

# Power Flow Analysis and Self-recovery of Electrical Energy Distribution Network Using Artificial Neural Networks

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## ABSTRACT

*A computational model for self-recovery of electricity distribution network was developed to simulate it, emulated by the IEEE 123 node model. The electrical system considered has automatic switches capable of identifying a momentary failure in the line and finding the best reconfiguration for its reclosing. An artificial neural network (ANN), backpropagation, was used to classify the type of failure and determine the best reconfiguration of the distribution network. Initially, five power failure scenarios were simulated in certain different parts of the power grid, and power flow analysis via OpenDSS was performed. Next, the most suitable switching was observed within the shortest time interval to restore the power supply. With the purpose of better visualization to identify the reclosing, an implementation was carried out via ELIPSE SCADA. In this way, it is possible to identify the faulted segment in order to isolate it, leaving the smallest number of consumers without power supply in shortest possible time. With the results of the simulations, tests and analyzes were performed to verify their robustness and speed, in the expectation that the model developed be faster than an experienced Operating Distribution Center.*

**Keywords:** Distribution Networks, Optimization, Self-recovery of networks, Smart Grid.



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## INTRODUCTION

The availability of electric energy represents an improvement in the quality of life of the population. As soon as an electric energy distribution system is installed, the local population immediately has countless benefits, both from the point of view of greater domestic comfort and better possibilities of employment, production towards more equipment and machines in operation, associating this with a higher production [1].

In this context, the constant search for the improvement in the quality of distributed electricity to consumers has been a motivating factor for a series of changes, both in the legal and regulatory instruments, and in the organization of companies in the direction of their strategies [2].

According to [3], self-healing is a system capable of detecting, analyzing, responding and restoring faults in the electrical energy network (EE) automatically (and in some cases instantaneously). This system uses real-time information, generated by sensors arranged in the distribution network to respond reactively (when service has already occurred) or proactive (still without restriction to the contracted service) to network problems, automatically avoiding or mitigating blackouts or problems with the quality of energy and the discontinuity of services.

As one of the features of the smart grid, self-healing aims to improve network reliability and has a rapid response when a Distribution Network (RD) failure occurs, isolating it and reducing the period of power failure in the network [4].

The benefits of applying the concept of self-healing in electrical systems include: (i) rapid restoration of the system to the operating mode; (ii) restoration of more loads and (iii) less need to send field teams to reconfigure the network [5].

Therefore, knowing the potential of the smart grid and its functionalities, such as self-healing, it is possible to solve the problem of disconnection of electricity distribution networks. For this, an artificial neural network, backpropagation, was applied to reconfigure an electrical energy distribution network in adequate time. The purpose of this work is to restore an electricity distribution network, represented by the IEEE model 123 nodes, according to the National Electric Energy Agency.

The modern power grid has evolved into a highly interconnected, complex and interactive system. The growing demand for energy independence, modernization of old infrastructure with new technologies, integration of multiple renewable energies and storage, more efficient use of energy, self-healing and resilience to natural disasters and attacks, coupled with the pressure for sustainable development, have motivated the development of intelligent network in the 21st century [6].

## MATERIAL AND METHODS

This article has the character of experimental bibliographical. It is based on information from the IEEE Xplore Magazine regarding self-recovery in the areas of electricity distribution network and information from COPEL (Local Electric Power Distributor) and ANEEL (National Electric Energy Agency).

### Artificial Neural Network (ANN)

ANN is a distributed and parallel system, which can be divided into several simple processing units, which are capable of processing the information obtained from the database. With this definition, it is observed that there are similarities between an ANN system and the nervous system. It can be shown, among them, the ability to process information in several simple units, called artificial neurons, the interconnection capacity between these units, establishing ANN and the transmission of information (signals), through connections between the elements.

With respect to the storage of information, it can be emphasized that each interaction between the simple units is represented by an associated weight, varying according to the efficiency of the connection. The assessment of the environment provides information to build a knowledge base and is part of the learning process, and this process is basically responsible for adapting weights to the connections made in response to environmental stimuli [7].

In this paper we used an artificial neural network (ANN), backpropagation, which considers five different types of failure to solve the reclosing restoration problem.

### **IEEE 123 nodes test feeder and tools used**

In this work the proposal is a self-healing and restoration technique, in an IEEE 123 node test feeder model [8], because it is widely used and diffused in the academic environment, using Artificial Neural Network (ANN).

Firstly, a study was performed on the power flow in the model through OpenDSS software. Using the software information provided by the simulations, a database was built, consisting of more than two thousand information per failure. From the possession of the values of the currents in the branches of the electric network, 5 scenarios of failures in this network were built. These scenarios were then simulated by OpenDSS.

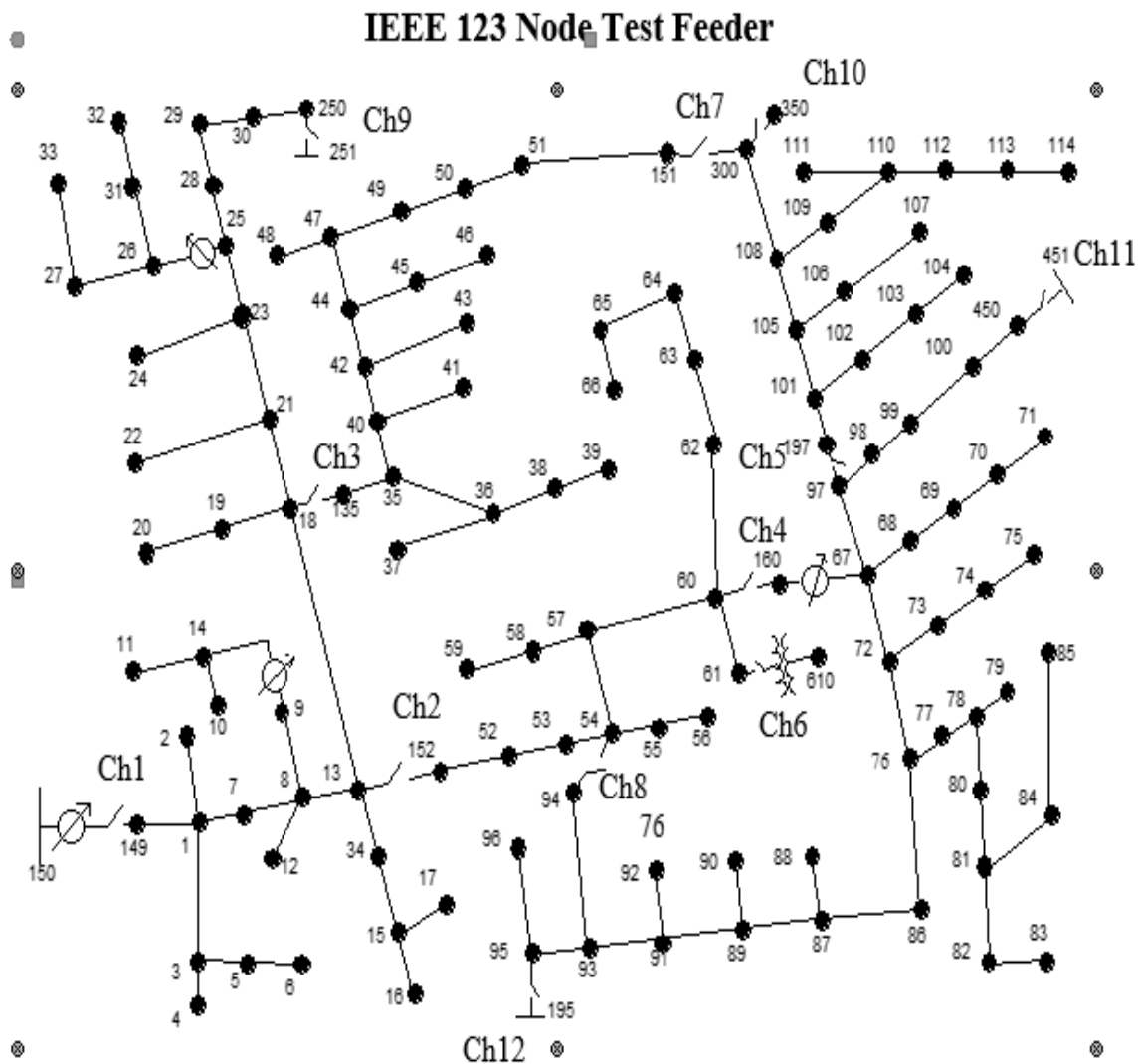
This database was then used to train ANN, which once trained, several tests were performed to obtain the desired information, thus evaluating the classification of the resulting failure type.

Since the switch was already known, a graphical interface was built by using the software ELIPSE, in order to simulate a Distribution Operation Center (DOC).

### **IEEE 123 node test feeder model**

The IEEE 123 nodes test feeder model was chosen because it is an already consolidated model, operating at a nominal voltage of 4.16 kV. Although this is not a popular voltage level, it provides voltage drop problems that must be solved with the application of voltage regulators and shunt capacitors.

This circuit is characterized by aerial and underground lines, unbalanced load with constant current, impedance and power, four voltage regulators, shunt capacitor banks and multiple switches. The model used [8], presents minimal problems of convergence with respect to its balance and is shown in Figure 1.



**Figure 1-** shows the IEEE 123 node test feeder model.

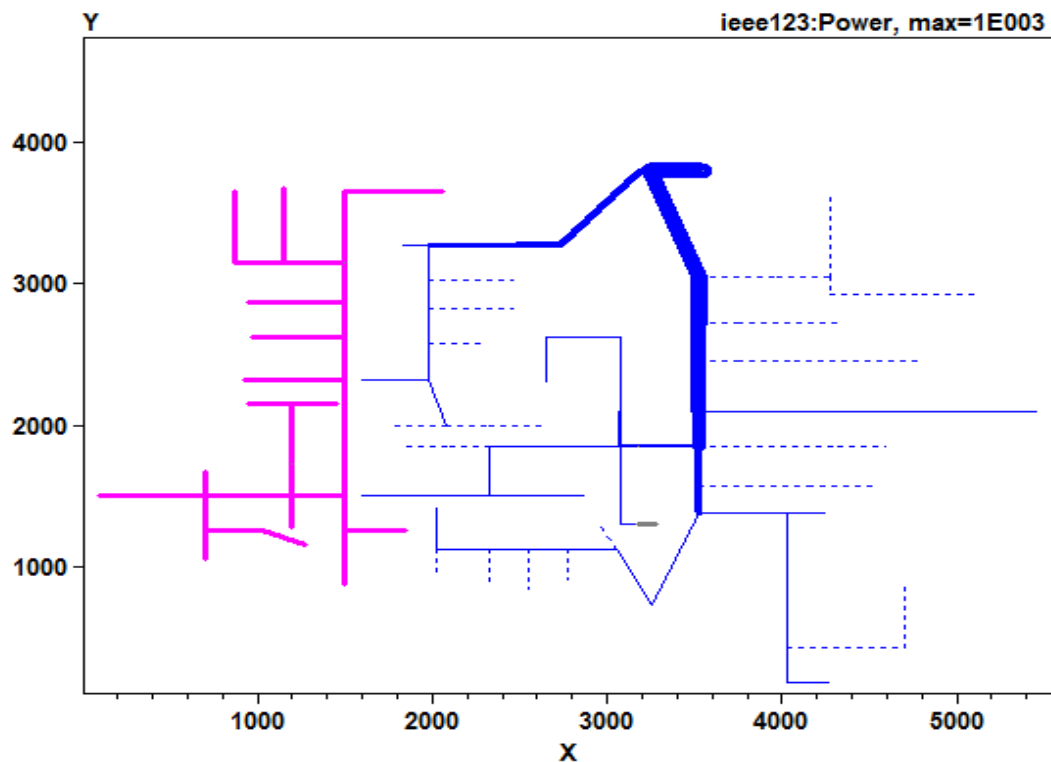
### The Open Distribution System Simulator

The Open Distribution System Simulator (OpenDSS, or simply DSS) is a simulation tool for electricity distribution systems.

OpenDSS refers to the open source DSS implemented as a standalone executable program for the in-process Dynamic Link Library (DLL) server designed to be moved from a variety of existing software platforms. The executable version has a basic user interface.

Figure 2 represents the IEEE 123 node test feeder model in OpenDSS. In it, there is a main power impeding the supply the electric circuit loads, due to a fault in the substation premises.

To solve this problem, alternative feeders have been made available, which will be able to re-connect as many consumers as possible, leaving only the defective sector isolated so that the maintenance sector solves the problem, reconnecting it later.



**Figure 2** - shows the scenario of simulation via the software OpenDSS.

Table 1 shows the failures of the IEEE model and OpenDSS solutions. The normal line represents the default configuration of the software. Within a failure there are alternatives to reestablish electric power, depending on where it is located. The letters "a, b, c, d and e" are the possible alternatives without a simultaneous failure, and the numbers 0 and 1 represent the open and closed key, respectively.

### **Treatment of power flow results with artificial intelligence**

With the results of the OpenDSS simulations, a spreadsheet with the electric currents was elaborated in each part of the system, that is, each piece between two consecutive posts.

In order to apply the neural network, the spreadsheet was divided into three parts, one for ANN training, the other for choosing the type of failure (five options) and the third and last one, their actual test.

**Table 1** - shows the failures of the IEEE model and OpenDSS solutions.

Failure		ch1	ch2	ch3	ch4	ch5	ch6	ch7	ch8	ch9	ch10	ch11	ch12
Normal		1	1	1	1	1	1	0	0	0	0	0	0
Failure1	a	1	0	0	1	1	1	1	0	0	1	0	0
	b	1	0	0	1	1	1	1	0	0	0	1	0
	c	1	0	0	1	1	1	1	0	0	0	0	1
Failure2	a	1	1	0	1	1	1	0	0	0	0	0	0
	b	1	1	0	1	1	1	0	0	1	0	0	0
	c	1	1	0	1	1	1	0	0	0	1	0	0
	d	1	1	0	1	1	1	0	0	0	0	1	0
	e	1	1	0	1	1	1	0	0	0	0	0	1
Failure3	a	1	0	1	0	1	1	1	0	0	0	0	0
	b	1	0	1	0	1	1	1	0	1	0	0	0
	c	1	0	1	0	1	1	1	0	0	1	0	0
	d	1	0	1	0	1	1	1	0	0	0	1	0
	e	1	0	1	0	1	1	1	0	0	0	0	1
Failure4	a	1	1	1	0	0	1	1	0	0	0	0	0
	b	1	1	1	0	0	1	1	0	1	0	0	0
	c	1	1	1	0	0	1	1	0	0	1	0	0
Failure5	a	1	1	1	1	0	1	0	0	0	0	0	0
	b	1	1	1	1	0	1	0	0	1	0	0	0
	c	1	1	1	1	0	1	0	0	0	0	1	0
	d	1	1	1	1	0	1	0	0	0	0	0	1

Figure 3 shows the training performance graph. It is verified that before reaching the seventh epoch the mean square error is reached within the established limits.

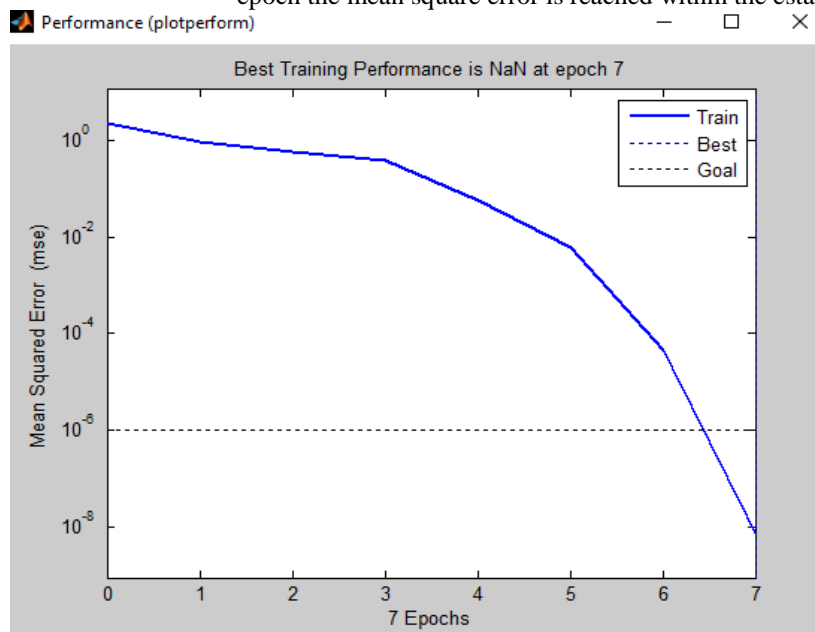
**Figure 3** - shows the training performance of the ANN.

Table 2 shows the results of the training performed in the neural network for each type of failure, the number of times that each training took to reach the solution, the time in seconds and the mean square error for each situation.

**Table 2** - shows the results for the failures.

Failure Summary Table

Classification	Epochs	Time (s)	Error
Failure 1	3	17	0,0251
Failure 1	6	42	0,0658
Failure 1	7	4	0,0884
Failure 1	17	38	0,0226
Failure 1	4	8	0,0454

### Elipse Simulation Software

One way to illustrate the necessary switching in a post-failure situation in the 123 node distribution network was through the Elipse software.

Elipse is ideal for mission-critical systems and control centers are a well-established SCADA tool for monitoring and controlling of processes, providing scalability and constant evolution for various types of applications, from simple HMI interfaces to complex real-time operation centers [9].

In Figure 4 a supervisory example is presented in a Distribution Operation Center (COD) through Elipse Software. The interface is user friendly and easy to view. Comparing the graphical part in DSS with the Elipse Software, the difference in this aspect is remarkable, because the visualization is easier on the interface in Elipse than in OpenDSS.

In Figure 4 a normal configuration of the IEEE 123 node test feeder model is presented, the yellow color being represented by the line in operation, keys in green are normally open, in red, normally closed.

In figure 5 it is considered a failure in sector 1 (gray), without energy and in yellow (other sectors) with energy. In the simulations performed in Elipse, the power supply is represented by the closure of alternative source 2 in the panel, where it is possible for the operator to observe the switching immediately after failure.

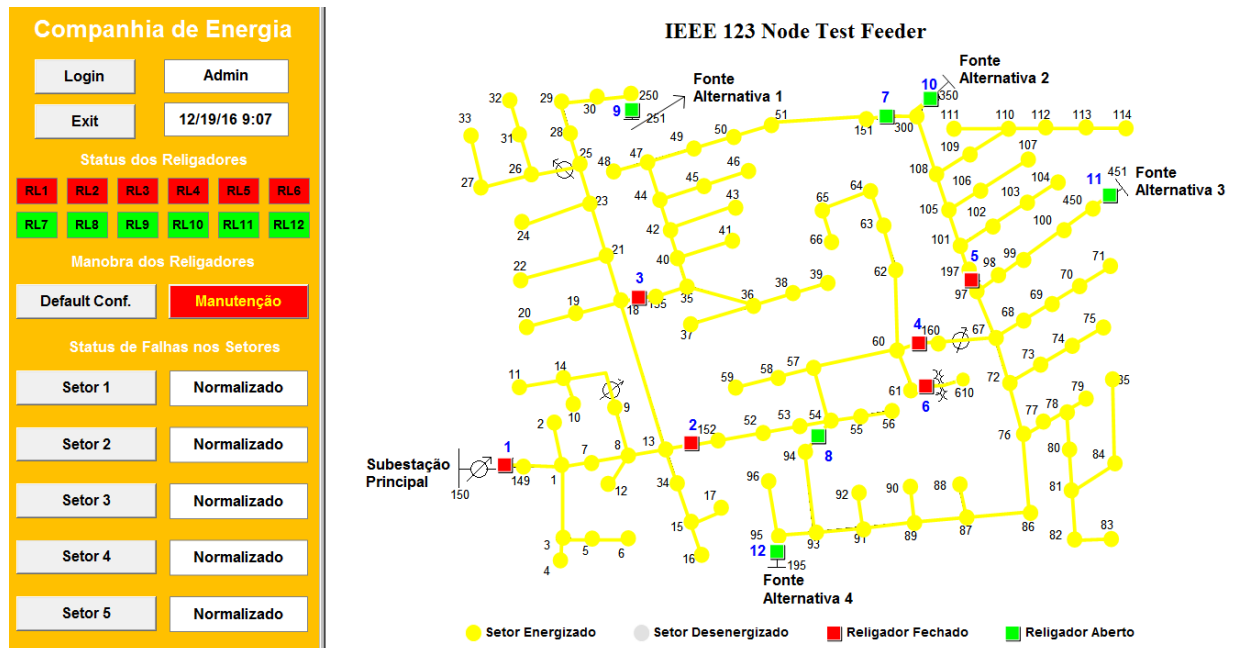


Figure 4 - shows the normal configuration of the IEEE model.

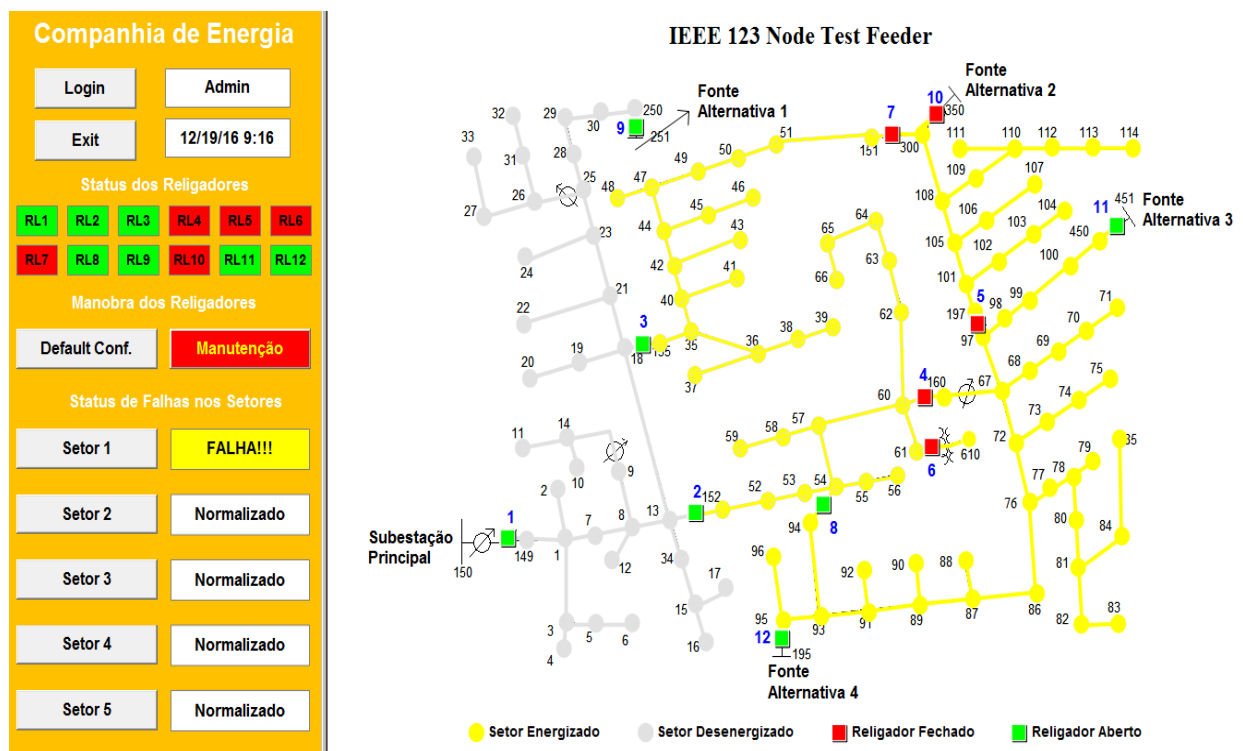


Figure 5 - shows results from failure simulations via Elipse Software.

## RESULTS AND DISCUSSION

The focus of this study was on the immediate reclosing of an electricity distribution network, considering that there was a failure in a certain part of the model.



According to [10], the solution of the problem of reestablishment of Electric Energy Distribution Systems (EEDS) is important. Thus, several works have been developed as: Comprehensive Search Methods [11], Automation Logics; Intelligent Systems [12], [13] [7].

Among the researches, it was observed that the researchers used many techniques of artificial intelligence to solve this type of problem, but little research was done using ANN for self-recovery, which motivated the choice of the technique.

In this way, it was possible to obtain the currents of each section through the power flow performed in the OpenDSS, and with this information to carry out the classification of the types of failures through an ANN and the demonstration of this information via Elipse Software. This is similar to what [13] has researched.

The way the problem was solved was innovative with respect to time, within the parameters stipulated by the National Electric Energy Agency (NEEA), that is, the recovery of the network took less than 3 minutes.

In Table II it can be noted that the time to perform the ANN training was adequate to what NEEA establishes.

The time in excess can be explored in the treatment of other variables, such as in the communication between the automation and the keys.

## CONCLUSION

Through the DSS, the IEEE 123 node test feeder network was selected. Some adaptations were made, including keys that were disabled in the default configuration, which enabled them to be fed, in order to increase the reliability of the system.

For the study, these secondary feeds are capable of supplying the entire system's needs, given the new reality, since a defective part is isolated and will no longer participate in the total system load.

Another important point is how the failures were selected: by sectors, classifying them in five, that is, any failure within that region will provide the same switching solution to isolate it, although there may be alternative power sources through the failures.

In order to make the solution friendly to the operators of an electrical power system or Distribution Operating Center (DOC), Elipse Software was used and made clearer what were the alternatives for the post-failure situation, that is, the solution of the problem. It has shown that this type of solution was efficient in solving the failures.

No simultaneous failures were considered, but the method can be applied in other systems to solve other failures in electricity distribution networks.

Thus, it is necessary to perform other experiments, to confirm the efficiency of the method in real time and make this new technique known.

## REFERENCES

1. Mehl E L M., "Qualidade da Energia Elétrica," pp. 1–8, 2013.
2. Bernardo, N. "Evolução da Gestão da Qualidade de Serviço de Energia Elétrica no Brasil Evolução da Gestão da Qualidade de Serviço de Energia Elétrica no Brasil," 2013.
3. Vieira S, Granato,J., "PLC como Tecnologia de Suporte à Smart Grid," 2011.
4. IEA, "International Energy Agency Iea.," in *Technology Roadmap - Smart Grid*, 2011.
5. Oualmakran ,Y., "Self-healing for smart grids: Problem formulation and considerations.," in *3rd IEEE PES International Conference and Exhibition on Innovative Smart Grid Technologies (ISGT Europe)*. Berlin. Proceedings,

- 2012, p. p.1–6.
6. Huang ,Q., Song ,Y., Sun,X., L. Jiang, and P. W. T. Pong, “Magnetics in Smart Grid,” vol. 50, no. 7, 2014.
  7. Decanini ,J. G. M. S., “Detecção, classificação e localização de faltas de curto-circuito em sistemas de distribuição de energia elétrica usando sistemas inteligentes,” Universidade Estadual Paulista., 2012.
  8. IEEE, “Distribution Test Feeders,” 2014. [Online]. Available: <https://ewh.ieee.org/soc/pes/dsacom/testfeeders/>.
  9. Elipse, “No Title,” pp. 1–10, 2016.
  10. Borges, T. T., “Restabelecimento de sistemas de distribuição utilizando fluxo de potência ótimo,” UFRJ, 2012.
  11. Glamocic, L. R., “Combinatory Search Method for Determining Distribution Network Automation,” pp. 1–6, 2011.
  12. Kaewmanee, S., Sirisumrannukul,J., , “Multiobjective service restoration in distribution system using fuzzy decision algorithm and nodes-depth encoding,” in *In: 8th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology*, pp. 893 – 896, 2011.
  13. Kondo D. V., A. D. E. Religadores, and A. Em, “Alocação de religadores automatizados em sistemas de distribuição,” 2015.

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