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A novel method for locating faults on distribution systems

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ABSTRACT

Accurate location of faults in an electric power distribution system is important in maintaining system reliability. Diverse methods have been proposed in the past, which usually have different assumptions and thus are applicable to specific circumstances. This paper attempts to put forth a novel, general fault location method that is applicable to distribution networks with unbalances and multi-sources by employing voltages and currents at the local substation. The method considers feeder shunt capacitances and is applicable to both overhead and underground networks. The method does not require the fault type to be known, and is applicable to any type of faults. The method is based on bus impedance matrix that enables the establishment of the equations governing the relationship of the measurements and the fault location. Evaluation studies have demonstrated the effectiveness of the proposed method and its robustness with respect to potential measurement errors and load variations.

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1. Introduction

Accurate location of faults in electric power distribution systems plays an essential role in system restoration and reliability improvement [1–3]. Significant efforts have been spent in the past for developing various types of fault location methods.

A method based on voltage sag data is proposed in [4] to pinpoint the fault location without considering fault resistances. The authors of [5] design an algorithm that makes use of superimposed quantities and iteratively estimates equivalent admittance matrices at both sides of the assumed faulted section. Voltage sag data are harnessed in [6] to locate the fault with the aid of iterative short circuit studies, with the assumption that the fault occurs on a node. In [7], fault location is identified by comparing feeder currents at different sections, where available data may be captured from various automation devices. Utilization of local measurements and network data to find the fault location is discussed in [8]. Ref. [9] derives the fault location by calculating the apparent impedance, and the load is represented by equipment impedance. Measurements from power quality meters are exploited to determine the fault location in [10], where the fault location is estimated through iterative simulation studies. A method for radial systems is described in [11] with suggested ways of ranking possible multiple fault location estimates. The fault-path-current concept is proposed in [12], and iterative short circuit studies are carried out to match the actual measurements. Employment of circuit analysis is expounded in [13–15] to simplify the fault location process. However voltages and currents for the assumed faulted feeder section still need to be iteratively computed. A fault location method is elaborated in [16] based on the principle that system parameters may experience steep changes due to a fault. An approach for trimming down multiple possible fault location estimates due to presence of laterals is provided in [17]. To eliminate or reduce the need of iterative short circuit analysis and iterative voltage and current updates, methods based on direct short-circuit analysis are proposed in [18]. In [19], a method is proposed based on local measurements, which assumes the fault type is provided and is applicable to radial distribution systems.

For underground distribution feeders, fault location poses extra challenges due to presence of large shunt capacitances of cables, ignorance of which may lead to tangible fault location errors [20,21]. A method based on distributed parameter line model by assuming the system is balanced is presented in [20]. Ref. [21] tackles this problem by iteratively compensating the effects of shunt capacitances. These methods are applicable to radial distribution systems. Article [22] presents a two-terminal fault location method for lines little longer than half-wavelength. A method for locating faults on transmission lines using voltage and current at a single bus is described in [23].

Although there exist various fault location methods for transmission lines [24–27], such techniques are generally not applicable to distribution systems since distribution systems are usually unbalanced and are equipped with very few recording devices, usually located at the main substation.

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This paper aims to propose a general fault location method that is applicable to radial systems or multi-source systems with unbalances, and considers feeder shunt capacitances. The new method obviates the demand for the fault type information and provides a solution for any type of fault, which eliminates errors due to possible fault type misidentification [1,28].

The proposed methods assume that the distribution system network parameters and topology are known, and are based on fundamental frequency phasors. The proposed methods fully model each section of the feeder, and are applicable to non-homogenous feeder that may have varied parameters for each feeder section.

In the rest of the paper, Section 2 presents the new fault location method. Evaluation studies based on simulated data are reported in Section 3, followed by the conclusion.

2. Proposed new fault location method

Fig. 1 depicts a typical power distribution system, including unbalanced loads, a remote source, and main feeders and laterals, which can be overhead or underground cables. For such a system, the following sections present the novel fault location method.

The proposed fault location method is applicable to any type of faults, including single line to ground faults (LG), line to line faults (LL), line to line to ground faults (LLG), three phase faults (LLL) and three phase to ground faults (LLLG) [18].

Existing fault location approaches need to first identify the fault type or assume the fault type to be already decided by another program, and then derive the formula for each type of fault. Erroneous identification of the fault type will lead to wrong fault location calculation. Hence this work will develop a general method that does not need to identify the fault type and thus eliminates the potential error due to fault type misidentification.

2.1. Basic idea of the fault location method

The proposed method is based on bus impedance matrix concept. The voltage and current quantities at any bus during the fault can be expressed in terms of the bus impedance matrix of the faulted network, which is a function of the fault location. The given measurements at the local substation, and the voltages and currents at the fault point can be written in terms of the fault location. Since the fault resistances only consume real power, the imaginary power consumed by fault resistances will be zero. The fault location can thus be obtained.

To cope with intrinsic unbalances, the distribution system will be represented in the three-phase domain, and the phase-domain short circuit analysis technique will be harnessed to derive the fault location. Therefore, the proposed method will naturally accommodate any unbalance in the system. The method will be applicable to non-radial networks.

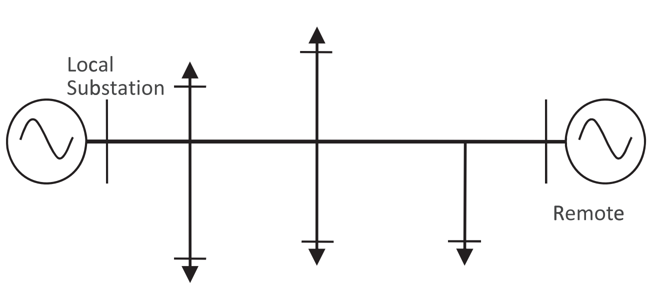

Fig. 1. A sample power distribution system.

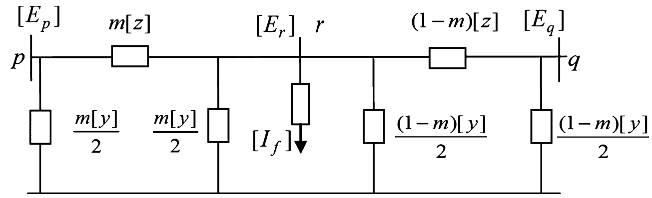

Fig. 2. A section of a power distribution system.

2.2. Derivation of transfer and driving point impedance

Fig. 2 shows the one-line diagram of a section of a distribution system, where a three-phase feeder is assumed. Note that the remaining part of the distribution system is not shown. The following notations are adopted:

$[\cdot]$: designation of a matrix or vector;
n: the total number of nodes of the entire distribution system without counting fault nodes r_1, r_2, and r_3. Note that a node corresponds to a single phase. A three-phase bus consists of 3 nodes, and a two-phase bus has 2 nodes, etc.
p, q: buses of the sample feeder. Bus p comprises nodes p_1, p_2 and p_3, and bus q includes nodes q_1, q_2, and q_3;
r: fault bus, containing nodes r_1, r_2, and r_2;
$[E_p]$: node voltage vector, $[E_p] = [E_{p1},E_{p2},E_{p3}]^T$, with T symbolizing vector/matrix transpose. E_{p1}, E_{p2} and E_{p3} are voltages at node p_1, p_2, and p_3, respectively;
$[E_q]$: node voltage vector, $[E_q] = [E_{q1},E_{q2},E_{q3}]^T$. E_{q1}, E_{q2} and E_{q3} are voltages at node q_1, q_2, and q_3, respectively;
$[E_r]$: node voltage vector, $[E_r] = [E_{r1},E_{r2},E_{r3}]^T$. E_{r1}, E_{r2} and E_{r3} are voltages at node r_1, r_2, and r_3, respectively;
$[I_f]$: fault current through fault resistances, $[I_f] = [I_{f1},I_{f2},I_{f3}]^T$. I_{f1}, I_{f2}, and I_{f3} are fault currents for phase 1, 2 and 3, respectively;
$[z]$: the total series impedance matrix of the feeder, with a dimension of 3 by 3;
$[y]$: the total shunt admittance matrix of the feeder due to shunt capacitances, with a dimension of 3 by 3;
m: per unit fault distance from bus p to the fault point;
$[Z_0]$: the bus impedance matrix of the entire pre-fault distribution system in phase domain, excluding fictitious nodes r_1, r_2, and r_3. $[Z_0]$ will be of size n by n;
$[Z]$: the bus impedance matrix in phase domain of the entire distribution system including the fictitious fault nodes. $[Z]$ will be of size $(n+3)$ by $(n+3)$;
Z_{kl}: the element in the kth row and lth column of $[Z]$;

In implementation, the fault nodes are numbered as follows: $r_1 = n+1$, $r_2 = n+2$, and $r_3 = n+3$.

Matrix $[Z_0]$ can be readily developed. It can be shown that the first n rows and n columns of $[Z]$ are identical to $[Z_0]$, and the other rows and columns of $[Z]$ consist of transfer and driving point impedances related to the fault nodes. The transfer and driving point impedance of $[Z]$ related to the fault nodes can be obtained as

$$[Z_{kr}] = [w]^{-1}\left(\frac{[Z_{kp}]}{m} + \frac{[Z_{kq}]}{1-m}\right) \tag{1}$$

$$[Z_{rr_i}] = [w]^{-1}\left(\frac{[Z_{pr_i}]}{m} + \frac{[Z_{qr_i}]}{1-m} + [z][u_i]\right), \quad i = 1, 2 \text{ or } 3 \tag{2}$$

$$[w] = \frac{[z][y]}{2} + \frac{[u]}{m(1-m)} \tag{3}$$

where $[Z_{kr}]$ is the transfer impedance between node k and fault nodes; $[Z_{rr_i}]$ is the driving point and transfer impedance related to

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