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Advanced fault location strategy for modern power distribution systems based on phase and sequence components and the minimum fault reactance concept

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A generalized strategy for fault location in modern power distribution systems, which normally include distributed generation, is presented in this paper. The fault location method considers the phase and sequence network parameters and voltage and current measurements at the main substation and at the distributed generators, in pre-fault and fault steady states. The fault distance is estimated from the analysis of all section lines, which is required to determine if the fault is located in a radial or non-radial zone of the power distribution feeder; next, a specific equation is used to determine the exact location. The proposed methodology is validated in the IEEE 34-node test power system, where single-phase to ground, phase-to-phase and three-phase faults were tested, considering 51 different and optimally determined operational conditions. The proposed method has range of estimation errors from −2.8% to 3.2%.

1. Introduction

During the past few years, a growing interest in installing small generation units along distribution systems, which are known as distributed generators (DGs), was experienced. These DGs are used to take advantage of primary energy resources as wind and solar radiation, among others, and also to improve voltage profiles and to reduce constrains of transmission and distribution systems [1]. The presence of DGs implies that new studies aimed to analyze their effects for reliability, losses, voltage regulation, relay coordination and fault location, among others [2–4].

Additionally, the DG presence causes relevant operational changes in power distribution systems, such as non-radial supplied feeders, which has a direct consequence in the performance of the impedance-based fault locators. Although several methods have been proposed for fault location in power distribution systems, most of them are not well suited when DG is presented [5]. Additionally, most of the methods proposed for fault location in power distribution systems with DG do not consider the different operating conditions, and then these are tested normally at the rated or well-known conditions [6–15]. This situation does not offer the possibility of an adequate evaluation of the fault locator performance.

At the previous research, a fault location methodology aimed to consider only single-phase to ground faults, based on sequence components as proposed in [11]. This uses information of the circuit topology and measurements of voltage and current at the main substation and the DG substation; however, this methodology neglects line capacitance, and phase-to-phase and three-phase faults are not considered. Additionally, a criterion for the selection of the fault distance was not defined in the case of multiple solutions. On the other hand, a method for three-phase to ground fault location based on the estimation of the positive sequence impedance is proposed in [10]; however, line capacitance and load variations are not considered and the method is not generalized for single-phase or phase-to-phase faults. A methodology based on the system phase-components is presented in [12], which considers an unbalanced power distribution system, but it is limited to three-phase to ground faults and its efficiency is not tested considering load variations. In [13], there is an interesting approach, which considers the line shunt admittance matrix at the power system representation. The authors consider any fault type but tests are performed under the rated operational condition of the power system. An additional approach is proposed in [14] and is aimed to discuss a ranking of the available fault location methods that take into account

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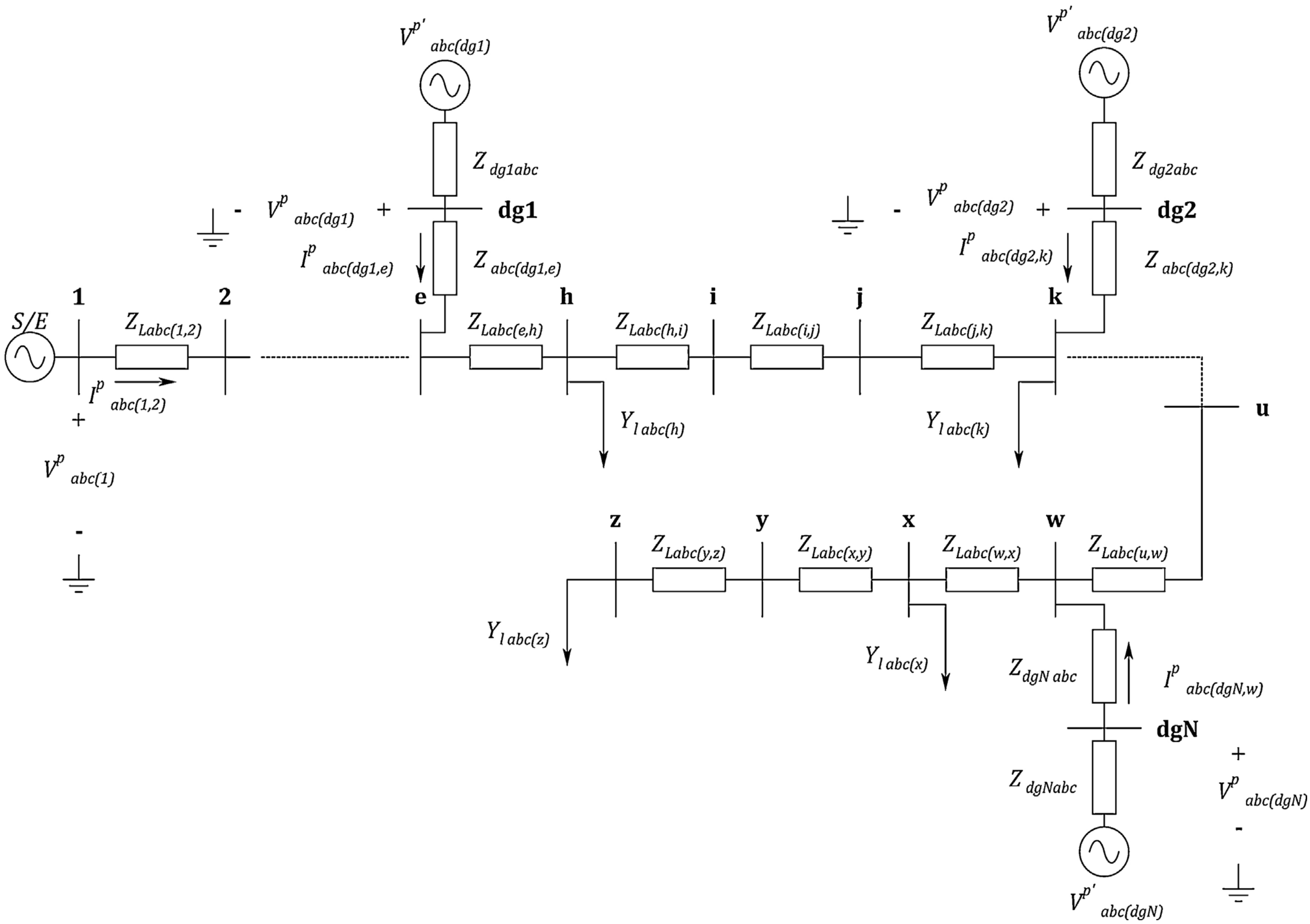

Fig. 1. Simplified power distribution system with *N* distributed generators.

application requirements and modelling limitations and uncertainties. This uses qualitative and quantitative analysis, and as a result, two impedance-based approaches were selected and tested in detail, considering the rated operating condition. In [15], authors propose a solution that eliminates or reduces iterative procedures applicable to all types of faults. The proposed methods are based on the bus impedance matrix. This paper neglects the shunt capacitances of feeders in the simulation model. Rated conditions of the power system are considered in tests. Finally in [16], a letter briefly presents a method for locating a fault in distribution systems using synchrophasor measurements. Using voltage and current phasor measurements at substations and/or feeder heads, candidate fault locations are identified by iterating every possible line segment. The tests, considering the rated operating condition, are commented on, where the solution is obtained by using a not described impedance-based method.

This paper is aimed to present a general methodology for fault location in power distribution systems with DG, considering the robustness of the method in the case of uncertainties associated to load variations and different DG penetration levels, and surpassing some of the main problems of the above-mentioned approaches. The method here proposed is oriented to use only measurements at the fundamental frequency component of current and voltage at the main power substation and at the DGs and the series and shunt parameters of a long line equivalent. The information required for the fault location are the fundamental phasors, during steady states of pre-fault and fault, for voltages and currents; these are available at protective relays, digital fault recorders and power quality metres. The measurements have to be synchronized and the fault time is normally used as the time reference. This makes the fault locator useful for most of the actual power distribution networks.

With regard to the contents, in Section 2, this paper presents the theoretical foundation of the proposed approach. The developed algorithm for the method implementation is completely described in Section 3. Tests, results and discussion are included in Section 4, and the most relevant conclusions of the research are summarized in Section 5.

2. Proposed fault location method

The proposed method is defined by using the simplified power distribution system as presented in Fig. 1, which consists of a main source (S/S), *N* distributed generators and several tapped loads. The power system upstream node **w** represents the non-radial circuit zones, where the fault current is supplied from the sending and the receiving-end nodes of the faulted line section. On the other hand, the power system downstream node **w** corresponds to a radial circuit zone, where the fault current is supplied only from the sending-end node of the faulted line section. Here, the proposed methodology considers more than one DG, laterals, tapped loads and different line configurations.

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