International Journal of Electrical Engineering & Technology (IJEET)
Volume 9, Issue 4, July-August 2018, pp. 58–66, Article ID: IJEET_09_04_006
Available online at http://www.iaeme.com/IJEET/issues.asp?JType=IJEET&VType=9&IType=4
ISSN Print: 0976-6545 and ISSN Online: 0976-6553
Journal Impact Factor (2016): 8.1891 (Calculated by GISI) www.jifactor.com

IDENTIFICATION AND LOCATION OF FAULTS IN ELECTRIC POWER DISTRIBUTION SYSTEMS FROM MEASUREMENTS AND DATA ON GIS PLATFORMS

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ABSTRACT

This paper presents the development of a collaborative computer tool for the location of faults in electricity distribution systems oriented to overhead lines. The methodology implemented for the location of the fault is based on the analysis of the fault impedance from the voltage and current data measured in the header of the damaged distributor and in the evaluation of all its branches. The results provided by the tool are displayed on the layout of the network in the environment of a Geographic Information System (GIS). The calculation algorithms developed use the topological and constructive information of the network that is stored in standardized files according to the requirements of State Control Organisms (Argentina). The tool was tested by modeling a distributor belonging to an electric power cooperative in a simulation program of power systems. The results of the implemented method showed maximum errors of the order of 5% in the actual location distance of the fault. The presentation of the results in the graphic environment of the network offers the operators a quick interpretation of the possible location of the fault, which results in a reduction of the repair times.

Key words: Power Distribution, Power Distribution Faults, Fault Location, Power Quality, Geographic Information System, Fault Impedance.

Cite this Article: G. di Mauro, C. Agüero, J. Vignerte, J. Strack and D. Anaut, Identification and Location of Faults in Electric Power Distribution Systems from Measurements and Data on GIS Platforms. *International Journal of Electrical Engineering & Technology*, 9(4), 2018, pp. 58–66.
http://www.iaeme.com/IJEET/issues.asp?JType=IJEET&VType=9&IType=4

1. INTRODUCTION

The State Control Entities, in order to ensure compliance with the quality of the electric service in the concession area of the power distributors, supervise various quality indices. In this regard, Standard IEEE 1366-2012 defines the ASIDI index (Average System Interruption

Duration Index) [1], while in the Argentine Republic the DMIK index is defined, which represents the average duration of interruption per kVA installed. in a given period [2].

One way to minimize the impact on the DMIK indicator is to locate faults in an efficient and timely manner, with the objective of quickly restoring electrical service. The main motivation of the distribution company in quickly restoring the electricity supply is to provide a good service to its customers and avoid the financial penalties it receives from the Control Entities in accordance with current regulations [2].

In an attempt to replace traditional methods such as the visual tour of the line, engineers and researchers have addressed the issue of fault location for several years now. On the other hand, to carry out an adequate and efficient management, the electricity distribution companies have incorporated different technological tools. Among them are Geographic Information Systems (GIS). A GIS is a computational tool that allows you to represent and analyse events that happen on earth. This technology integrates database operations such as queries and analysis, with the visualization and location of results on geographic maps [3].

Currently, in the jurisdiction of the Province of Buenos Aires (Argentina), the Control Organism of concessions of electricity distribution companies requires the preparation of georeferenced cadastres where all the constructive and topological information of their networks is stored. The information must be exported in a standardized format to enable the exchange of information with the entity.

In the context indicated above, this paper presents the development of a computer tool to facilitate the location of faults in medium voltage overhead distributors, based on the measurements of voltages and currents of the pre-fault and fault taken at the beginning of a fault distribution. The methodology is based on the analysis of the fault impedance and contemplates the investigation of all the branches in derivation belonging to the affected distributor, with the purpose of contributing to discriminate the faulty section. The response of the calculations is displayed in a graphical interface in a Geographic Information System environment where the network under analysis is digitized [4]. The calculation algorithms developed use the topological and constructive information of the network stored in the Georeferenced Cadastre according to the regulations, Law of the Province of Buenos Aires (Argentina) No. 11.769 [2].

2. ANTECEDENTS

Several of the methods proposed in [5-16] to solve the problem of the location of faults in distribution systems are based on the estimation of the fault impedance from pre- and post-event voltages and currents measurements taken at the beginning of the line.

According to the bibliographic review, the authors expose different mathematical methodologies to approximate the location of a fault in a distributor of the electric network. Each of them achieves results with greater or lesser accuracy according to the information and resources available. Concentrated in the development of the methodologies, it is observed that the authors do not take as a priority issue the use of existing data in digital storage systems of the distribution companies or how to display and show the results obtained. However, in order to a tool to be effective in its implementation, it must be able to take advantage of the information available and offer a friendly and easily interpretable environment for the operators of the electricity grids. That is the reason why this work emphasizes on the linkage of the standardized data available in the distribution companies, fault location algorithms and Geographic Information Systems.

3. METHODOLOGICAL APPROACH

3.1. Fault Location Method

The model implemented in this work for the location of faults is based on the development proposed by G. Morales et al. [17] highlighting the accuracy and adaptability in its implementation. The method, based on the fault impedance analysis, assumes that it is of a purely resistive nature, whit null inductive reactance [5, 17]. The implemented algorithm proposes to mathematically determine the fault reactance as a function of a variable distance from the voltages and currents measurements of pre-fault and fault taken at the header of the faulty distributor. Through iterative calculations, it is assumed that the point where the event occurred is correct when the reactance calculated of the failed phase reaches a minimum value, resulting in the distance measured from the head of the distributor. This process is repeated for each possible branch considered from the start of the distributor.

3.2. Program Structure

The generalized method of fault location implemented in this work was codified in the programming environment of the MATLAB® software.

3.2.1. Reading Network Data

The Provincial Energy Directorate (DPE) of the Province of Buenos Aires (Argentina), in the provisions N°1452/08 and 1536/09, requires distribution concessionaires to prepare an information exchange file in a standardized format. It has detailed information on the constructive and topological characteristics of the distribution networks and it is contained in their respective GIS, which is kept up-to-date by the companies themselves. In order to the fault location tool to be compatible or applicable in any distributor, the above files are used as a source of information to reconstruct the network on which the disturbances are analysed.

The main information of each line section is rescued from the exchange file: Identification code; Initial node code; Final node code; Length; Coordinates (x, y) of each node; Phase; Cable section and constructive material; Type of air support.

3.2.2. Line Impedance Calculation

The phase parameters are used to define the own and mutual impedances of each line section and that integrate the line impedance matrix (Z_L) developed in [18,19].

3.2.3. Branches Reconstruction

The treatment of the different branches and derivations is an important issue in the identification of the place in fault and is considered by some authors and left aside by others. The method implemented here proposes the analysis of as many serial circuits as there are terminal nodes in the network.

Once the data of the lines have been read and elaborated, the different branches are reconstructed according to the succession of sections or line segments. To perform this task, the algorithm works with the initial and final nodes of each of them. Through an iterative process, the program searches for terminal nodes of the distributor, that is, the one that no other segment connects to. Based on them the program begins to reconstruct the circuit going from the terminal node to the initial node, analysing and looking for the initial nodes that coincide with end nodes of the upstream section of lines. The final goal of this process is to obtain as many vectors as terminal nodes that contain the sequence of sections, from the substation to the different terminal nodes.

Figure 1 shows a simple representative circuit of a distributor. It has three terminal nodes (T_1, T_2, T_3), from which three vectors will be built (V_1, V_2, V_3) where each one contains the sequence of line sections from the initial node (SE) to the respective ones end nodes.

Using the previously obtained, all series circuits are defined with their impedances, lengths, initial and final nodes, phases and corresponding geographic coordinates.

3.2.4. Failure Type Determination

The next step is to determine the type of contingency from the fault current values analysed. The strategy developed, based on [20], requires the current measurements of each phase in the substation and also the definition of a reference value It, to determine if the system is effectively in fault condition. By successive comparison of the measured values with the reference, the type of fault (single-phase, two-phase or three-phase) and the phases involved are identified. For each type of fault, the corresponding equations are used [20].

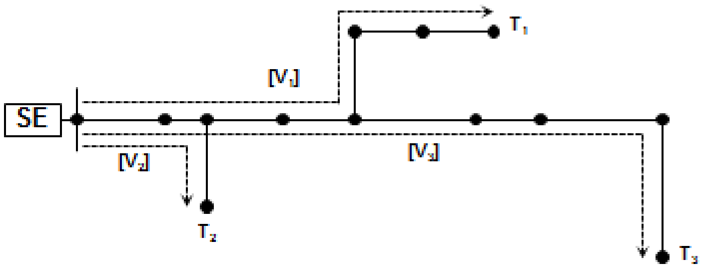


Figure 1 Circuit with three terminal nodes: three branches. Source: Authors

3.2.5. Calculation Process

Once all the branches have been defined and the type of fault determined, the program continues to perform an iterative calculation process for each of those [21]. First, the algorithm assumes that the fault occurred in the first segment of the feeder. If the condition arises that the point of least value of the inductive reactance coincides with the final node, the next section of line is analysed. To do this, the Z_L impedance of the segment and the pre-fault and fault voltages are updated considering the voltage drop produced by the respective currents.

This process is repeated until a minimum is found in the calculation of the fault reactance or until the end node of the analysed branch is reached. In the latter case, it can be established that the fault is not found in said branch: the branch is electrically short to have been affected by the contingency. This usually happens in cases of low short-circuit current, which are located in the final sections of lines of large extensions.

As mentioned above, there are as many outcomes as there are end nodes. Once the analysis of all the branches has been completed, those whose failure was located at the end node are discarded. In turn, several branches may have the same fault location as a result. This can happen if the segment where the fault is found is common to all of them. In this case, the repeated result is only reported once.

3.2.6. Sample of the Results on Geographical Planes

The location of the possible points of failure in the digitalized plans in the Geographic Information System is the culmination of this process.

The development of the graphic interface was carried out in the programming environment of the AutoCAD Map® with the VLISP® language.

An exchange file is generated by the routine dedicated to the location of the fault. In it, all the possible locations of the contingency are read, identifying the coordinates of the nodes of the segments indicated as failed and the distance within them from the initial node. After a conversion to Cartesian coordinates, the points of failure found by a tag are identified on the map.

3.3. Modeling the Network

The technique to estimate the location of the faults was tested to evaluate its reliability in a real distributor. From the georeferenced plane and the standardized file that contains the descriptive information of the constructive and geographical characteristics, a network was modelled in the DIgSILENT® PowerFactory® program environment.

The electricity network selected for the analysis was a 13,2 kV overhead distribution line belonging to an electricity cooperative in the District of General Balcarce, Province of Buenos Aires (Argentina). The distributor has 116 sections of lines, forming 26 branches. The substation (SE) has a 33/13,2 kV transformer with 2 MVA power. The network has three-phase, two-phase and single-phase lines. As for the conductors, they are mostly made of aluminum or aluminum alloy for the three-phase and two-phase lines and the single-phase ground return lines are made of zinc-coated steel. The farthest terminal node from the substation is 33 km away.

As can be seen from Fig. 2, the digitalized electrical network on a cartographic plane has multiple derivations and loads in its path.

With the assistance of the DIgSILENT® software, for a representative load state, the load flows necessary to obtain the pre-fault currents and voltages were calculated. Short-circuit events were also simulated in different points of the network to acquire the respective voltage and fault current phasors.

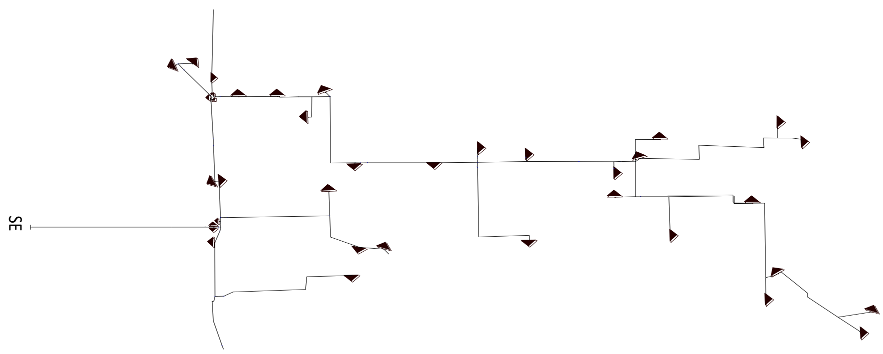


Figure 2 Distributor on cartographic map. Source: Authors.

4. VALIDATION OF THE PROPOSED METHODOLOGY

Simulations were performed varying the type of fault, the fault resistance and the distance of the event in order to analyse the accuracy of the method and the location on the georeferenced map. To compute the errors of the algorithm, and compare the results obtained with those of other publications [20], the equation proposed in IEEE Std. C37.114-2014 [22] and presented in (1) was used:

$$Error\% = \frac{Length_{est} - Length_{real}}{Length_{branch}} * 100 \qquad (1)$$

Where:

$Length_{est}$: length estimated by the method

$Length_{real}$: real length to the point of failure

$Length_{branch}$: total length of the branch

A total of 121 events were simulated with single-phase, two-phase and three-phase short circuits. The fault resistance was varied from 0 Ω to 40 Ω with 8 Ω breaks. Finally, failure situations were analysed every 2.5 km. The three phase faults were analysed on three phase lines; the biphasic ones on three-phase and two-phase lines; whereas the single-phase faults were simulated on three-phase, two-phase and single-phase lines.

Of all the events analysed, the single-phase fault located at 30 km length was the one with the highest error values, reaching a maximum of 4.8% with a failure resistance of 40 Ω (Fig. 3).

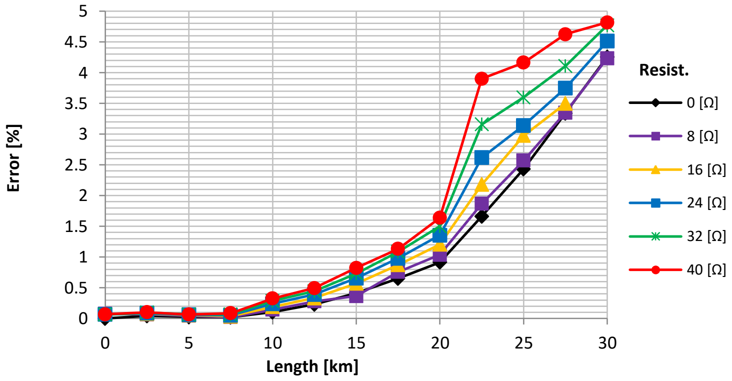


Figure 3 Percentage errors for single-phase faults. Source: Authors.

Multiple Fault Distance Estimation

According to the type of failure and the section of the network where the event has been simulated, unique results were obtained in its location or multiple estimation. Below, some examples are illustrated considering that the fault resistance assumes a null value.

The single-phase fault shown at point A of Fig. 4(a) was simulated at a distance of 5 km from the substation. The result obtained by the developed tool shows as possible points of failure those marked with A', B' and C' (Fig.4(a)). The line sections up to the three estimated sites have the same type of conductor, section and head, that is, they are electrically equal. That is why the results have the same distance from the substation to each of these points.

Distance SE – A´: 5001,34 m

Distance SE – B´: 4999,73 m

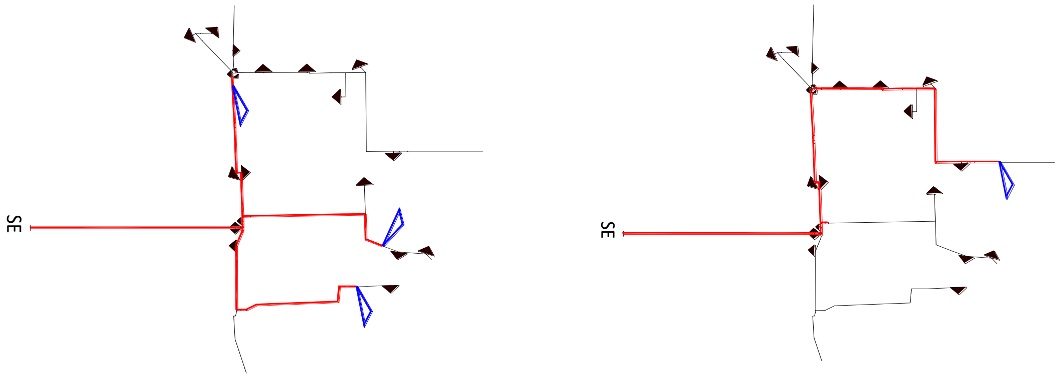
Distance SE – C´: 4999,55 m

At point A of Fig. 4(b), located at a distance of 15 km, three-phase, two-phase and single-phase faults were simulated. The sequence of line segments up to the point of failure is unique throughout the distributor, so for the three events, the algorithm displayed a single point (A) found as the location of the fault at a very close distance from the real point.

Three-phase fault: distance SE - A: 14933,23 m

Two-phase fault: distance SE - A: 14854,99 m

Single-phase fault: distance SE - A: 14851,07 m



(a) (b)

Figure 4 (a) Estimation of three-phase failure at 5 km. (b) Estimation of three-phase failure at 15 km. Source: Authors.

When simulating a single-phase fault 30 km from the substation, at point A of Fig. 5, the computer tool results in a single possible failure location, very close to the actual location. This is because the electrical characteristics (type of conductor, section and head) of the line path to the simulated point are unique.

Distance SE – A: 28495,23 m

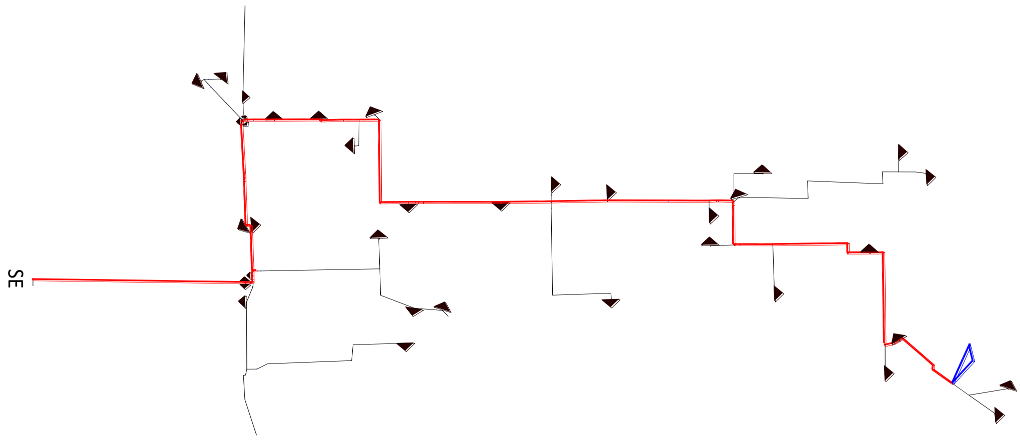


Figure 5 Estimation of single-phase failure at 30 km. Source: Authors.

As can be interpreted from the previous results, for a certain failure, the algorithm will calculate and show only as place of occurrence that which is electrically unique in the circuit. On the other hand, if the point of failure has places in the circuit electrically equivalent, they will be identified as possible faults.

The advantage of this tool in cases of multiple estimation is that the visualization of the geographical location of the failure site in collaboration with the experience of the network operator helps to more easily determine the actual location of the same. Other additional and inexpensive elements could help further solve this dilemma, such as the strategic placement of short circuit detectors on the lines.

5. CONCLUSIONS

The tool developed is an additional support for locating faults in overhead distribution systems as opposed to traditional methods, such as visual line routing. The sample of results on geographic maps (GIS) simplifies the interpretation and identification of the branch and section in fault, resulting in the reduction of repair times, with the consequent improvement in the quality of service and reduction in the penalties imposed by the regulations.

The implemented fault locating method, showed acceptable results with a maximum registered error of 5%, delimiting sensibly the fault search sectors

On the other hand, the use of standardized data already existing in the distribution companies, as well as the Geographic Information Systems, that they have constantly updated due to the requirement of the control entities, make the implementation of this tool not implies a significant additional cost and is easily adaptable to the distribution concessionaires.

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