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# A new methodology of fault location for predictive maintenance of transmission lines

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ABSTRACT

This paper presents a new methodology for monitoring, in real-time, the conditions of the insulation of an power transmission line, detecting and locating anomalies in its operation, before the supply of power is interrupted, thus allowing for preventive maintenance. This method uses the harmonic decomposition of the leakage current to analyze the condition of line insulation and employs a neural network to locate the fault. Experimental measurements were obtained to validate the simulated results.



## 1. Introduction

Electric energy is one of the most important resources for the economic development of a country, as well as promoting the satisfaction and well-being of society. Thus the Electric Power Systems must ensure a high degree of reliability in the continuity of the power delivery. However, due to the increased complexity of these systems, energy demand and the interconnection of existing systems, outages of electricity tend to be more frequent.

This new and challenging scenario has required a considerable improvement in equipment and devices for fault location, control and protection, to ensure a reliable and economic operation of the power system, either under normal operating conditions or in contingencies. According to [1] the contingency conditions can be of two types: faults or failures. A fault is an unexpected deviation in at least one of the characteristics, properties or parameters of the system from an acceptable, common or standard condition, i.e. a malfunction or defect. On the other hand, a failure is a permanent interruption in the capacity of a system to perform a requested task under specific operating conditions.

Among the various constituent parts of an electric power system, transmission of energy is one of the most susceptible to faults. This is due to the physical dimensions of the transmission lines (TLs) and the environment in which they are installed. These characteristics hinder their maintenance and monitoring. TL faults can be caused by the occurrence of different types of phenomena, such as end of life of its components, influence of the environment, pollution, humidity or heat, and also possible accidents, such as mechanical shocks.

Due to its length, the detection and location of faults in TLs is very important because it reduces the shutdown time, allowing quicker maintenance, and contributing to the return to normal operation of the system [2,3].

For the verification of a fault in operation of a system, it is necessary to identify parameters that indicate this fault. In the case TLs the insulation conditions determine the operating state of the TL. Since the insulation depends on the resistance and dielectric strength of the TL, an observable variable that can be used to indicate the level of insulation is the leakage current. This is because the lower the TL insulation level, the higher its leakage current.

This paper proposes a method for fault location on transmission lines using harmonic decomposition of the leakage current. The main tools are the mathematical model of the transmission section to simulate an TL, and an artificial neural network (ANN) of the perceptron multilayer backpropagation type to locate faults inserted into the model. Actual measurements of voltage and current, obtained through power meters installed in substations, are used to validate the model used in location. The methodology described is registered as an international patent under number 00002200600491835 of April 19, 2006.

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## 2. Methods of fault location in transmission lines using artificial neural networks

Different methods for faults location have been proposed by different authors. The two most common approaches are based on: (i) the calculation of the impedance from the current and voltage phasor data measured in one, two or three line terminals, and (ii) traveling waves.

New concepts such as artificial neural networks (ANNs) and wavelet transforms have been used successfully in fault location in transmission lines [4,9,10,20,26,27].

The methods of fault location using ANN commonly required current and voltage data of the three phases from one, two or three terminals of the transmission line. The ANNs most used in this type of problem are the multilayer Perceptron (with techniques of feeding backpropagation for training). ANN is usually fed by data generated (simulated) by Alternative Transients Program (ATP) software.

There are many articles that present, in addition to methods for faults location [4–8], methods for detection and classification [4,10,28,29].

Purushotama et al. [6] present two approaches using a modified ANN to determine the location and resistance of a fault. Protection relays are used to indicate the faulted line and the type of fault. The first approach uses only data from one terminal and the equation of Eriksson et al. [11]. The input data are the values of voltage and current in the three phases in pre- and post-fault situations. Seven ANNs were developed, where the first determines the type of fault, and the other six were made to locate the fault. The second approach is independent of the current data or failure resistance, because it uses voltage data from two line terminals.

Purushotama et al. also presents two different topologies of ANNs. One is the multilayer perceptron, and the other is the Fahlaman technique [12], which is the correlation technique in cascade.

Gracia et al. [7] show that several topologies of ANNs can be applied to the process of fault classification and location in transmission lines with two terminals, either in single or double circuits. This range of possibilities is far from being perceived as a disadvantage. It is an advantage that ensures the applicability of the use of ANNs in the process of fault location and classification, provided there is a selection of these taking into account its performance. Also in this study, it was estimated that the average error in fault location oscillates between 0.015% and 0.4%. In determining the resistance, the average error is between 0.017% and 0.46%. If shorter times of training are required, a single hidden layer in the network can be used.

Ramos et al. [8] demonstrated the technique of locating and identifying faults in transmission lines using ANNs with measurements from only one terminal, with five ANNs, one used for the classification of faults, and the other four for location. The authors compared the results obtained with this technique to the Takagi Method [13]. In this comparison, improvements were observed in accuracy of location and absolute errors smaller than 2%.

This paper proposes a method that allows detection of defects in the TL before the occurrence of the fault, enabling predictive maintenance. Unlike most methods mentioned, this article uses actual measurements of the power system. The detection and location of the defect is performed by monitoring the behavior of harmonic decompositions of the leakage current from the TL.

## 3. Model of transmission line chosen

The Guamá–Utinga was the section of the TL chosen to be monitored. This stretch of TL, shown in Fig. 1, belongs to the 230 kV Transmission System of Tucuruí (TUC 86-3003R-5) of the Power Plants of Northern Brazil – ELETRONORTE (Pará-Brazil). The voltage and current data for obtaining and validating the mathematical model used for fault location was acquired from this stretch of TL.

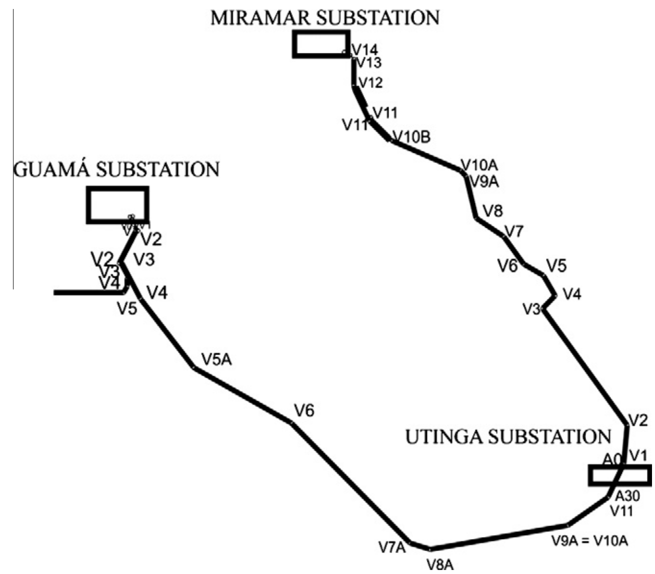


**Fig. 1.** Route of the Guamá–Utinga–Miramar TL.

The construction data on the GUAMÁ–UTINGA TL, like structure of the towers, number of openings, portals and partial and total distances were provided by ELETRONORTE and used for the calculations of the circuit elements of the line. Between substations Guamá and Utinga there are 50 towers, with an average separation of 374.36 m and a total extent of 19049.68 m. Table 1 shows the average distances between towers and landmarks. Table 2 shows the types and number of towers between the two substations.

In each substation power meters were installed, as illustrated in Fig. 2. These meters are synchronized by GPS and capable of providing measurements of voltage and current up to the 50th harmonic, with an accuracy of 0.025%.

The TL model chosen for this work is the distributed, since it is suitable for short lines, without transposition, like Guamá–Utinga.

The mathematical model simulation was performed using the program Matlab/Simulink.

The $\pi$ distributed mathematical model represents the 50 towers of the GUAMÁ–UTINGA stretch. Ten $\pi$ circuits are used in this simulation model, represented by blocks called towers, a view shown in Fig. 3, where each block represents five towers along the stretch of the GUAMÁ–UTINGA TL.

The circuit elements are resistance ($R = 1.0955\ \Omega$), inductance ($L = 31.88$ mM) and capacitance (116.76 nF). The latter is obtained by using the Finite Element Method (FEM) [17], as can be seen in Fig. 4, in which may include the effects of soil and the cable lightning rod.

Studies conducted by the authors of this paper indicate that the leakage current is influenced by climatic conditions such as temperature and relative humidity. For this reason, in addition to the electrical voltage and current variables, the environmental variables were used in the mathematical model: temperature (TA), solar radiation (SR), wind speed and direction (WS and WD) and relative humidity (RH).

### *3.1. Determination of the leakage current, detection and diagnosis of the fault*

To determine the leakage current, the Gaussian theory of closed surfaces was used, where the algebraic sum of all currents entering