Electric Power Systems Research 142 (2017) 153–162

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

A new impedance-based fault location scheme for overhead unbalanced radial distribution networks

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ARTICLE INFO

Article history:
Received 5 May 2016
Received in revised form 16 August 2016
Accepted 17 September 2016

Keywords:
Impedance-based fault location
Load variation
Modal transformation
Radial distribution systems

ABSTRACT

This paper proposes an analytical impedance-based fault location scheme for distribution systems. The approach is based on voltage and current measurements extracted at only one-end feeding substation. Modal transformation is implemented to decompose the coupled three phase equations due to mutual effects into decoupled ones, and hence directly calculating fault distance in each section without iterative processes. The proposed approach considers various aspects of distribution systems: intermediate loads along the feeder, tapped laterals and sub-laterals at various nodes, time varying loads, and unbalanced operations. The proposed algorithm is extensively investigated on a typical real 11 kV distribution system, South Delta electricity sector, Egypt using MATLAB environment. Different cases are studied considering various loading conditions, varied fault resistance values and different fault types. The achieved results ensure the effectiveness of the proposed fault locator irrespective to fault conditions. Besides, the robustness of the proposed scheme against unbalanced loading, network topology change and non-homogenous network sections is also confirmed.

1. Introduction

Power distribution systems experience several faults caused by environmental impacts such as trees crash over lines or faults due to infrastructure aging and low maintenance such as insulations breakdown. Such faults affect the power supply continuity, hence its reliability. Detecting faults and disconnecting the faulty feeder as quickly as possible is the main important role of protection system. Estimating the location of the fault with acceptable accuracy comes into view in a next step. Determining the fault location can save the maintenance crew time and diminish the duration of interruption, therefore restoring the service speedily and raising the reliability indices.

Impedance-based fault location methods in [1–4] are very familiar for transmission networks, however these techniques are not preferred in distribution networks owing to their peculiarities: non homogenous feeder sections due to the utilization of conductors with different cross sections, also the presence of laterals and tapped loads, unbalanced loading, and daily load variation.

It is worth mentioning that many efforts have been exerted in last years to propose techniques for fault location in distribution networks. The impedance-based fault location methods in [5–9] use the fundamental RMS of voltage and current measured at substation so as to calculate the impedance seen at substation to estimate the distance to the fault in distribution networks. In [5], the fault reactance at varied distance for the whole feeder is calculated to avoid the fault resistance effect. The fault is located at zero fault reactance, considering the total feeder loads are concentrated at the end of the feeder with an equivalent load. Fault location algorithms are proposed in [6] for all types of faults based on the published research work of [7]. However, these algorithms are iterative-based methods. The error in the iterative calculations may accumulate to an unacceptable limit. Methodologies of [8,9] introduce a direct circuit analysis technique that is suitable for unbalanced distribution systems, however [8] introduces a fault location technique for line to line faults only, and uses measurements at each load point for load compensation purposes, while [9] considers only single-line-to-ground faults.

Several other methods have been reported in the literature to overcome the shortcomings of traditional impedance based fault location methods using artificial intelligent techniques [10,11]. In fact, they need huge training data for tuning the algorithm parameters, and eliminating multiple estimation problems. The difficulties

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http://dx.doi.org/10.1016/j.epsr.2016.09.015

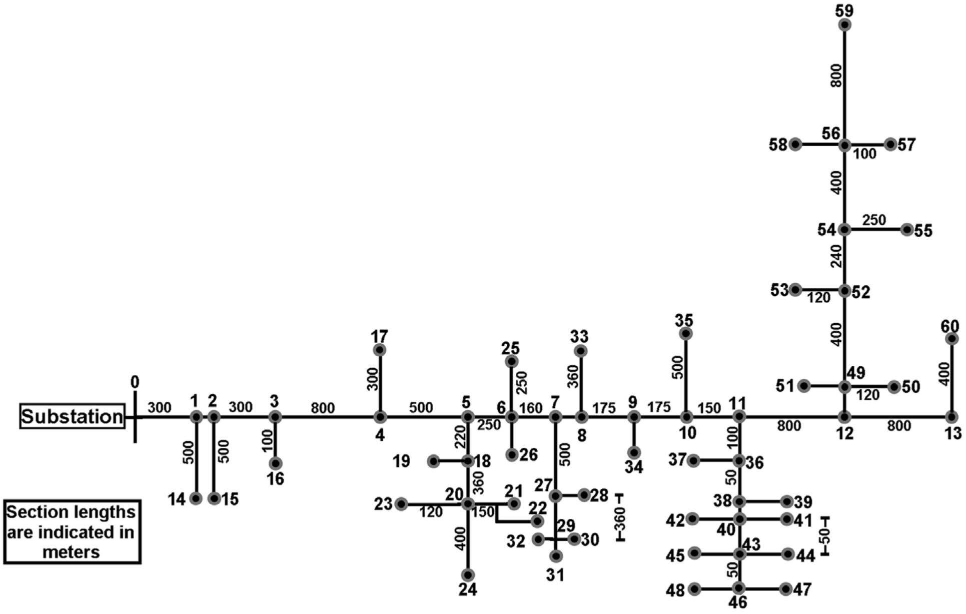

Fig. 1. A typical 11 kV real distribution system.

will increase if the network topology is changed. Such techniques need to be re-trained again for each topology modification. Travelling waves based methods [12–14] use various transformations to capture the high frequency disturbance generated by the fault, hence estimating its location. These methods have limited use in distribution systems because of the short distances of feeder sections and the difficulties to catch the high frequencies [15].

This paper, introduces a new impedance-based fault location scheme for overhead unbalanced radial distribution networks using Clarke transformation of voltage and current measurements at one-end substation only. It calculates the distance to the fault for all fault types in a reasonable accuracy using only one formula and two groups of constants. It also considers all tapped laterals, and compensates the time varying loads. It is not affected by unbalanced loading, network topology change and non-homogenous network sections.

In the Second Section of the paper, a general description for the problem of locating faults in distribution networks is introduced that ensures paper contribution. Then the paper is structured as follows: the details of proposed fault location scheme are discussed in Section 3 considering the proposed methodology for locating all fault types, compensation of load tabs and laterals and updating voltage and current in the cascaded sections using a simple power flow algorithm. Besides, the overall description of the proposed scheme procedures is also introduced in the end of Section 3. Sections 4 and 5 present the case study and the achieved results for the extensive simulated tested fault conditions, besides a comparison of the proposed scheme with some other published research works. Finally, in Section 6 conclusions are drawn.

2. Problem statement

It is worth repeating that distribution systems have their own complex structure, due to non-homogenous feeder sections, presence of laterals and tapped loads as shown in Fig. 1. The problems also include unbalanced loading, and time load variation. Numerous attempts are exerted in order to introduce a comprehensive fault location technique covering all of these peculiarities. Each method has its own limitation in a certain situation. This paper introduces an attempt to formulate a comprehensive fault location technique valid for all of distribution network fault types considering most of distribution systems characteristics using measurements available at substation end only.

One of main processes related to calculating the distance to the fault is fault current estimation handling. Most of impedance based fault location methods calculate the fault current iteratively, that may be a cause of calculation error, and time consuming. The paper introduces a non-iterative impedance-based method for calculating the fault current, hence directly introducing the fault location. Shortly the paper covers most of problems related to fault location process in distribution systems such as: time varying loads, faults on laterals, high fault resistance, unbalance operation, sections with no homogeneity problem for all fault types.

3. Proposed fault location scheme

The proposed fault location scheme is based on using the measured three phase current and voltage at the substation. Once a fault occurs in the distribution system, the protective relays should detect and classify all types of faults using the extracted phasors of voltage and current via discrete Fourier transform (DFT) filter. Then, the fault locator is fed by pre and during fault phasor quantities.

It should be indicated that the proposed fault location algorithm is enabled offline after detecting, classifying the fault and identifying the faulted phases. The algorithm also requires the recorded pre-fault voltage and current data in order to calculate equivalent loads impedances at each bus, which are modeled as constant impedances.

The algorithm starts with modal transformation of phasors as explained in the following equations:

$$V_m = T^{-1} V_p$$

$$I_m = T^{-1} I_p$$

$$Z_m = T^{-1} Z_p T \tag{1}$$