault location methods should be proposed considering the different available data in distribution system; (2) to enhance the reliability of fault location, more measurements could be placed in the system for accurate calculation; (3) single method cannot solve the accurate fault location completely, combining several methods for calculation is a better choice in the future..

REFERENCES

[1] M. Mirzaei, *et al.*, "Review of fault location methods for distribution power system," *Australian Journal of Basic and Applied Sciences*, vol. 3, no. 3, pp. 2670-2676, 2009.

[2] J. Mora-Florez, J. Melendez, and G. Carrillo-Caicedo. "Comparison of impedance based fault location methods for power distribution systems," *Electric Power Systems Research*, vol. 78, no. 4, pp. 657-666, 2008.

[3] IEEE Power Engineering Society, IEEE Guide for Determining Fault Location on AC Transmission and Distribution Lines, IEEE Std. C37.114-2004.

[4] S. Lin, *et al*., "Travelling wave time–frequency characteristic-based fault location method for transmission lines," *IET Generation, Transmission & Distribution*, vol. 6, no. 8, pp. 764-772, 2012.

[5] A. Borghetti, *et al.*, "On the use of continuous-wavelet transform for fault location in distribution power systems," *International Journal of Electrical Power & Energy Systems*, vol. 28, no. 9, pp. 608-617, 2006.

[6] M. S. Choi, *et al*., "A new fault location algorithm using direct circuit analysis for distribution systems," *IEEE Transactions on Power Delivery*, vol. 19, no. 1, pp. 35-41, 2004.

[7] Z. Galijasevic and A. Abur, "Fault location using voltage measurements," *IEEE Transactions on Power Delivery*, vol. 17, no. 2, pp. 441-445, 2002.

[8] J. Kim, M. E. Baran, and G. C. Lampley, "Estimation of fault location on distribution feeders using PQ monitoring data," in *Proc. IEEE Power Engineering Society General Meeting*, 2007.

[9] V. N. Gohokar and M. K. Khedkar, "Faults locations in automated distribution system," *Electric Power Systems Research*, vol. 75, no. 1, pp. 51-55, 2005

[10] J. J. Mora, G. Carrillo, and L. Pérez, "Fault location in power distribution systems using ANFIS nets and current patterns," in *Proc. IEEE/PES Transmission & Distribution Conference and Exposition: Latin America*, 2006, pp. 1-6.

Qi Yin was born in Sichuan Province, China. She received the M.Eng. degree in electrical engineering and its automation from Sichuan University, Chengdu, China. Her research focuses on. Her research is primarily related to smart grid, dispatching and operation, power electronics and drives. She is currently working as an engineer with State Grid Deyang Power Supply Co. Ltd., China. She is director of regional dispatch center of State Grid Deyang Power Supply Co. Ltd.

Rui Ding was born in Sichuan Province, China. He is working as an engineer with State Grid Deyang Power Supply Co. Ltd., China. His research interests focus on smart grid including fault location, machines and power transmission lines. He has extensive research experience in modelling of fault location in self-healing distribution networks. He has involved in many large scientific research projects of smart grid.