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Robustness of a generalized impedance based fault locator considering distorted measurements

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ABSTRACT

Power quality is a relevant aspect in power distribution systems, which among others, considers service continuity and distortion of the current and voltage waveforms. This paper proposes a generalized application strategy of an impedance-based fault location method for power distribution systems and also analyses the effects of the waveform distortion on its performance, by comparing the location errors in the case of distorted and not distorted measurements of voltages and currents. Different sources of waveform distortion, such as transformer saturation, low resolution of the measuring devices, harmonics, low sampling frequency, signal noise and DC offset are analysed. According to the obtained results, the worst performance of the fault location method is obtained in the case of distortions caused by current transformer saturation. An additional circumstance of reduced performance is in such cases of simultaneous presence of low sampling rate and high harmonic distortion. Finally, the analysed values of resolution, signal noise, presence of DC offset and potential transformer saturation, cause a negligible reduction on the locator performance.

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1. Introduction

Power quality is one of the main issues in power distribution systems. Service discontinuity and waveform distortion of the input voltages and currents might impact equipment connected to the power grid; some of them would keep operating regardless changes of waveform, while others work improperly or stop functioning [1,2]. In the case of waveform distortion, the research is oriented to determine which cases could be detected and mitigated [1]. The service discontinuity is a problem where the power distribution system design and the fault management play an important role as solution alternatives [3–5]. It is widely recognized that faults cause most of the problems of service discontinuity and then fault location strategies are commonly used [6–25].

In recent years, significant research efforts have been devoted to the development of methods for fault location, aimed to assist utility operators in expediting service restoration, and consequently reducing outage time and relevant costs. According to Ref. [4], distribution network fault section identification methods can be classified into impedance-based methods [6–12], algorithms based on sparse measurements [13], traveling waves-based methods [14], learning-based methods [15–17], and integrated methods [5,18,19]. It is recognized that impedance-based methods are the most mature class, and the subject of most of the literature. The sparse measurements-based algorithms are also based on the fundamental frequency component of the measured current and voltage, but provided by sparse meters installed throughout the network. The third class of methods is based on the analysis of the high-frequency traveling waves, originated by the fault. The learning-based fault locators use the information in fault database to determine a possible faulted zone and to reduce the multiple estimation problem. Finally, the integrated methods use combination of the previous explained approaches. According to the analysed papers, the effects of distorted voltages and currents on the fault locator performance have not received major attention [20–23].

Additionally, the impedance-based methods, which is the focus of this paper, are normally defined only at the faulted line section, but a generalized application strategy, which makes these methods useful in any power distribution system, is not commonly found. On the other hand, the assumption of ideal sinusoidal waveforms as inputs of the fault locators is frequently considered [3,5,17], as is presented in Ref. [4], where more than 45 impedance based approaches are analysed.

Considering the exposed, this paper is focused on the generalized implementation and evaluation of an impedance based fault locator, taking into account the analysis of common wave-

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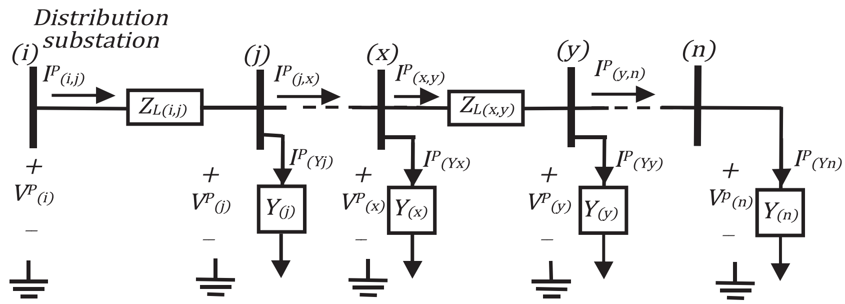

Fig. 1. Equivalent model of an unfaulted power distribution feeder.

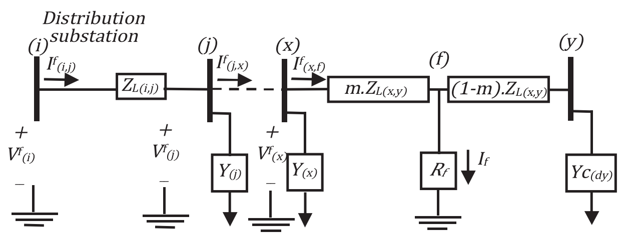

Fig. 2. Equivalent model of a faulted power distribution feeder.

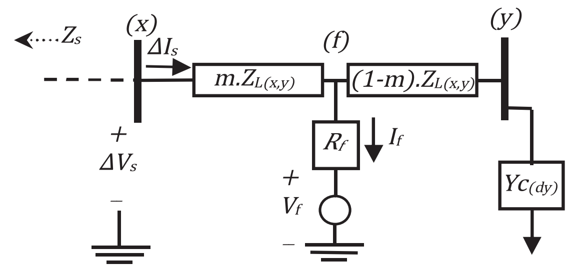

Fig. 3. Equivalent superimposed circuit for the method.

form distortion cases. The considered distortions are produced by the measuring devices or by the electromagnetic environment [1,2,20–22]. Studies as the one herein is oriented to assist with finding a balance between the investments on equipment and the minimum requirements of the fault locator for power distribution systems.

This paper is organized as follows: section two provides the basic aspects for the understanding of the analysed fault locator and the definitions of the considered power quality disturbances. Then, the generalized implementation strategy and the determination of the waveform distortion are described in section three. Section four presents the tests and the result analysis. Finally, section five is devoted to highlight the main findings of the presented research.

2. Basic theoretical aspects

This section presents the basic aspects used in this paper. Detailed information is out of the scope of this paper but it will be obtained at the provided references.

2.1. Fault location basis

The impedance based fault location methods consider measurements of voltage and current at a single end and the model of the power distribution system [4]. Next, the main steps of the fault location method are described:

2.1.1. Estimation of the fault type

The fault type is required to estimate the distance to the faulted node. To determine the fault type, a strategy based on the phase and the zero-sequence overcurrent is used [9]. This strategy proposes a comparison between the measured phase currents and a defined threshold current, to determine the faulted phases. Additionally, a comparison between the estimated zero sequence current and the ground threshold current is performed, to determine the presence of ground faults.

2.1.2. Estimation of the fault distance and resistance

The power distribution systems in Figs. 1 and 2 represent the unfaulted and faulted feeders, respectively. The following variables are defined: $V^{\beta}_{(x)}$ identifies the phase voltages at node (x); $I^{\beta}_{(x,y)}$ corresponds to the phase currents flowing from node (x) to node (y); $I^{\beta}_{(Y_x)}$ is the phase currents in the load admittance $Y_{(x)}$; $Z_{L(x,y)}$ identifies the phase impedance of the line section between nodes (x) and (y); $Z_{c(dy)}$ corresponds to the phase equivalent impedance downwards node (y); variable β is used to define the pre-fault (p) or fault (f) steady states and m is the per unit fault distance from node x to the faulted node f. The $Z_{c(dy)}$ in Fig. 2 is obtained from Fig. 1 using Eq. (1).

$$Z_{c(dy)} = \frac{V^{p}_{(x)}}{I^{p}_{(x,y)}} - Z_{L(x,y)} \tag{1}$$

The estimated impedance from the node x (Z_{est}), in the faulted power system in Fig. 2 is given by Eq. (2). It contains three unknowns (m, R_f and I_f).

$$Z_{est} = \frac{V^{f}_{(x)}}{I^{f}_{(x,f)}} = mZ_{L(x,y)} + R_f \frac{I_f}{I^{f}_{(x,f)}} \tag{2}$$

Additionally, k_s is defined as the ratio between the fault current I_f and the current at the fault steady state $I^{f}_{(x,f)}$ estimated at the node x, as is given by Eq. (3).

$$k_s = \frac{I_f}{I^{f}_{(x,f)}} \tag{3}$$

One of the differences of the proposed method with the basic reactance approach, is the consideration of the angle of the fault impedance, given by the angle of k_s. To consider the variations of the power distribution system during fault and pre-fault conditions, the superimposed component concept is used, which is represented by the equivalent circuit shown in Fig. 3 [10].

The method is based on the estimation of the fault impedance as seen from both ends of the faulted line section, it uses the pre-fault and fault steady states of voltages and currents. From Fig. 3, the impedance (Z_s) upstream node x, is estimated using Eq. (4).

$$Z_s = -\frac{\Delta V_s}{\Delta I_s} \tag{4}$$

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