New Approach to Improve High Voltage Transmission Lines Reliability

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***Abstract* — This paper presents a remote fault detection and identification system for transmission lines, which allows eliminating, or at least minimizing, the use of maintenance methods employed by power utilities, due to its technical potential and capability to reduce operational costs. It is a data acquisition system, capable of acquiring and storing high frequency signals present in the TLs. The signals, after their storage, are treated and identified through signal processing techniques such as digital filters and neural networks. Such system has been installed in the reception terminal of the power line carrier system, in an electric power utility in Brazil. Many tests were carried out simulating faults in the transmission line with the objective of defining patterns. Therefore, it is possible to develop an algorithm capable for identifying any potential transmission line faults. With the results obtained in this first part of the research, and with the continuity of the project, new signals will be obtained, identified and trained in the neural network.**

***Index Terms* - Digital filters, fault identification, insulators, neural network, signal processing, transmission lines.**

I. INTRODUCTION

The maintenance of transmission lines (TLs) is important since possible faults may lead to the interruption of electric energy supply, and, thus, should be diagnosed and repaired in the least possible time. Nevertheless, according to the possibilities, it is also essential not to perform maintenance only in a corrective manner, but in a preventive manner too, so lines operate without interruptions.

Maintenance in the transmission line (TL) is carried out from the results of the visual inspection associated with the level of experience of the inspectors, methods based on the combination of Ultraviolet [1], ultrasound, infrared [2], electromagnetic field measurements [3], corona discharges [4], electric field measurements used to check torn, cracked or broken insulators [5], and acoustic radiator to detect broken insulators [6]. All of these methods demand that the maintenance staff inspects systematically the entire transmission line in order to detect faults by land or by properly equipped helicopter. The most frequent TL faults are broken insulators (often caused by vandalism), and cables with broken strands. These types of inspections, besides being very expensive, many times are time consuming, since all of the collected signals are not automatically analyzed via software.

Therefore, it is important to create an intelligent system able of automatically and continually inspecting TLs, besides being able of detecting, identifying and locating disturbances originated in eventual occurrences in the line. Usually, these occurrences present low amplitude and high frequency which are difficult to be record by conventional measuring devices; however, they are too important to be ignored for it is not uncommon for them to convert into more critical events, even leading to the interruption in the electric energy supply.

In this sense, this paper aims at presenting a new system developed for remote detection and identification of faults in the TLs. The project was divided into two parts. In the first one, the objective was for the system to detect and identify faults in insulators, since the majority of defects in the TLs occurs in them. In the subsequent part, besides the detection and identification of faults, the objective was also to locate them.

Thus, this new system proposes an innovative way of detecting, identifying and locating faults in the TL that can lead to a great impact in the reduction of operational costs of the electric power utilities, due to its automation and efficiency.

II. PROPOSITIONS

A. Main Faults in Transmission Lines

The faults that occur in a TL are classified into two groups that need to be detected, identified and located.

The first group is the one related to short-circuit occurrences, which are called faults. It is known that short-circuits may occur for different causes, i.e.: due to fires in the right of way of the TL, atmospheric discharges, rupture and fall of cables and/or towers, due to extreme weather conditions as hail and wind vibrations.

The second group is the one that includes many types of such faults, which may also result in a possible TL tripping, simply called defects. Some examples of defects in the TLs are: string insulators with one or more defective insulators due to internal perforation, cracks, shed damage, surface calcification, etc,.

Another phenomenon that appears in the TLs and in the components of a substation, which has been object of researches and studies for more than half a century, is the Corona effect [7]. It brings about power losses in the TLs, audible noise (AN), radio interference (RI), electro-erosion and accelerated degradation of polymer and ceramic insulators, as well as attacks to the metallic parts of these devices. The losses by corona in extra-high voltage lines may vary from a few kW/km to hundreds of kW/km.

In this scenario of defects in insulators, according to the information of the technical personnel of the power utility, the accumulation of 30% of damaged insulators in a string insulator may generate the interruption in the electric power supply, caused by arc bridging. Besides that, it is important to highlight that, in average, in each hundred insulators, two or three present defects in a one-year period [6].

Therefore, present development aims at detecting these defects in a predictive way. In this sense, the investigation tries also to find out defect patterns or signatures that are still hidden, so they can be solved before they effectively interrupt the transmission system, as in Fig. 1.

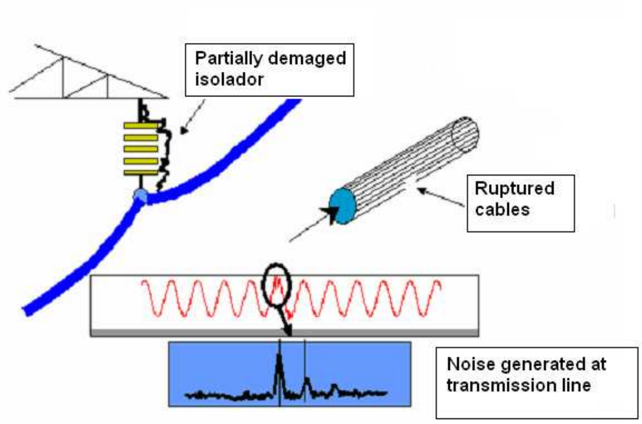

Fig. 1. System Noise

The various previously mentioned defect types are expressed through electromagnetic, thermal, and noise effects, thus resulting in the development of many techniques for their detection.

III. The Remote Detection and the Identification System

A. Using the Communication System

The usual methods for inspecting transmission lines require their whole extension to be inspected, looking for possible defects, be it by simple visual inspection, by using infrared techniques or by electromagnetic field analysis. One of these methods, that is carried out from the ground up to 50 m away from the tower, was called remote detection [6].

The objective of the present method is the definition of a new defect detection and identification procedure that makes possible the detection of TL defects from the substation or control center, and not near the defect, as in the current methods.

For such, information from the technical personnel of the power company was collected, relating to the interferences in the pattern of noise in the power line carrier (PLC) systems. It was noticed the correlation of these noises with problems in the TLs that, with time, could lead to the shutting down of the line.

From this observation and its correlation with defects in the components of the transmission lines, especially in string insulators, arouse the opportunity to investigate and study the interferences that appear in the PLC system. Thus, the partnership with the power utility enabled the setup of a defect detection and identification system in insulators of a 138 kV TL of approximately 110 km long.

For the detection of the noises caused by defects in the TL, it was used a data acquisition board to collect disturbances generated by defects in the TL and, for their identification, signal processing techniques were applied, which are dealt with next.

B. Power Line Carrier (PLC) System

The power line carrier (PLC) system is used by electric power utilities in the TLs above 33 kV for transmission of voice, data, and teleprotection signals in the range of 30 kHz to 500 kHz. The system is constructed with a line matching unit, line-traps, coaxial cables, and capacitive potential transformers (CPT), mounted with potential transformers and coupling capacitors [8].

C. Topology of the Detection System

The proposed system uses PLC input and output of the communication signals for the acquisition of signals alluding to TL defects. Figure 2 illustrates the topology of the proposed system.

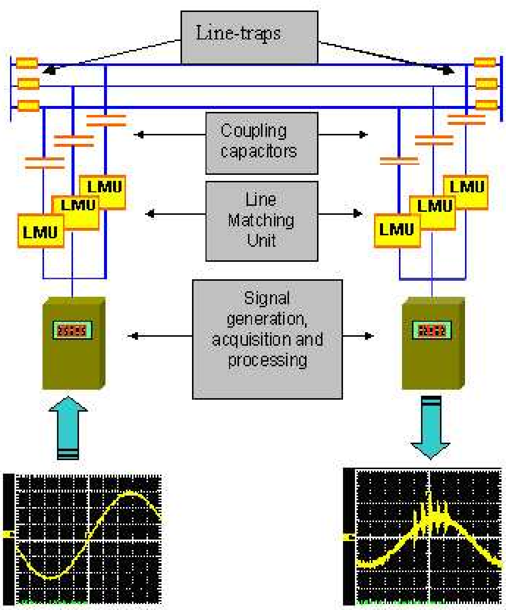

Fig. 2. System Topology

The system consists of a PLC, selective filters, teleprotection equipment, data acquisition boards and computers.

D. *The Defect Detection and Identification System*

The defect detection and identification system was assembled and developed to allow signals generated by any type of relevant occurrences in the transmission line to be acquired by a data acquisition board and stored in the computer installed in the substation of the power utility.

The equipment that forms the transmission and receiving systems were installed in two substations and connected to the transmission line.

Figure 3 depicts part of the installed system, including line trap, coupling capacitor and the line-matching unit, used for defect detetion.

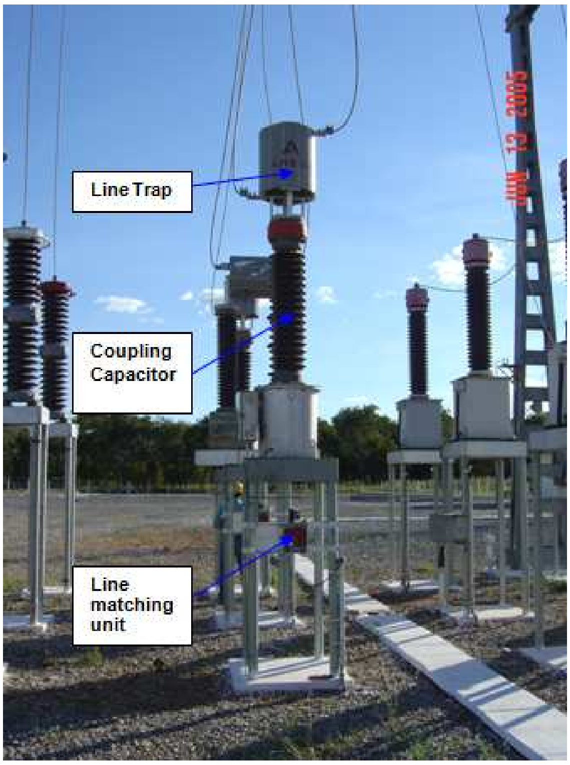

Fig. 3. System Equipament

The TL signal, transmitted by the line matching unit, was conducted by a coaxial cable to the data acquisition board, installed in a computer of the substation.

After the installation, it was verified at both stations that 232 kHz attenuated the least in PLC system.

Thus, in order to evaluate the PLC system, a 232 kHz carrier signal was input at one of the substations with a power level of 24,7 dBm/75Ω. A carrier reception level of 4,5 dBm/75Ω was measured in another substation. This signal was satisfactory since it presented a level above the minimum necessary [9], which made it possible for the board to perform the acquisition of noises generated by the defects.

IV. ANALYSIS TOOLS FOR DEFECT IDENTIFICATION

Many signal processing techniques can be applied to analyse of electromagnetic waves for defects detection. Among them, there are: Fourier series, short time Fourier transform [10], Wavelet transform [11], digital filters [12], neural networks [13] [14], least-mean-square algorithm (LMS), fuzzy logic, genetic algorithms, independent component analysis (ICA).

In this paper, two results obtained considering two tools are presented: digital filters and neural networks. The first one was chosen due to its performance in separating desirable signals for future analysis, and the second due to its capacity to automatically recognize the patterns generated by defect signals.

V. SIGNAL MONITORING AND ACQUISITION

In this section, the main characteristics of the data acquisition and monitoring system are presented.

A. *Data Acquisition Board Programming*

The identification system requires the data acquisition board to accurately collect in high frequency signals. For such, it was used a board with two input channels, sample rate of 200 MS/s, 12 bits resolution, 8 MB memory per channel, and a software –adjusted trigger was used to collect events that only exceeded a pre-determined value.

Besides these equipments, it was also used the Labview software as interface from the data acquisition board to Matlab software, wherein filtering and signal analyses were implemented.

Since the system continuously monitors the reception signal and it is not viable to tape the signals at all times, the board was programmed in such a way that, only in the occurrence of some significant disturbance, a valid trigger command is generated. Thus, the received signal is recorded in text form for posterior treatment by the Matlab software. Among these signals, it is possible to mention those that represent broken insulators, cracked insulators or ruptured cables.

B. *- Data Transfer System*

In order to transfer via Internet the signals stored in the computer of the power utility to UNIFEI, the VNC (Virtual Network Computing) software was installed in both computers.

C. *Functionality and the first tests of the system*

With the system properly installed, some preliminary tests were carried out to check its functionality, i.e., verify if the system is really able of transmitting and receiving signals with conditions to be acquired.

Figure 4 shows a signal acquired by the data acquisition board, during a normal TL operation.

It is important to note that this signal does not present any disturbance resulting from a defect in the transmission line. It was acquired only to evaluate the level of system reception.

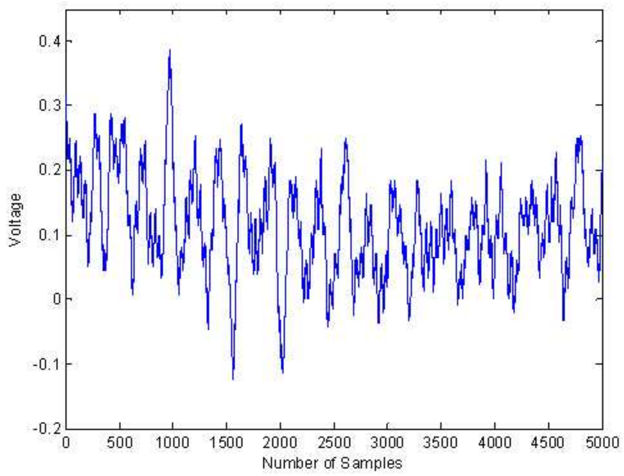

Fig. 4. Acquired signal

D. *Field Test*

For the study, the acquired signals were divided into two large groups:

1. Signals acquired without forcing a defect. These are signals that were acquired due to some unknown occurrence in the transmission line;
2. Signals acquired through the field of tests. These are signals that were acquired due to the intended introduction of a defect in the transmission line.

The second group is obviously the one of greater interest for signal analysis because through the knowledge about the type of forced defect and with the recording of the corresponding signal, it is possible to build a data base to be used later by the defect identification software.

Thus, it is necessary to describe the types of tests performed in the TL.

E. *Some Examples of Field Tests*

Some tests performed in the hot line by the maintenance staff include:

- Fork test: performed with the introduction of a fork in which one or two string insulators are short-circuited.
- Figure 5 (a) shows the test being performed by the maintenance team 10 km away from the data acquisition board installation. Figure 5 (b) illustrates the schematic drawing of an insulator being short-circuited by a fork.
- Insulator Replacement: performed through the replacement of a damaged string insulator by another one in perfect condition;
- Opening of the circuit breaker: test in which a transfer bar circuit breaker near to the TL is opened;
- Closing of the circuit breaker: test in which a transfer bar circuit breaker near the TL is closed.

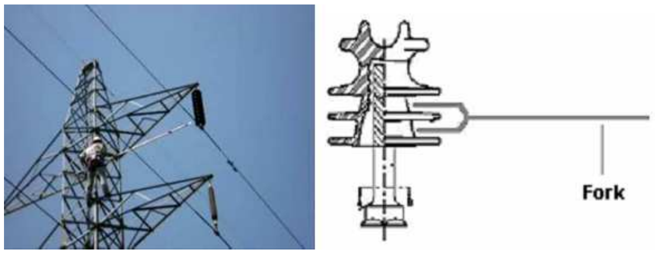

Fig. 5. (a) Fork test; Fig. 5. (b) Drawing

Due to its simplicity, the fork test was more frequently carried out. This test was performed in order to simulate a short-cut in one or two insulators, or their breaking down in a string of nine insulators, resulting in the reduction of the TL insulation.

From these tests, it was possible to define correlation patterns between the forced defect and the resulting disturbance in the acquired signal, as described in item VI.

F. *Acquired Signals*

Figures 6 and 7 show, respectively, the signals acquired through the fork and the broken isolator tests.

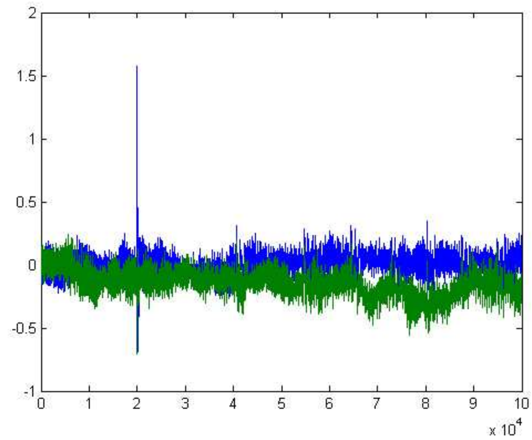

Fig. 6. Fork test

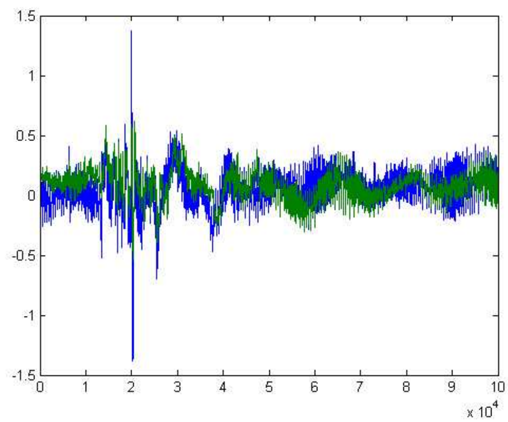

Fig. 7. Broken isolator 40 km from the substation

VI. Automatic Defect Identification

In the following subitems, the procedures used by the developed algorithm are presented, besides the identification results after the neural network training.

A. Algorithm Developed for Defect Identification

The signals originated in the tests carried out in the TL are the input data for the developed algorithm. In practical terms, the algorithm has the following steps:.

- Test signal input;
- Filtering of the signal through a pass band elliptic filter in the band of 1 to 3 MHz;
- Normalizing the filter output signal in order to capture only wave shapes, avoiding the representation of the amplitudes in the patterns analysis;
- Isolation of the signal interest samples. The algorithm removes those samples that do not characterize the signal disturbance. This is done in order to avoid an unnecessary computational time;
- LPC (*Linear Prediction Coding*) Application. The LPC algorithm determines the coefficients of a linear predictor through the minimization of prediction errors in the meaningful least squares;
- Neural Network Training. This application is more carefully evaluated in item B.

Fig. 8 shows the flow chart of the defect identification process in a TL.

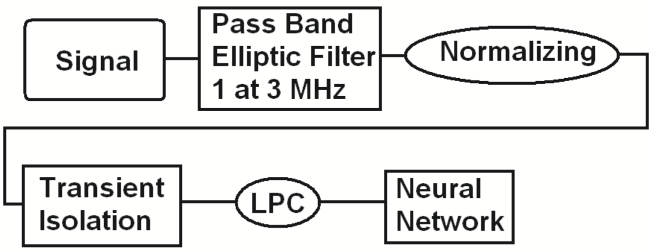

Fig. 8. Defect identification flow chart

B. Artificial Neural Networks (ANN)

Neural Networks are used to the analysis and processing of signals, process controls, robotics, data classification, voice analysis, image analysis, pattern recognition in production lines, smell/odor analysis, credit evaluation, financial market as well as in TL for the detection, classification and localization of faults [12] [13].

The MLP (multilayer perceptron) neural networks [15] have been successfully used to solve many problems, through supervised training with an algorithm known as error back-propagation. This algorithm is based on an error correction learning rule.

In the project, the use of neural network, as well as all of the development of the algorithm, was done in a Matlab environment, using the MLP network.

During the development phase of the defect identification algorithm, many MLP neural networks topologies were tested with the objective of optimizing the training procedure, so as to recognize which topology presented greater efficiency in training the neural network when using the TRAINRP (Resilient Back Propagation) training function.

The best results were obtained with the MLP neural network with 3 layers, 12 units in the input layer, 65 neurons in the first hidden layer, one output layer with 5 units (architecture 12-65-5). The transference function used was the Logsig (sigmoid) function.

C. Identification of Some Signals by the Neural Network.

The signals acquires by the hot line tests were organized into groups in a data base specially developed to provide input signals for the neural network in question. For the application in the network, two groups of signals were used, i.e.: (1) Fork Test in phase A and (2) Fork Test in phase C;

According to the studies carried out, the recommendation to use 60% of the signals for training was followed, besides 25% of validation and 15% for tests [12].

Thus, the results obtained from the validation of the defect identification system are shown in Table 1.

Table 1 – Results of the defects identification

Fork Test Phase A	80%
Fork Test Phase C	92%

Considering the quantity of signals acquired by the fork test and the occurrence frequency of each disturbance, one notes that at each five signals originated from defects, at least ffour are correctly identified, i.e., 80%.

During the test period, the data acquisition system detected disturbances generated during the hot line insulators and circuit breaker opening and closing. In order to validate this neural network configuration with other disturbances, these were treated and applied in the neural network for training and validation. The percentage of signals correctly identified was superior to 78%.

VII. Final Remarks

The detection and identification of defects in a transmission line are challenging tasks, since they depend on tests performed by the maintenance staff with hot line conditions and on the identification of many types of defects, nevertheless, with great future prospects. Such prospects are a consequence of the results achieved by the solution proposed in this defects detection and identification work.

Thus, in the current conditions, new tests in the system should be carried out, sine the tests and different events in the transmission line yielded promising results, with percentage above 78%.

It is worth noting that the system reliability is directly connected to the quantity and diversity of tests performed in the TL. In other words, as more tests of different types are carried out, the best the defects identification results are.

Hence, with the objective of improving the detection and identification system, works on four main issues are still being carried out:

- Increase in the number of events for a better pattern recognition by neural networks;
- Increase in the number of signals of each event for the optimization of the neural networks training process;
- ATP software simulations;
- Insulators lab tests.

VIII. CONCLUSIONS

The power line carrier (PLC) system along with the data acquisition board proved to be efficient in the assessment of signals generated by transmission line defects, since it was possible to capture many types of events in the test, such as broken insulator, insulator short circuit, cable rupture, circuit breaker opening and closing, among others. Besides that, the use of MLP neural networks in the identification of defects in the TL has shown to be very promising, demonstrating the potential of the idealized system.

Due to simplicity and easy installation the present proposal tends to have a great impact in the electric power utilities. Ground inspections or even high cost aerial ones currently in use may be reduced or eliminated by this approach, generating great operational cost reduction for the electric power companies.

IX. ACKNOWLEDGEMENT

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