9th International Conference. Electrical Power Quality and Utilisation. Barcelona, 9-11 October 2007

Application for Fault Location in Electrical Power Distribution Systems

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***Abstract*— Fault location has been studied deeply for transmission lines due to its importance in power systems. Nowadays the problem of fault location on distribution systems is receiving special attention mainly because of the power quality regulations. In this context, this paper presents an application software developed in Matlab™ that automatically calculates the location of a fault in a distribution power system, starting from voltages and currents measured at the line terminal and the model of the distribution power system data. The application is based on a N-ary tree structure, which is suitable to be used in this application due to the highly branched and the non-homogeneity nature of the distribution systems, and has been developed for single-phase, two-phase, two-phase-to-ground, and three-phase faults. The implemented application is tested by using fault data in a real electrical distribution power system.**

***Keywords*- power quality, monitoring, fault location, voltage sag**

I. INTRODUCTION

Traditionally, fault location techniques have been developed for transmission electric lines due to the importance they have in the electric system and the impact that faults would have on these kinds of lines. More recently, distribution lines have been taken more into account due to the improvement in the quality of power supply derived from operating in a deregulated environment, and the high competition between companies. Due to the growing interest in power quality, power quality monitors that capture power quality phenomena have become an important tool, so measurements of voltages and currents before and during the fault are easily available and suitable to be used to estimate where the origin of the fault is located.

The faults that these lines experience are caused by short circuits caused by birds and other external objects, insulation breakdown, storms, lightning, etc. This application described in this paper focus on faults that cause voltage sags. Voltage sag is a temporary decrease in the RMS voltage magnitude between 10% and 90% of the declared voltage for durations of one-half cycle to 1 minute [1]. Its frequency of occurrence is between a few tens and several hundreds times per year, its duration of mostly less than 1 s and voltage drops rarely below 40% [2]. It is the most important power quality problem facing many industrial customers since voltage sags are responsible of the shortness of electronic devices life, undesired reset of industrial production lines, among other many harmful effects. Moreover, the causes that produce voltage sags can later produce interruptions if they are not located and cleared.

Most of the current interest in voltage sags is directed to which are due to short-circuit faults, so it is interesting to find where the origin of disturbance sources is located. In literature, different methods for estimating the location of distribution line faults are described. One of these methods uses the fundamental frequency voltages and currents measured at the origin terminal of the line, and it is known as impedance-based method, since it consists of calculating line impedances as seen from the line origin terminal and estimating distances of the faults [2]. Another approach proposed by R. Das uses voltages and currents measured at a line terminal before and during the fault [3]. These methods are based in the knowledge of the network model.

Due to the branched nature of distribution networks, non homogeneity and presence of laterals, data structures based on N-ary trees are used to contain all the information about the parameters of the network in a compact way. Moreover, N-ary

This work has been supported , in part, by ENDESA DISTRIBUCIÓN under contract with the University of Girona

tree structures allow to design software applications for locating faults, by means of algorithms and methods as the ones commented above, in an easy and friendly way.

The application described in this paper compact the information of the electric power line and estimates the location of a fault, starting from data registered during the fault, in a manual or automatic way.

II. Data Structure Based in N-ary Trees

The implementation of the data structure based on N-ary trees has been developed in Matlab™. This structure will contain the information about the topology of the distribution network and the values of its parameters as length, resistance and impedance of its different sections, and the consumptions that are supplied in the different nodes of the network.

As it is described in [4], a tree, T, is a finite set of one or more nodes, such that there is one designated node R, called the root of the tree, and the remaining nodes in (T-{R}) are partitioned into n ≥ 0 disjoint subsets T1, T2, …, Tn, each of which is a tree, and whose roots r1, r2, …, rk, respectively, are children of R. Each node has only one parent. A tree is a data structure used to model data such that related data is in close proximity called branches. A tree can also be used to model hierarchical data. The use of a N-ary tree structure has been motivated by the nature of the distribution networks, because of the presence of laterals and load taps, resulting in a highly branched network. Moreover, there is only one path between one node and its predecessor.

The main advantage of a data structure based in a N-ary tree is the use of recursion in order to implement different functions. The use of recursion allows the programmer to simplify and reduce the size of the functions, resulting in an increase of simplicity. The functions that have been implemented allows to use the presented data structure together with methods or algorithms that locate the origin of faults in distribution systems:

- Calculate impedance “seen” from one node.
- Calculate accumulated impedance and distance from one node to the initial node.
- Application in impedance-based fault location algorithms.
- Update the information of the power system (add / remove lines of the system).
- Compact the stored information if it is possible (not consider fictitious nodes).

Description of the data structure implementation, as well as the functions that have been implemented starting from this data structure, can be found in [5]. The functions are easily implemented due to recursion, an inherent property of N-ary trees data structures. These functions allow someone to calculate the impedance between two nodes, neglecting the laterals between them, and to implement fault location algorithms such as the described by R. Das.

III. Fault Location Application

The N-ary-tree-based data structure allows storing the distribution line data (topology, conductor parameters, loads, etc.) in such a way that it can be used in an easy and friendly way to make any analysis where only impedances and admittances parameters are involved.

The original data of the available distribution power lines are stored in an access database. First of all, the distribution power line of interest is selected and its information is organized in a N-ary tree data structure.

Figure 1 shows the resulting tree for the considered distribution power line. Each node is identified with an integer and the data structure contains how the nodes are related and the parameters of the different sections (length, resistance and reactance), as well as the consumptions that are connected to the considered line.

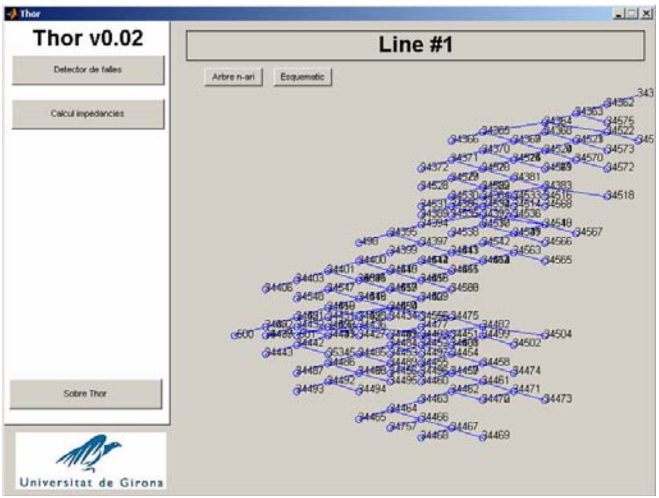

Figure 1. Representation of a considered line.

Once the line is “loaded”, the analysis of a fault can be done starting from the measurements of voltage and currents during the fault. The digital fault recorder is at substation level.

The application allows two types of analysis: manual and automatic analysis.

A. *Manual analysis*

In manual analysis, it is selected one instant of time corresponding to the period when the fault occurs. Figure 2 shows the results for a real voltage sag. It can be seen the plots corresponding to measured voltages and currents at the substation for the tested case. The voltage sag has one episode: single-phase voltage sag. For this kind of fault, an estimation of the location of the fault can be made by comparing the apparent reactance computed by using the faulted phase voltage and current (RMS values calculated in one cycle, in the chose instant of time), and the modified reactance of the line between the substation and the location of the fault, with:

$$X_{mr}^{m} = X_{1mr} + \frac{X_{0mr} - X_{1mr}}{3} \quad (1)$$

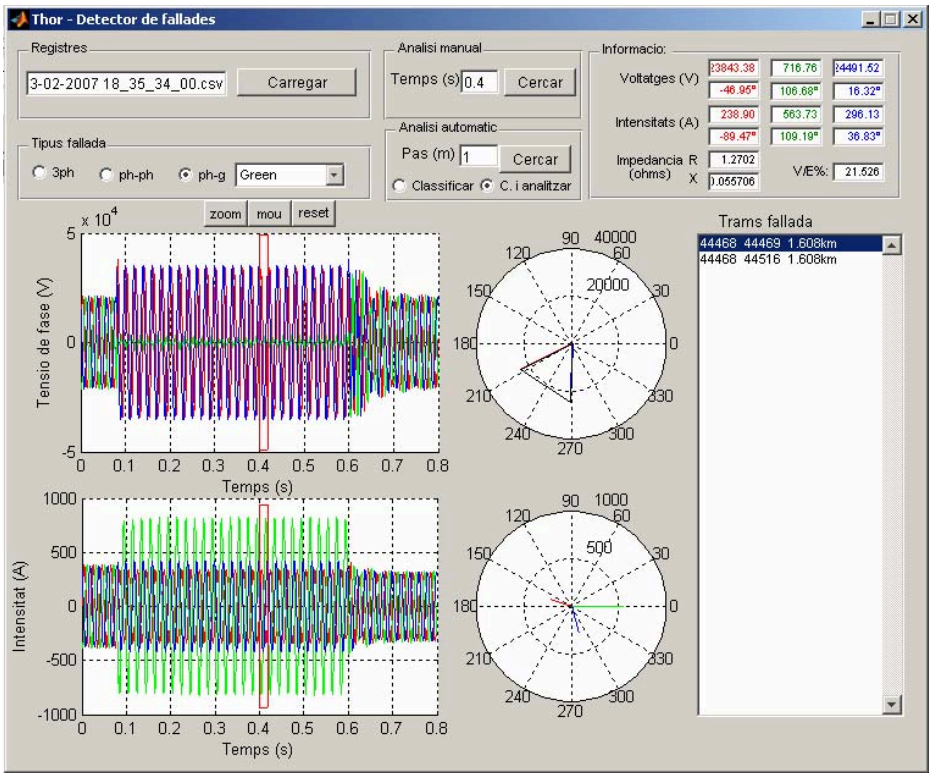

Figure2. Fault location: manual analysis

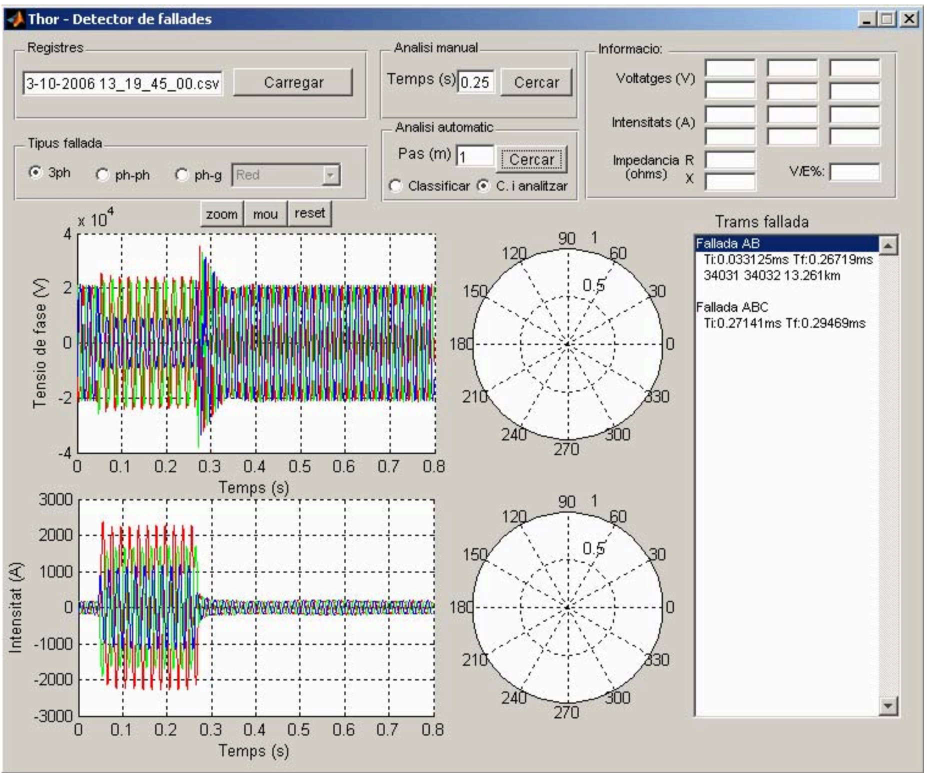

Figure3. Fault location: manual analysis

where, X_{0mr} and X_{1mr} are the zero and positive sequence reactance of the section.

In this calculation, only impedance parameters are involved so the algorithm is easily automated by using the N-ary tree data structure. For this example, the real location of the fault is 1,608 km from the substation and the calculated location is also 1,608 km. The application gives two results due to the existence of fictitious nodes (for example, in protection devices, or sections of length zero).

B. Automatic analysis

The application allows to perform an automatic analysis, that is, starting from the fault-current phasors classifies what kind of default has occurred. Figure 3 shows the results for a real voltage sag. For this fault, the application detects one segment that corresponds to a single-phase fault, and calculates the location of the fault according to this classification. The application gives a distance of 13,261 km but the real distance is 12,667 (an error equal to 4,7%). The result is good enough to reduce the time of actuation in solving the incidence.

IV. CONCLUSIONS

A software application for fault location in distribution power systems is presented. The application N-ary trees have been used to store information related to the topology and parameters of distribution power systems.

The used data structure and its derived functions are applied to design a software application for automated fault location starting from the measured voltages and currents at one terminal of the line.

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