THE USE OF ARTIFICIAL NEURAL NETWORKS FOR IDENTIFICATION AND LOCATION OF DEFECTIVE INSULATORS IN POWER LINES THROUGH CURRENT TRANSFORMERS

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ABSTRACT

This paper presents a new technique for identification and location of defective insulator strings in power lines based on the analysis of high frequency signals generated by corona effect. Damaged insulator strings may lead to loss of insulation and hence to the corona effect, in other words, to partial discharges. These discharges can be detected by a system composed of a current transformer as a coupling capacitor, a data acquisition board and a PC. Analysing the waveform of these partial discharges through a neural network based software, it is possible to identify and locate the defective insulator string.

INTRODUCTION

The maintenance of insulator strings in power lines demands much time and money. Inspections have to be carried out in loco and usually require expensive tools and vehicles as heavy duty pickup trucks and helicopters. Moreover, most of them are based on visual observations, leading to low precise results.

The method presented in this paper comes to improve the quality of these inspections and drastically reduce the amount of resources spent in these activities, once it is done remotely and based on electric signals measurements.

These signals, acquired by a simple data acquisition system, are generated in the defective insulator strings due to the corona effect and their waveforms depend on the type of the damage and the location of the insulator string in the power line. Once acquired, the signals are compared to a data bank that contains thousands of signals related to known defects. The software created for this task is based on neural networks, an artificial intelligence technique widely used for pattern recognition.

THE CORONA EFFECT EMULATION

The corona effect in an insulator string is generated when the insulation is affected by, for example, a fractured insulator or excess of humidity. Thus, reproducing this effect was necessary to emulate insulator strings in bad condition. Using a thin metal wire connected between two insulators, as shown in figure 1, a partial discharge is generated, resulting in a good approach of the corona effect [1].

Figure 1: Corona effect emulation.

The typical partial discharge waveform is shown in figure 2.

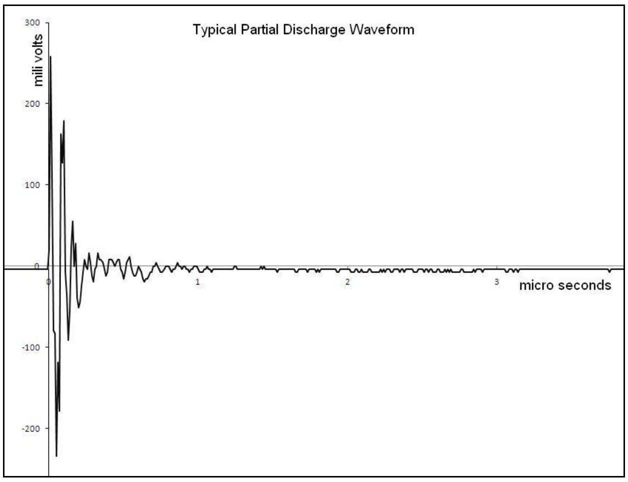

Figure 2: Typical partial discharge waveform.

THE LABORATORY

Once the corona effect was successfully reproduced, the next step was the building of a power line in laboratory. Using inductors and capacitors to form π models[2], an artificial transmission line was created, representing a 48 km real transmission system, as shown in figure 3.

Figure 3: The transmission system built for the tests.

The monophasic system, that represents a 69kV real system, is composed of π models (inductors and capacitors), line trap, transformer, current transformers and a reactor for reactive power supply, once the transmission line has no load.

The transmission line has 48 taps that enable the installation of an insulator string across the line. Five insulators are used to compose the insulator string, and as mentioned before, some defects can be emulated, resulting in the corona effect. Both beginning and end of the transmission line have one current transformer, however the function of this equipment in this case is not measurement or protection: it is used as a coupling capacitor. Instead using the expensive and not so easy to find capacitive voltage transformer, the capacitance between the phase and the metal body of the current transformer can be used as coupling device. Many tests were carried out with current transformers and they demonstrated that this capacitance has a very wide frequency response in average, as shown in figures 4 and 5.

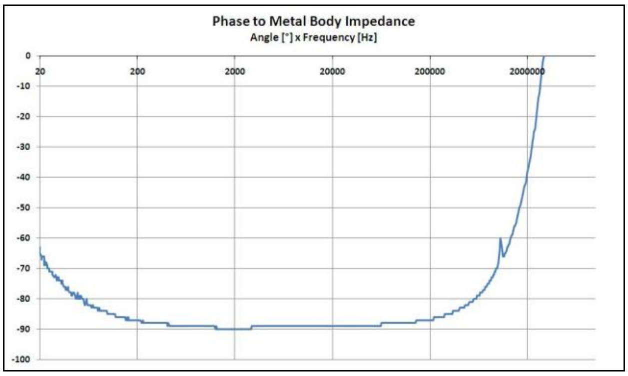

Figure 4: 69 kV current transformer behaviour of the phase to metal body capacitance – Phase x Frequency.

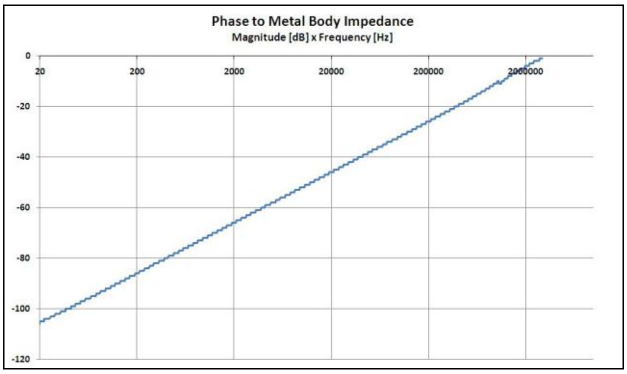

Figure 5: 69 kV current transformer behaviour of the phase to metal body capacitance – Magnitude x Frequency.

The partial discharge signal is acquired from the power line through a Rogowski coil installed in the ground cable of the current transformer. Hence, this signal is acquired by a data acquisition board, in this case a 8 bit / 100MS/s model, and recorded in a PC. The simplified scheme of the system is in the figure 6.

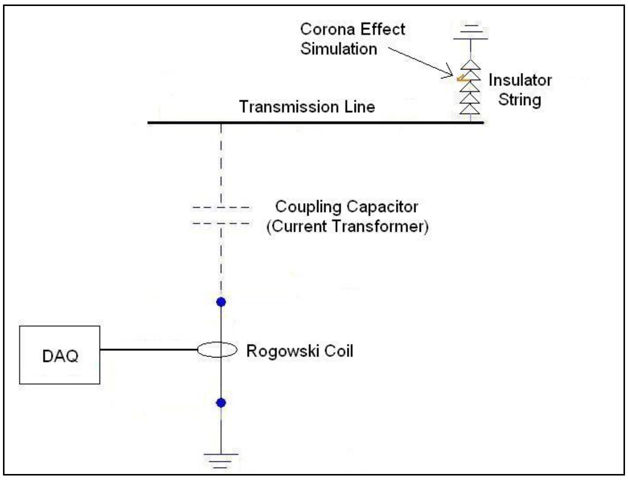

Figure 6: Simplified scheme of the system in built in the laboratory.

SOFTWARE ANALYSIS

The identification and location of the bad insulator string, as mentioned before, depends on the waveform of the partial discharge signal. For each occurrence point, the signal has it waveform changed, in other words, the waveform is affected by the position of the partial discharge in the insulator string and the position of this insulator string in the transmission line

Hence, for identification and location of the insulator string was necessary to create a software dedicated to read the acquired signals and associate the waveform to the problem in the insulator string and it location, and for this pattern recognition task neural networks were used[3].

Neural Networks

The neural network is a very simplified model of the human brain, composed of processing units called neurons. These neurons, based on the real biological neurons, represent a combination (sum) of inputs multiplied by their weights and shifted by the bias input. The result of this combination has it amplitude limited by the activation function. A simple neuron is represented in the figure 7.

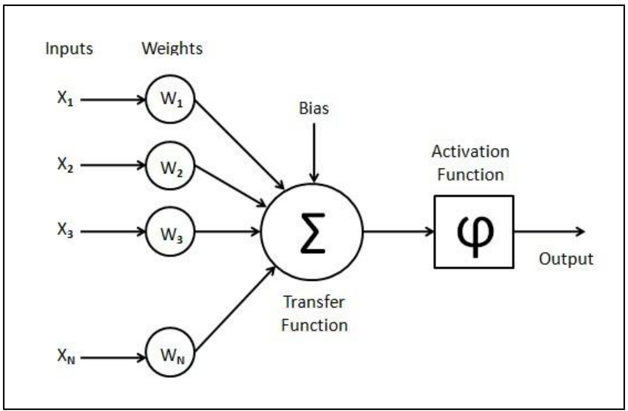

Figure 7: Artificial neuron.

The neural network is composed of many neurons organized in layers: the input layers, the middle (hidden) layers and the output layers. It is possible to connect the neurons in many ways. One of then, the feedforward backpropagation, is the one used in the software. In this model the output of a neuron is the input of the subsequent and there is an error signal feedback, in other words, the error generated by the difference between the wanted output and the real output is sent to the neurons in order to adjust the output. An example of this topology is in the figure 8.

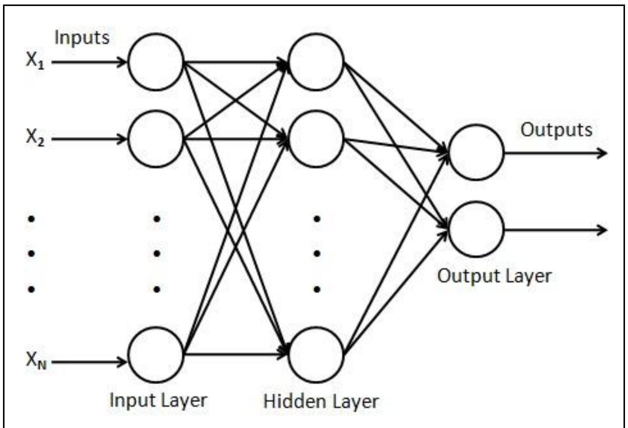

Figure 8: Feedforward backpropagation neural network topology.

Among the advantages of the neural networks, it can be highlighted the parallel processing capacity, the tolerance for noise, easy adaptation and training. Serious disadvantages of this artificial intelligence method is the amount of time used in the training and the impossibility of explicit knowledge representation, once this knowledge is stored in the neurons connections and weights.
The way this knowledge is acquired is called learning process and it is analogue to the human learning process. For example, a child learns to perform a summation when the teacher shows an example of this operation. A neural network learns to recognize a certain signal when an example of this signal is presented to it.

Software Development

All the software was developed in Matlab® and its Neural Network Toolbox. As explained before, the waveform of the partial discharge depends on it position in the insulator string and the position of the insulator string in the transmission line. Hence, the software function is to recognize the waveform pattern and associate it to the situation. Some programs were created for test. One of them was used only for location of the defective insulator string, independently on the position of the problem in the string. Twenty independent and identical neural networks were used for this task and their outputs were combined to result in just one answer, what tend to reduce possible errors or poor results. All the neural networks were trained with the same data bank. This data bank was created from thousands of signals obtained from 12 taps of the transmission line and for each tap the position of the corona simulation metal wire were changed (5 possible positions).
Hence, some known signals not included in the data bank were presented to the neural networks, resulting in an answer composed of probabilities, in other words, the answer shows the probability of the analyzed signal come from each known position. The figure 9 shows an example of this analysis.

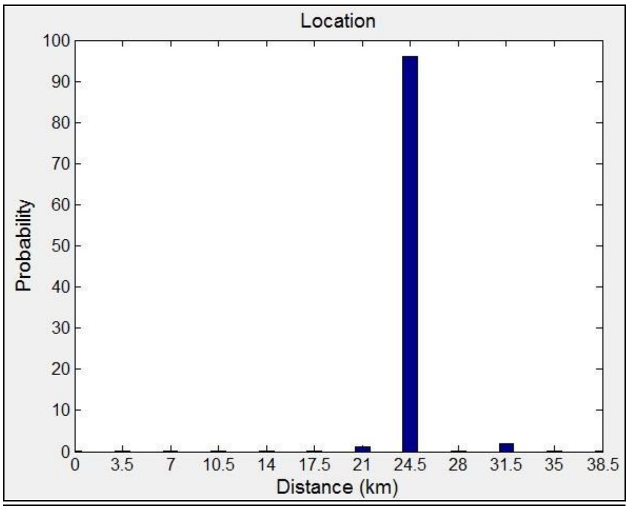

Figure 9: The answer of the neural networks for one signal from the km 24.5.

Note that the horizontal axis of the figure 10 shows all the possible positions (distances) used in this test and for each position there is a probability bar. In this case, the software answered that the present signal comes from the km 24.5 of the transmission line with a probability of almost 100%, whereas there is a very low probability of the signal comes from other position – just km 21 and km 31.5 probability bars are visible in the graph, the other ones can be interpreted as a null probability.
Many tests were performed with this software with a very good hit rate. There were situations where the answers were not as good as shown in figure 9, where there is a huge difference between the right answer and the other ones, however occurrences where the wrong answers probabilities were higher than the right answer probability were unusual. As the location was successfully performed the identification can be performed as well. Other test was previously carried out just to confirm if the neural networks were able to identify the defective insulator in the string. For the data bank building, one defective insulator had it position changed in the string – from position 1 to position 5 – and the corona effect was simulated. Signals from a perfect insulator string were collected as well. Hence 72 previously known signals were presented to neural networks, resulting in the answer in the figure 10.

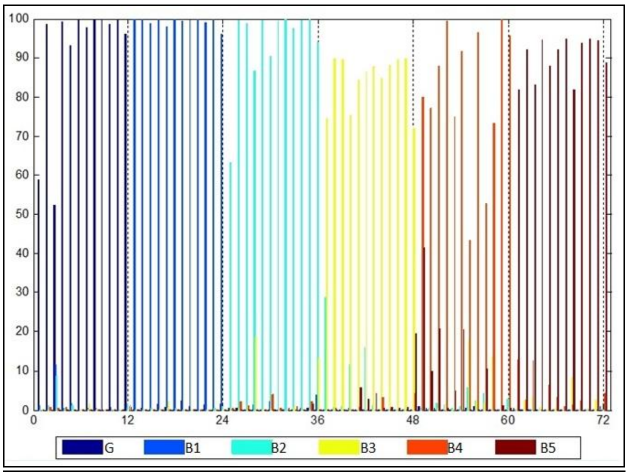

Figure 10: identification of the defective insulator in the string.

The signals are: 1 to 12 – from perfect string, 13 to 24 - defective insulator in position 1, 25 to 36 – defective insulator in position 2, 37 to 48 - defective insulator in position 3, 49 to 60 - defective insulator in position 4 and 61 to 72 - defective insulator in position 5. The colours represent G as the probability of the signal comes from the perfect insulator string, B1 the probability of the signal comes from the string with the defective insulator in the position 1 and so on. As seen in figure 10, the hit rate was very high. However, this test was performed just for evaluate if the neural networks were able to identify situations in this level of complexity. For transmission line maintenance application, only the location of the defective insulator string is necessary, once it has to be replaced as a whole.

CONCLUSION

This technique for identification and location of defective insulator strings has been working well since the signal acquisition to the software processing. It shows that it is possible to use the current transformers as coupling devices instead the expensive capacitive voltage transformers (CVTs). Moreover, current transformers are present in all substations, unlike the CVTs. The neural networks have been confirmed as a very suitable way to recognize the waveform of the present signals, exceeding the expectations.
The new steps of this work will include improvements in the neural networks topology and the increase of the data bank, which need to be larger to a better training of the neural networks.

ACKNOLEDGEMENTS

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