Abstract—The main purpose of this paper is to present architecture of automated system that allows monitoring and tracking in real time (online) the possible occurrence of faults and electromagnetic transients observed in primary power distribution networks. Through the interconnection of this automated system to the utility operation center, it will be possible to provide an efficient tool that will assist in decision-making by the Operation Center. In short, the desired purpose aims to have all tools necessary to identify, almost instantaneously, the occurrence of faults and transient disturbances in the primary power distribution system, as well as to determine its origin and probable location. The compilations of results from the application of this automated system show that the developed techniques provide accurate results, identifying and locating a batch of several occurrences of faults observed in the distribution system.

Keywords: fault detection, fault location, intelligent systems.

1 Introduction

The detection, classification and location of faults in power systems are the target of transmission and distribution utilities. Thus, it is observed by the related literature, propositions of works that make use of a diversity of tools in a variety of conjunctions.

According to [1,2] the major limitation of the some approaches is the need to make measurement in at least two points of the system. It can be verified that this kind of method is more suitable for transmission systems than distribution systems.

Another successful combination about fault identification is to use the set of measurement and its decompositions into symmetrical components, because that the faulted section can be determined through the temporal dynamic of impedance matrix [3].

Simulations are indispensable for this purpose in order to validate any approach developed. So, case studies are conducted and the results provided by the methodology are compared with those who actually denote the reality of simulated faults.

Despite the correct identification of faults in most cases, the authors of [3] point out that the efficiency some techniques is conditioned to the accuracy of distribution lines impedance. Hence, the simple and constant changes in load and ambient temperature would be able to compromise the efficiency of this approach.

Computational-based models can create great amount of data of impedance and the limitations of the feeder modeling should be decreased, as in [4] where authors use calculated impedances obtained by means of the power system topology and by voltage and current measurements. A computational model of the distribution line is used to create faults conditions and these models are constantly updated by measurements realized on the substation secondary. However, errors can up to 25% if the system is unbalanced and no smart system is used to compensate this condition.

To suppress that limitations intelligent systems emerge as a new proposal to the tractability of problems whose solutions are inherently complex, such as identification a location of faults on power distribution systems. Besides the non-linearity of the problem, unbalanced load and huge types of faults, good results have been achieved using combination of tools.

An example of this new trend is the paper presented in [5], where techniques related to genetic algorithms and sparse areas are combined to form a system capable of locating faults in power distribution systems.

In [6] a approach was developed to classify faults in electric power systems via multi-level analysis provided by the wavelet decomposition of the waveforms of voltage and current. This type of analysis is known for providing information on disturbances in electric power systems and has broad applicability in the power quality context. However, analysis of results from this tool for signal processing does not proceed naturally and much experience is necessary so that the findings are feasible to the actual facts.

On the other hand, fuzzy inference systems have the goal of emulating the approximate shape of human reasoning. In this way, the works [6,7] presents a method for fault classification in power distribution systems capable to distinguish real faults of programmed tasks into the system, for example, the energization of transformers.

In the study reported in [8] authors conduct their research using a vector decomposition of voltage and current waveforms and artificial neural networks for determining the location of fault occurrence in the system.

However, despite the use of intelligent systems, evidential results may not possess all desired requirements, or, these results could be improved. With such features as a premise, it
is increasingly common to develop systems for detection, classification and location of fault that do not use only one expert system, but several of these systems arranged in an orderly manner [9].

In parallel, integration and communication systems directed to the operation of an electric power system is a worldwide tonic since the mid-70s, however, that over those 30 years of development of systems to control and monitor, many concepts were created, as well as new alternatives to reduce costs with such systems were implemented, as outlined in [10,11].

Following the trends for a modern system of supervision and control of power distribution systems, this paper presents a complete solution for faults identification and location, working as a decision making tool that helps operators.

This approach is called solution because uses a great number of methods, algorithms and techniques combined with hardware equipment to produce a very accurate fault identification and locations. Expert systems are the kernel of this purpose solution, due to handle a great variety of faults types, non-linearity’s, signal contaminations and external events. In Table 1 is shown a little statistical history about interruption events registered in the case study feeder of this paper.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processed events</td>
<td>1384</td>
</tr>
<tr>
<td>Interruptions events found</td>
<td>363</td>
</tr>
<tr>
<td>Cases involving switch breaker (%)</td>
<td>26.83</td>
</tr>
<tr>
<td>Cases involving reclosers</td>
<td>73.17</td>
</tr>
<tr>
<td>3 phase faults (%)</td>
<td>26.82</td>
</tr>
<tr>
<td>1 phase faults (%)</td>
<td>7.31</td>
</tr>
<tr>
<td>Phase-phase faults (%)</td>
<td>14.63</td>
</tr>
<tr>
<td>Other types of faults or not identified (%)</td>
<td>51.24</td>
</tr>
<tr>
<td>Occurrence with the highest incidence (%)</td>
<td>29.26</td>
</tr>
<tr>
<td>Branch Tree touching line</td>
<td></td>
</tr>
<tr>
<td>Occurrence involving climatic conditions (%)</td>
<td>9.75</td>
</tr>
<tr>
<td>Atmospheric Discharge + Strong Wind</td>
<td></td>
</tr>
<tr>
<td>Weather conditions with the highest incidence (%)</td>
<td>24.39</td>
</tr>
<tr>
<td>Good weather</td>
<td></td>
</tr>
</tbody>
</table>

It can be seen from Table 1 that a huge number of faults type is unknown. In other hand, in most of cases involving interruptions the weather conditions were considered good and same analysis could also extended from atmospheric discharges impacts on the distribution network.

These statistics data must be used to adjust and refine feeder simulations models, because it is intrinsically fulfill of non-linearity and imprecision information.

The case study feeder can be seen in Fig. 1, with the highlighted substation at the beggin. This feeder possesses 1255 primary branches.

In the follow sections will be presented the solution approach proposed on this paper, to solve the fault identification and location problem, using the feeder of Fig. 1 as case study.

2 Automated system for identification and location of faults

The development of any automated system can be divided into several objectives. Thus, by means of Fig. 2, there is a schematic illustration of the modularization of the proposed identification and fault location system. One can see that the system consists of the data acquisition module, pre-processing module, transients’ identification module, identification system for phases participating of the fault, fault classifier system and fault locator system. Briefly, this system operates by using data acquired in the distribution system substation. In principle, these data consists of three phase voltages and the three line currents. Considering that Current Transform (CT) is not commonly used to measure ground current, this value is calculated resulting in a residual current of CTs allocated in phase.

The data acquisition module has the functionality to adequate levels of voltage and current of the distribution system so that they can be digitalized and acquired. These digitized data are, in turn, processed and its main parameters are determined by the pre-processing module. By using these parameters, the transient’s identification module detects when a disturbance starts, and because of its identification, this module classifies it as arising from load changes or fault condition. The identification of a fault condition, in turn, triggers the operation of the identification system of the phases participating in the fault. Finally, with the data of the phases participating in the fault, the fault classifier system informs what kind of fault has been identified, while the fault locator system indicates the location where it occurred. The main feature of the pre-processing module is to group or compress the waveform data so that the excessive amount of data coming from these signals can be represented by a smaller number of parameters. The transient’s identification module
identifies the existence of transients of current and voltage in distribution systems, regardless of its origin. This result will follow up the identification process of participating phases and their classification. More specifically, the schematic representation shown in Fig. 2 can be complemented by the block diagram shown in Fig. 3, in which the steps for the identification of faults, discrimination of participating phases and estimation of distance and resistance of fault can be observed.

Through this schematic diagram it is possible to see that, by the identification of a fault, there is the consequent determination of the type of this fault. The identification of the fault type is very important, since this characteristic determines the way in which the disturbance data will be processed in order to determine the participating phases of the fault, so as to proceed with the estimation of the distance of incidence and fault resistance.

The operation of the Fault Classifier system assigns to each kind of fault a probability ratio which, if close to the unity, indicates a strong tendency of the disturbance to be associated with this kind of fault.

If, on the other hand, this rate is nearing zero, the opposite applies. Thus, the fault classification module indicates the kind of fault based on the highest calculated probability, in which FFF label refers to three-phase faults, DLF to the phase-phase faults, FFT to the phase-to-phase-earth faults, FFP to parallel phase-earth faults and FFS to phase-series earth faults.

Once the kind of fault is identified, the participating phases of the fault must be identified.

The kind of fault as well as the discrimination process of the participating phases of the fault used data coming from the technique of decomposition in orthogonal components [12,13]. The number of components used in each of these tasks is five. Moreover, receiving such components as inputs, there is artificial neural networks of multilayer perceptron architecture, which were trained by compound samples sets for each kind of fault, for a total of 18 thousand cases of faults computationally simulated. Finally, the Fault location system can be shown in Fig. 4.

One of the most important points related to the faulty section selection for any location method is the choice of the candidate branch, which most represents the electrical characteristics observed during the fault. Methods that analyze purely the impedance end up across multiple sections choice to the same universe search values.

The analysis proposed in this paper consists in investigating the maps for resistance R0 and R1, and maps of X0 and X1 on the distance. The Impedance estimation process uses a great amount of simulation data involving the case study feeder, which database is composed using all feeder models. The map for reactance distribution along the feeder could be seen in Fig. 5. In Fig. 6 is shown the map for resistance distribution along the feeder.

![Fig. 2. Diagram representing the identification and location of faults.](image)

![Fig. 3. Diagram of the fault identifier.](image)

![Fig. 4. Diagram of the fault location module.](image)

![Fig. 5. Map from reactance distribution along the feeder.](image)

![Fig. 6. Map from resistance distribution along the feeder.](image)
The disturbance occurred during a fault could be used as a filter for more accurate faulty section determination. By observing oscillography records was possible create a power disturbance analysis in time, such as shown in Fig. 7.

It is observed from this figure that the power from phase green is considerable high at 0.04 seconds in opposition the normal operation for other phases (blue and red). This disturbance can also help for identify candidate branches with same electrical response when experiment similar fault conditions.

For all process described on this section it is import mention the relevance of the feeder real data simulation, responsible for create a high fidelity electrical condition database from this circuit.

The identification of the disturbances is performed based on instantaneous values of currents and on instantaneous values of zero sequence of current and voltage. Therefore, if those signs exceed the predetermined threshold, the software identifies this as a disturbance, thus, resulting in the recording of the acquired signals.

In this first version of the system, an acquisition rate of 96 samples per cycle, i.e., a total of 5,760 samples per second is being used. But, if necessary, the developed system can reach up to 30,720 samples per second, equivalent to 512 samples per cycle. Still, the system considers when the acquired signals are stored, a time of 5 cycles for pre-disturbance, by recording a total time which takes a second.

Fig. 8 is presented with the purpose of illustrating some of man-machine interface of the developed supervisory. Subsequently, by means of Fig. 9, the scanning module of records made is also pictured.
4 Results related to the system of identification and location of faults

The computer simulations sets used in this research were each composed by a population of 18,000 simulations. Figure 8 shows the histogram of percentage distribution of simulations depending on distance.

The histogram in Fig. 10, besides showing the percentage distribution of the number of simulations based on distance, also allows inferring that the number of bars at a distance equal to or less than one kilometer is the highest one. Moreover, the concentration of bars at a distance between 5 and 10 km is considered more important for this specific feeder.

![Fig. 10. Histogram of percentage distribution of the quantity of simulations in function of distance.](image)

This section emphasized the importance of having a discrimination of the participating phase of fault as an additional process. This importance can be justified by the graph shown in Fig. 11. In this figure we have the histogram of error to estimate the distance of fault occurrence, disregarding, for such purposes, the phases involved.

![Fig. 11. Histogram of error for distance estimation without considers the participant phases.](image)

Through the graph in Fig. 11, one can then verify that the distance estimation error, not considering the participating phase of the fault, has (in these conditions) concentration within the range of -10% to 10%.

If the participating phase information of the fault is considered, the error behavior changes and appears more suitable to the purposes of the project. This aspect is illustrated in Fig. 12, which highlights the error behavior considering the faults where Phase A participated. It is noted here that the error in the estimation of distance is much more accurate than the cases of Fig. 10.

![Fig. 12. Histogram of error for distance estimation considering faults involving phase A.](image)

For all other phases, the results produced by the automated system for identification and location of fault were also similar to those presented in Fig. 12.

Real location fault condition can be seen in Fig. 13. An artificial condition of fault was created to validate the approach, at substation. The system was adjusted to generate 10 possible solutions.

![Fig. 13. Fault location with real candidates branches.](image)

Due to the proximity of the “occurrence” of the fault the accuracy of the method can be observed.
5 Conclusions

This paper presented a scheme based on the use of intelligent systems for efficient identification and location of faults in distribution systems, taking into account the voltages of phase and line currents observed at the substation.

The proposed architecture was designed in a modular way in order to provide a higher degree of redundancy procedures for identifying and locating faults. The sequencing of tasks of transient identification with the discrimination of fault and, finally, with the task of identifying the participating phases of fault brings a greater robustness to the system as a whole.

In addition to a modular and robust architecture from the faults occurrence point of view, the intelligent system for identifying faults was implemented by using tools, proven to be effective, dedicated to the achievement of pre-processing the voltage signals and current sampled at the substation. These tools operate on these signals in order to extract features that individualize and distinguish fault conditions from other normal operating conditions.

Thus, the efficiency of these pre-processing tools, which are based on decomposition technique for orthogonal components, give the system a robustness and accuracy with regards to the identification of phase-to-earth faults, as well as for determining the participating phase. The answers helped confirm how correlated the orthogonal components can be to the execution of both tasks.

The final results derived from the implementation of the proposed system were fully satisfactory, and they were tested and validated by using data from both simulations and fault oscillography acquired at the substation.

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7 References