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An impedance relation index to predict the fault locator performance considering different load models

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ABSTRACT

This paper aims to discuss the influence of load modeling on power system behavior and also proposes a relation index (α) based on the estimated impedance, to predict the accuracy of a fault locator. The 24.9 kV IEEE 34 nodes power distribution system modeled using ATP and considering load models as constant impedance, constant current, constant power and hybrid, all coded using ATP *Models* is used for tests. As a result, an analysis of the fault location using the proposed relation index is performed. The results show that both the load model and magnitude uncertainties affect the fault location and the relation index (α), which directly influence the locator performance. Finally, as it was demonstrated, high values of α imply low errors in fault location.

1. Introduction

Power distribution systems are an important part of the power network and are directly related to the end user, then the requirements of high quality of power are mandatory [1]. This is the reason why the research activity in power quality has experienced a remarkable development in recent decades, specifically in relation to the waveform, service continuity and customer assistance [2]. The current importance of these aspects is related to the active participation of private resources in the electricity sector, which requires the establishment of adequate quality indexes and remuneration guidelines [3,4]. Product quality means satisfying conditions of wave quality (or power) and supply continuity [5]. The problem discussed here is strongly associated with supply continuity.

Faults in power distribution systems deteriorate the continuity indexes, and therefore their improvement has become an important goal for utilities, since this will avoid penalties. Currently, there are several applications which estimate both the distance to the fault and the faulted zone, using techniques such as model-based methods (MBM) and knowledge-based methods (KBM) [5]. However, an important aspect for the adequate performance of the fault locators is the power system modeling.

On the other hand, normally the records obtained from fault events in power system simulation are appreciably different from the measurements obtained at the utility. These differences affect the performance of fault locators, since all the methods are based on the pre-fault and fault steady states of voltages and currents [5]. Information uncertainties at the distribution utilities, lead to assume modeling parameters, which normally are not the same as those in the real power system, as the value and type of load, among the most important ones. Additionally, most of the reported fault location applications use constant impedance load model [6–8]. Considering the dynamics of the electrical power system, the set of protective devices and loads, this paper is devoted to analyze the possible influence of load behavior on fault location. Also, a relation index based on the fault impedance (α) is proposed to give an indication of the fault locator performance in a power distribution system.

This paper proposes an analysis considering several load models (constant impedance, constant current, constant power, and hybrid models [6,9]) and variation on the load magnitude for fault location, by using the proposed relation index (α) in a test power system. Different shunt faults (single-phase to ground, phase to phase and three-phase), fault resistances (R_f) and distances from the main power substation are also analyzed.

2. Basic theoretical aspects

In this section, the basic aspects required for this research are presented. Specific details are out of the scope

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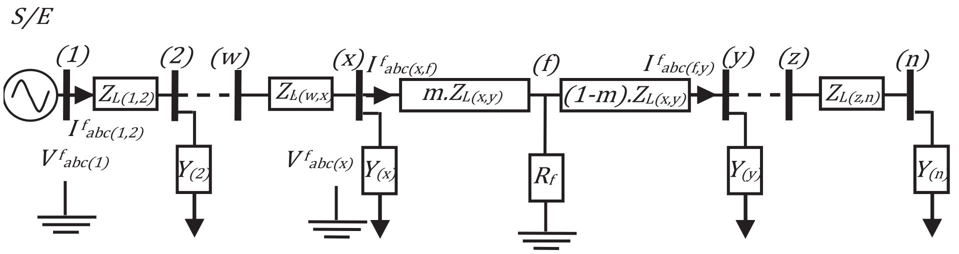

Fig. 1. Single-line diagram of faulted system between the nodes (*x*) and (*y*).

of this paper, but these could be found in the provided references.

2.1. Static load modeling

Static load models are those that generally can be represented as polynomial functions of the applied voltage [6–8]. In general, load is represented as (1).

$$\begin{aligned} &S = P_n \sum_{k=0}^{n_p} a_{pk}\cdot (V_{(x),p.u})^{b_{pk}} + jQ_n \sum_{k=0}^{n_q} a_{qk}\cdot (V_{(x),p.u})^{b_{qk}} \\ &s.t. \quad \sum_{k=0}^{n_p} a_{pk} = \sum_{k=0}^{n_q} a_{qk} = 1 \end{aligned} \tag{1}$$

where $V_{(x),p.u}$ is the phase voltage of the load in per-unit at the node (*x*), *n* denotes the nominal value, a_p/a_q indicates the power participation coefficient, n_p/n_q represents the maximum number of power participation coefficients (usually 3), and b_p/b_q are the characteristic power exponents. This model is commonly known as the ZIP load model (constant impedance Z_{cte}, constant current I_{cte} and constant power S_{cte}) [8].

On the other hand, a special case is presented in (2) to represent the exponential load model [6,8].

$$S = P_n \cdot (V_{(x),p.u})^{b_p} + jQ_n \cdot (V_{(x),p.u})^{b_q} \tag{2}$$

In this case, b_p and b_q are real values. If $b_p = 0$, the load has constant active power despite fluctuations in voltage magnitude (S_{cte}). If $b_p = 1$, the load has constant current despite fluctuations in voltage magnitude (I_{cte}). In the case of $b_p = 2$, the load maintains the same impedance despite fluctuations in voltage magnitude (Z_{cte}). The same consideration applies for the reactive power by varying the value of b_q.

2.2. Simulation software

The software used is the Alternative Transient Program (ATP), which helps to adapt the load model according to the voltage variation, and is therefore a useful tool for modeling the power distribution system [10,11].

Until now, the power distribution systems used for fault location were modeled using constant impedance loads which are normally estimated from the average values and statistical registrations of power, and also the rated values of the power transformers [6–8].

2.3. Fault location methods based on the circuit model (MBM)

There are a variety of methodologies proposed for fault location in power distribution systems. Some of them are based on the power system model (MBM), and use the steady state voltage and current measurements before and during the fault at one single line end, to locate the fault [5]. These are the most commonly used methods due to the easy implementation and high accuracy [12–15].

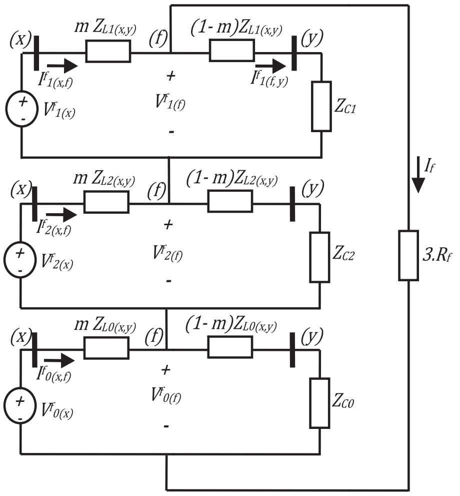

Fig. 2. Equivalent sequence circuit in case of single phase to ground fault at node (*f*).

Normally a fault location methodology is defined using a power system as shown in Fig. 1, where the line section between nodes (*x*) and (*y*) is faulted.

From Fig. 1, $V^f_{abc(i)}$ are the phase voltages in fault steady-state at the node (*i*); $I^f_{abc(i,j)}$ are the phase currents in fault steady-state, flowing from node (*i*) to node (*j*); $Y_{(x)}$ is the load admittance at the node (*x*); $Z_{L(x,y)}$ is the line section impedance in Ω, between nodes (*x*) and (*y*); R_f is the fault resistance and *m* is the fault distance in per-unit based on the line section length.

In case of a single phase to ground fault at node *f* between the nodes (*x*) and (*y*) of the power feeder in Fig. 1, the equivalent sequence network is presented in Fig. 2.

Sequence impedances, voltages and currents depicted in Fig. 2 are estimated using the transforming matrix **A** [16]. The equivalent load impedance at node (*y*) Z_{C1} is estimated using the pre-fault positive sequence of voltage at node (*x*) $V^p_{1(x)}$ and current flowing from node (*x*) to node (*y*) $I^p_{1(x)}$, as presented in (3).

$$Z_{C1} = \frac{V^p_{1(x)}}{I^p_{1(x,y)}} - Z_{L1(x,y)} \tag{3}$$

From Fig. 2, Eqs. (4) and (5) are obtained.

$$\begin{aligned} &V^f_{0(x)} + V^f_{1(x)} + V^f_{2(x)} - m[Z_{L0(x,y)}I^f_{0(x,f)} + Z_{L1(x,y)}I^f_{1(x,f)} \\ &\quad + Z_{L2(x,y)}I^f_{2(x,f)}] = 3R_f I_f \end{aligned} \tag{4}$$

$$I_f = \frac{Z_{L1(x,y)}I^f_{1(x,f)} + Z_{C1(x,y)}I^f_{1(x,f)} - V^f_{1(x)}}{Z_{L1(x,y)} - mZ_{L1(x,y)} + Z_{C1}} \tag{5}$$