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# Comparison of impedance based fault location methods for power distribution systems

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**Abstract**

Performance of 10 fault location methods for power distribution systems has been compared. The analyzed methods use only measurements of voltage and current at the substation. Fundamental component during pre-fault and fault are used in these methods to estimate the apparent impedance viewed from the measurement point. Deviation between pre-fault and fault impedance together with the system parameters are used to estimate the distance to the fault point.

Fundamental aspects of each method have been considered in the analysis. Power system topology, line and load models and the necessity of additional information are relevant aspects that differentiate one method from another. The 10 selected methods have been implemented, tested and compared in a simulated network. The paper reports the results for several scenarios defined by significant values of the fault location and impedance. The estimated error has been used as a performance index in the comparison.


*Keywords:* Fault location; Impedance based methods; Power distribution systems; Power quality

## 1. Introduction

Power quality requirements resulting from the deregulated electrical markets have motivated the improvement of fault location methods in distribution systems to speed up the restoration process [1]. Faults and outages affect power quality in terms of service continuity and disturbance propagation. Utilities are forced to improve quality indexes associated to these phenomena in order to be competitive in the current electric open market [2,3]. With this aim, several strategies for fault location in distribution systems have been developed.

Some methods have been adapted from of those proposed for fault location in transmission systems, i.e. high frequency component based methods (e.g. [4]) or those that analyze travelling waves (e.g. [5]), but considering the specificity of distribution systems (single end measurements, radial operation, etc.). For example in [6] high frequency components from travelling waves are analysed using wavelets in order to deduce the fault. In [7] correlation analysis between transmitted and reflected waveform is performed, whereas in [8] peak detection on the reflected waveform is used to identify possible fault locations base on the delays estimated. A drawback of these methods is the necessity of measuring devices with a very high sampling rate (MHz). On the other hand, impedance based methods works on steady states values of currents and voltages during the fault to estimate an apparent impedance (or reactance) that is directly associated to a distance to the fault. The main drawback of impedance-based methods is the multi-estimation due to the existence of multiple possible faulty points at the same distance.

Difficulties in developing effective fault location methods in distribution systems are due to the radial topology, the existence of short and heterogeneous lines and also a lower degree of instrumentation of these systems. Therefore, the join exploitation of available information has to be considered. Registers of voltage and current at substation must be complemented with additional knowledge to assist fault location procedure in distribution. Three different, but complementary, sources of

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knowledge can be distinguished: system knowledge, data history and external information.

System knowledge is necessary to build models. These models allow checking the consistency between the impedance calculated, from measured voltages and currents, and the nominal one. On the other hand, data history allows analyzing the relevance of waveform attributes and frequency of occurrence. The observation of, previously registered, similar behaviours may be used to infer possible location according to probabilistic models, e.g. [9,10]. Finally, external information as weather, existence of construction sites, consumer calls and so on, can be very useful to delimitate a searching area.

Despite the benefit of dealing with these three complimentary views of the fault, in this paper we have focused on those methods that exploit system knowledge for fault location. Ten methods based on the impedance calculation from measures of voltage and current in a single point have been compared. The use of currents and voltages for fault location is described in the early literature as the reactive component method [11]. A simplified model of the feeder, equivalent to the voltage divider model used in [12], is used to explain the dependence of sag magnitude on the distance to the fault. These simple models differ in the availability of currents (in the reactive component method) or in the necessity of the source/transformer impedance (in the voltage divider model) to compute the equivalent impedance.

The nine additional methods analyzed in this paper are improvements of this simple approach to cope with the complexity (radial topology, heterogeneity of lines and variety of loads) of distribution networks. Also the uncertainty, in the estimation of the distance to the fault, caused by the unknown value of fault resistance is treated in these models under different assumptions.

Srinivasan and St-Jacques [13] proposed one of the first algorithms considering the existence of loads in a radial transmission system. Yang and Springs [14] propose a fault location method which corrects the fault resistance effects while Aggarwal et al. [15,16] propose a methodology based on the analysis of the superimposed components. The methodology proposed by Novosel et al. [17] focus on the idea applied for short transmission lines with loads and laterals represented by a lumped parameter impedance model placed behind the fault. Zhu et al. [10] model loads as an injected current and they analyze current patterns for fault location. In Das [18,19] first, the faulted section is located and next the distance to the fault in this section is calculated. It considers laterals and load taps. The method proposed by Saha and Rosolowski [20] estimates the fault location by comparing the measured impedance with the calculate feeder impedance assuming faults each section line. Finally, Choi et al. [21] differs from the previous approaches because refuses to apply the classical symmetrical component theory [22] to analyze unbalanced power systems.

The paper presents in Section 2 the signal processing requirements of each method. Next, in Section 3, the power system assumptions required in the methods are compared. In Section 4 we analyze the requirements from the point of view of line section model. The load modelling and the necessity of additional information is reviewed in Sections 5 and 6, respectively. Finally last two sections are devoted to test the algorithms in benchmark and conclude about its performance.

## 2. Fundamentals of the methods

### 2.1. General methodology

The nominated methods use the distribution system parameters and combinations of pre-fault, fault and post-fault values of current and voltage, measured at fundamental frequency on a single line end; typically at the substation. Pre-fault values are used to estimate the initial conditions of the power circuit before the fault. Fault values are used as known values in a set of equations where both, the distance from the measurement point to the fault location and the fault resistance are the unknown variables. From the 10, only [10] uses post-fault values of current or voltage to reduce the multiple estimation problem induced by the existence of multiple fault points in the network with the same impedance. The method proposes the identification of patterns of the disturbance waveform with the operation of protective devices as well as changes in substation load.

### 2.2. Treatment of measurements

All methods considered in this paper use the fundamental rms values of voltage and current measured at the substation. Pre-fault and fault values of these variables are used in [9,13,17,18,23] to estimate the load parameters while [14,16], only make use of the rate of change between pre-fault and fault voltage and current rms values. Others as the reactive component method [11] and a recent approach proposed in [21], do not use the pre-fault measurements.

Faulted circuit analysis is performed by symmetrical component analysis in [13,14,17,18,23,24], while approaches presented in [10,14–16] use phase voltage and current vectors to perform a direct circuit analysis.

## 3. Distribution system topology

The most important aspects considered by fault location methods are directly related to the characteristics of distribution systems:

(a) Heterogeneity of feeders given by different size and length of cables, presence of overhead and underground lines, etc.
(b) Unbalances due to the untransposed 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.

These aspects introduce errors in the estimation of the fault locations performed by means of a simplified model. Its reduction has motivated the majority of approaches compared in this paper.

Heterogeneity of distribution lines could be considered in [10,14,15,17,18,23,24] since these algorithms consider the analysis of each section line independently.