Electrical Power and Energy Systems 102 (2018) 11–22

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

A novel single-phase-to-earth fault location method for distribution network based on zero-sequence components distribution characteristics

Liang Rui[a,b,*], Peng Nan[a], Yang Zhi[a], Firuz Zare[c]

[a] School of Electrical and Power Engineering, China University of Mining and Technology, Xuzhou, Jangsu 221116, China
[b] Jiangsu Province Laboratory of Electrical and Automation Engineering for Coal Mining, Xuzhou, Jangsu 221116, China
[c] The University of Queensland, St. Lucia, 4072 Brisbane, Australia

ARTICLE INFO

Keywords:
Zero-sequence components
Distributed parameter
Fault factor
Distribution features
Single-phase-to-earth fault

ABSTRACT

Based on distribution characteristics of the zero-sequence voltages and currents of the distributed lines, this paper proposes a novel single-phase-to-earth fault (SPTEF) location scheme for distribution network. Firstly, the distributed parameter model of distribution feeder lines is appropriately simplified according to Taylor series expansion of the hyperbolic functions in the model. The fault factor is constructed to select the faulted feeder. Then, the distribution features of the zero-sequence voltage (ZV) along the feeder line are analyzed. In each section of the faulted feeder, golden section search algorithm is adopted to distinguish the faulted section. Finally, based on the concept of maximum fault current, accurate fault location is realized by genetic algorithm (GA). A radial distribution network model containing different types of distribution lines is established in PSCAD/EMTDC. The calculation results of MATLAB prove the validity, reliability and accuracy of the proposed fault location scheme.

1. Introduction

With the rapid progress of the smart distribution grids construction, electric power companies are confronted with new challenges, among which reliable, fast and accurate fault location is of great significance for expediting power restoration, reducing maintenance expense and improving service quality. Due to the fact that ***neutral non-effectively earthed operating mode*** and complex structure are widely adopted in Chinese distribution grids, fault location, especially most common SPTEF location, becomes more difficult. According to statistics, SPTEF accounts for roughly 80% of the total fault [1]. Although the faulted system could continue operating for some time after SPTEF, it will, if not addressed promptly and effectively, get even worse and cause more damage to both customers and utilities. Therefore, SPTEF location for distribution network is the issue this paper mainly focused on.

In the past few years, many researchers have explored various SPTEF location methods for distribution grids. These methods could be grossly divided into two categories: travelling wave- based methods and impedance-based algorithms.

A single-terminal traveling wave-based fault location methodology for radial distribution network is presented in [2]. The preliminary fault distance is calculated based on the time difference of arrival (TDOA) between zero-mode and aerial-mode voltage traveling waves and their velocities. Another double-terminal traveling wave-based fault location scheme for distribution network is introduced in [3]. A traveling wave and impedance combined fault location method is proposed in [4]. Considering the characteristics of power distribution networks, several candidate fault locations are calculated using impedance method and the accurate fault location is determined based on the relationship between the transients frequency and fault distance.

Although traveling wave based methods have the advantage of high accuracy and robust to arcs, the reflection and refraction of traveling waves are complex due to the characteristics of power distribution networks which restrain the application of this kind of methods. Compared to traveling wave based fault location methods, the impedance methods are more appropriate for low implementation cost which leads to a broader application of them.

Ref. [5] proposes a voltage sag search algorithm to locate SPTEF in distribution network. The possible fault locations are firstly determined by an impedance-based method. Then the same fault is simulated in these locations to establish the voltage sag data bank containing the magnitude and phase differences between the sending and receiving end voltages of the feeder lines. The real faulty section is identified by matching the real measured voltage sag with the data in data bank. In paper [6], the concept of maximum fault current is proposed based on distributed parameter model of feeder lines. After obtaining the

* Corresponding author at: School of Electrical and Power Engineering, China University of Mining and Technology, Xuzhou, Jangsu 221116, China.
E-mail address: liangrui@cumt.edu.cn (L. Rui).

https://doi.org/10.1016/j.ijepes.2018.04.015
Received 3 October 2017; Received in revised form 19 February 2018; Accepted 17 April 2018

sequence components of the voltages and currents at both terminals of the fault feeder line via symmetrical component method, the real fault location is determined by searching the maximum value of the zero-sequence fault current along the line. In Ref. [7], an impedance method considering load variation is presented, which is suitable for large distribution networks and different fault types. In paper [8], the fault location equation, based on the hypothesis of pure resistive fault, is iteratively solved in each feeder section and the calculated fault distance which lies in the length of the corresponding section is taken as the real fault distance. A novel fault location scheme based on the generalized admittance matrix and load demand estimation is presented in Ref. [9]. The equivalent admittance matrix of the faulted feeder section is firstly calculated and load currents are estimated at the same time. Then the faulted line segment and fault location are identified through the comparison of the calculated fault current and the measured one. The authors in paper [10] put forward a method for bolted SPTEF locating. After the load demands of the faulted feeder estimated by means of a load flow procedure, known as backward/forward sweep method, the current distribution of the fault section can be obtained. The faulted line segment judgment and the fault location calculation are achieved by checking the change of the bus voltages of the faulted phase and searching the zero voltage point, respectively. Literature [11] introduced a circuit-analysis method to locate fault in distribution grids. The equivalent two-port equations of the circuits of the upstream part, fault part and downstream part are established with several unknown coefficients. Fault location calculation is carried out by solving the equations obtained from the matrix. An active fault location scheme for loop distribution network is applied in paper [12]. Through the analysis of the change of ZC before and after closing the loop switch, the faulted section could be identified. Then the feature values of the ZC at the starting end of the faulted section are extracted via db4 wavelet and input into the adequately trained support vector machine to realize accurate fault location. Ref. [13] introduces a novel fault location algorithm for power distribution feeders. With regard to different fault types, the accumulated reactance and calculated reactance of each feeder section are obtained according to the topology and coefficients of the corresponding feeder lines. The final fault location combining the information of other field intelligent devices (FIDs) is realized.

Most recently, a concept of minimum fault reactance used for fault location is presented in some research work [14,15]. The fault location method in paper [14] utilizes the data acquired from the main substation and the distributed generators to calculate the fault voltage and current based on lump parameter model of distributed lines. Then the fault reactance could be described and the fault distance corresponding to the minimum fault reactance is determined by Fibonacci search algorithm. Although paper [15] used the same concept, the fault voltage and current are obtained through thevenin's equivalent. A state estimation of branch currents was employed in literature [16]. First of all, the faulted area is distinguished with a wide range of the information from FIDs. The nearest node to fault location is then determined by calculating the index defined in advance. The fault location is finally calculated according to the change law of the angle difference between the measured node voltage and the calculated fault current. The idea of calculating the parameters online by using the synchrophasor measurements is presented in Ref. [17]. After determining the thevenin's equivalent of the faulted feeder section, the accurate fault location is achieved by solving the fault ZV equations based on lump parameter model. In addition, some other methods, such as fault indicators (FIs)-based method [18] and multi-source information-based scheme [19], were also put forward. The core idea of these methods is to locate fault by checking the state of the field devices, like circuit breakers, ISs, FIs, etc.

Though the travelling wave-based methods have been widely applied to transmission line fault location for its high accuracy, the fault location accuracy of distribution systems using this kind of method [2,3] can be sensitive to quite a few factors, such as the complex structure of network topology, short length of lines and so on. Therefore, the impedance-based methods have been playing an important role in distribution system fault location in the past few years. However, despite the advantages of these methods, some of them need a large data bank [5,16], some of them need a mount of computations [9,10,15], and some other methods [6,17] only focus on the accurate fault location for one distribution line rather than for the whole distribution network. The main characteristics of the aforementioned state-of-the-art impedance-based fault location methods and the proposed method are summarized in Table 1.

Table 1
The main characteristics of the state-of-the-art and proposed fault location methods.

Reference	[11]	[6]	[8]	[12]	[10]	[17]	[9]
Line model	D	D	D	L	L	L	L
Load estimation	×	×	√	×	√	×	√
Network type	RD	SL	RD	RD	RD	SL	RD
Source type	SS	SS	SS	SS	SS	MS	SS
Laterals	√	×	√	√	√	√	√
Fault type	All	SPTEF	All	All	SPTEF	All	All
Fault impedance	Imp	Imp	Re	Re	Re	Re	Imp
Calculation domain	PD	SD	PD	SD	PD	SD	PD
Reference	**[12]**	**[5]**	**[15]**	**[22]**	**[16]**	**[14]**	**Proposed method**
Line model	L	D	L	L	×	L	SD
Load estimation	×	√	×	√	√	√	×
Network type	LP	RD	RD	RD	RD	RD	RD
Source type	SS	SS	MS	MS	SS	MS	SS
Laterals	×	√	√	√	√	√	√
Fault type	SPTEF	All	All	All	All	All	SPTEF
Fault impedance	Re	Re	Imp	Re	Re	Imp	Imp
Calculation domain	SD	SPD	SPD	PD	PD	PD	SD

Symbol Meanings in Table 1:
• D/L/SD: distributed parameter/lump parameter/simplified distributed parameter model.
• LP/RD/SL: loop network/radial network/single line.
• SS/MS: single source/multiple sources.
• All/SPTEF: all faults/single-line-to-ground fault.
• Imp/Re: impedance fault/resistive fault.
• PD/SD/PSD: phase domain/sequence domain/phase and sequence domain.
• √/×: this aspect is/not considered.

This paper proposes an explicit, accurate and applicable SPTEF location scheme for single-terminal radial distribution systems with mixed feeder lines. The presented fault location scheme considers the zero-sequence network of distribution lines and utilizes the zero-sequence voltages and currents acquired at both terminals of each feeder lines to pinpoint the fault. The main contributions of this paper are presented as follows:

(1) A novel fault location method for SPTEF is proposed based on the distribution characteristics of zero-sequence currents and voltages along the distribution feeders after SPTEF occurs.
(2) Compared with other latest SPTEF location methods, the proposed fault location method has the advantages of low fault location error, network topology independence and low computational burden.

The remainder of this paper is organized as follows. The complete fault location scheme is described in Section 2 where the model simplification, faulted feeder selection, faulted section identification and accurate fault location are shown in Sections 2.1-2.4, respectively. The simulation test, related results and discussions are presented in Section 3. Section 4 draws the conclusions.