REAL TIME AUTOMATED DIAGNOSIS OF INSULATING SYSTEM EMPLOYNG ULTRASOUND INSPECTION

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ABSTRACT

A methodology was developed and applied to the inspection of insulating systems such as insulators using ultrasound equipment to automate the decision whether the inspected device is in operational condition or not. The audible noise in the output of the ultrasound equipment is fed to a notebook PC which obtains FFT of this noise. The FFT signature of the noise is used to classify the inspected device, in real-time, allowing for quick and precise inspection procedure, as shown by the obtained results.

INTRODUCTION

The inspection of insulating systems such as insulators, bushings, surge arresters, and switches used in aerial distribution networks is a procedure employed for decades [1]. It basically uses ultrasound and radio interference instruments in order to locate defective insulating components. Generally speaking, these instruments are used in combination; the radio interference instrument is able to capture radio frequency signals from a radius of about 300m or more, but it is not directional. Its intensity gives the inspection personnel an indication of the source’s location, so the search can be restricted to a couple of poles. The ultrasound instrument is equipped with a parabolic bowl, which can pinpoint ultrasound sources from distances of about 20m, thus locating discharge activity in insulating systems.
The electrical discharges in insulating systems originate from many different causes, such as contamination on the surface of the insulating device, cracks or puncture, [2] as shown in Figure 1.

Fig. 1: Sources of radio interference and ultrasound from: (a) contaminated insulating surfaces; (b) cracked insulator.

There are different techniques to process the acquired ultrasound noise [3, 4], but, in general, the ultrasound instrument delivers an audible noise that is used by the technician to judge the operational condition of the inspected device. Please note that hearing abilities vary from person to person, and is a subjective way to measure something.
In this work a notebook PC running LabVIEW was connected to the sound jack to acquire the sound delivered by the ultrasound instrument, and used to perform FFT in order to classify 25kV porcelain distribution insulators and has proven useful, as shown in the next sections.

MATERIALS AND METHODS

This section present the samples used in the study and the setup of the analysis. The samples were used to simulate the different conditions of the insulator in the field.

Samples

Figure 2 shows a new insulator that is to be used as a reference, is clean and has no detectable problems.

Fig. 2: New and clean insulator used as reference.

The second sample is an insulator taken from the actual grid and has contamination residues on its surface, composed basically by dust from unpaved roads, as shown in the Figure 3.

Fig. 3: Insulator sample taken from the grid, with actual contamination preserved.

To represent punctured insulators due to lightning surges, two insulators were taken to a bench driller where a hole was drilled in each one. In the first sample the hole was drilled from the side to where the inner supporting pin is attached, as shown in Figure 4. The other insulator was perforated from the top to where the inner connection pin is attached, as shown in Figure 5. The holes had a diameter of 3mm.

Fig. 4: Insulator with a hole drilled from the side to the locking pin, simulating an electrical puncture.

These samples simulate a puncture due to fast high voltage surges, which is a very common problem in the region. This kind of failure is hard to identify in visual inspection, because the holes are usually small and can be hidden under the cable and / or wiring harness. This type of defects may cause sporadic failure of the distribution feeder, leading to a trip of its protection thus switching it off. When the feeder is turned back on, the conditions of the puncture surface may have changed, not leading to a new protection trip. When certain conditions of the puncture surface are met, like more contamination accumulation and / or humidity level, a new short circuit may happen, repeating the process and keeping the main cause, *i.e.* puncture, undiscovered.

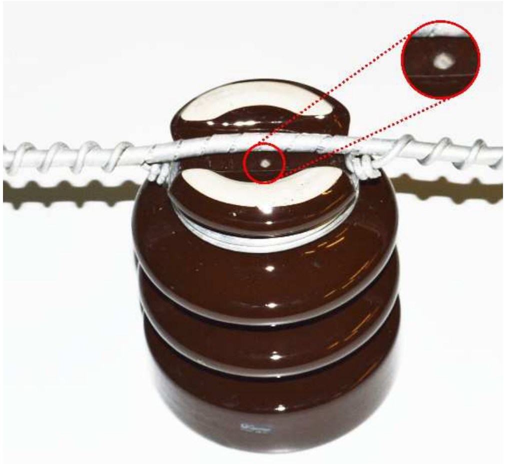

Fig. 5: Insulator with a hole drilled from the top to the locking pin, simulating an electrical puncture.

Laboratory Setup

The insulator samples used in the study were mounted as they would in the field. The ultrasonic instrument was positioned 2,2m from the sample, as seen in Figure 6. The voltage applied to the samples was 13,8 kV RMS, 60Hz, same as used in the actual feeder by the utility in urban areas. The ultrasonic detector used to capture the ultrasonic signal from the sample was Model 250 from Radar Engineers.

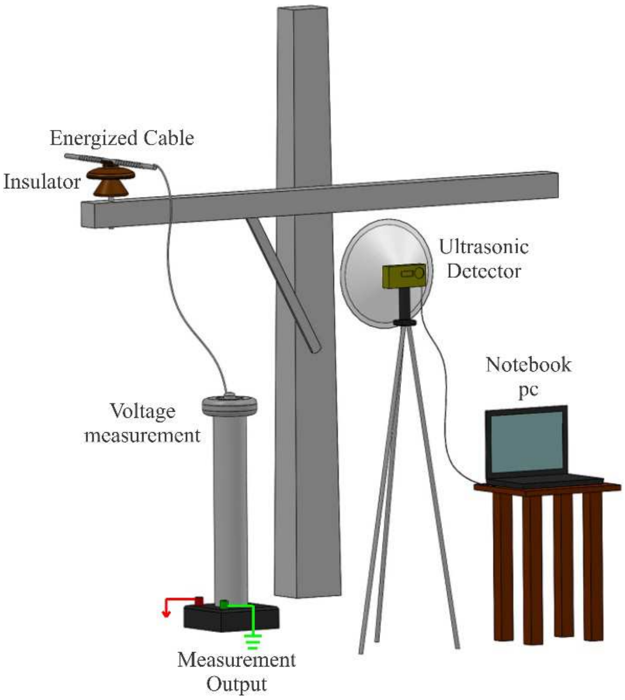

Fig. 6: Laboratory setup.

The signal available on the sound jack of the ultrasound instrument was fed to a notebook PC, and processed by the developed LabVIEW.

Analysis

The audible signal generated from the ultrasound instrument depends of the source of ultrasound as different types of defects in insulating systems would generate distinct type of audible noises. This audible noise varies in pitch and intensity. A typical wave form for the audible noise is shown in Figure 7.

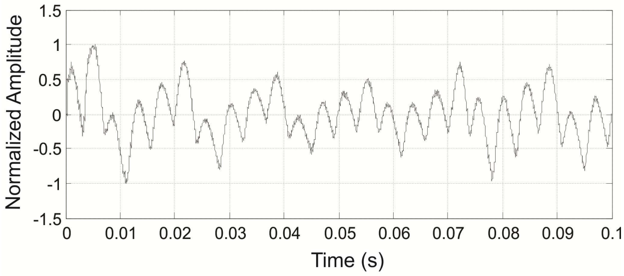

Fig. 7: Typical signal acquired from ultrasound inspection instrument.

To analyze the signal, the Fast Fourier Transform (FFT) technique is used, given by the equation 1. This technique reduces complexity and the processing time demand of a Discrete Fourier Transform (DFT) analysis, thus allowing for a real time analysis [5].

$$F(u) = \frac{1}{N}\sum_{x=0}^{N-1} f(x).W_N^{ux} \qquad (1)$$

A typical result of a FFT analysis is shown in Figure 8, which corresponds to the signal shown in Figure 7. The amplitude of each frequency component is different for each type of defect analyzed, and was used to identify and classify these types of defects.

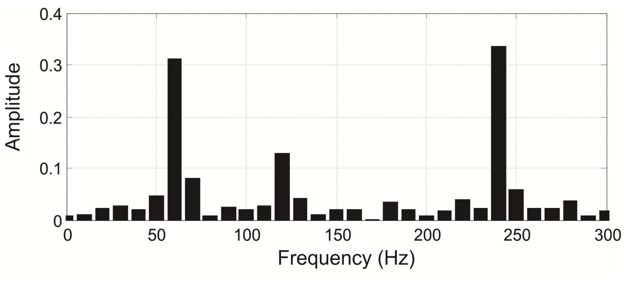

Fig. 8: Typical result of a Fast Fourier Transform analysis, corresponding to the signal show in Figure 7.

Since the intensity of each component is related to the intensity of the original signal, which depends of the distance of the inspected insulating system from the ultrasound instrument, the ratio among frequency components where investigated.

In order to avoid the influence of the eventual presence of interference in the field, such as a bird singing and other sporadic sound sources, it is used the moving average of the acquired signal, so that three measurements are used to present the result to the operator.

LabVIEW Interface

The software LabVIEW can be programmed to compare the differences between the frequencies, based on the FFT technique of the signal delivered from the ultrasound instrument. After a couple of seconds of acquisition the software interface displays the condition of the insulating system, indicating whether it is a “Good Insulator”, “Dirty Insulator” or “Broken Insulator”, which also stands for a punctured insulator. Figure 9 shows an example of a “Good Insulator”.

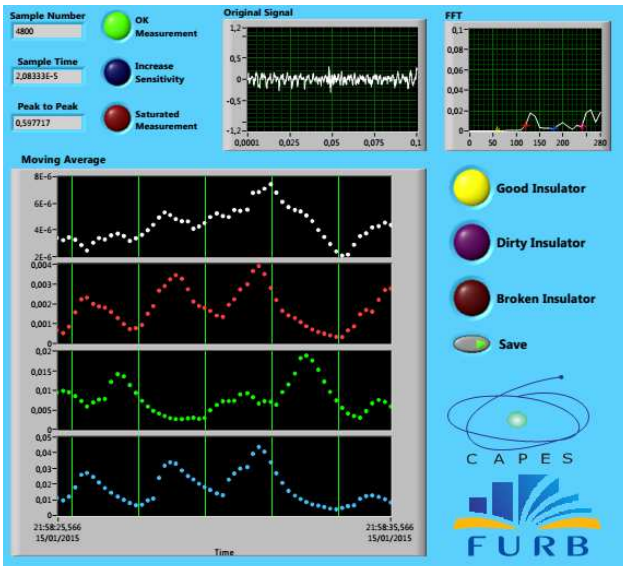

Fig. 9: Print screen of the developed LabVIEW interface.

The interface also informs the instrument operator whether the acquired ultrasound signal is too low or saturated, so he/she can adjust it for proper processing. This is shown in the upper left corner of Figure 9.

RESULTS AND DISCUSSIONS

In order to define the characteristics in terms of harmonic components ratios for each sample, the acquisition was divided in 50 processing periods of 100ms each, totalizing 5s of acquisition. To these 50 processing periods the moving average of three periods was applied, rendering a more consistent analysis. The percentages of processing periods matching the ratio conditions of less than 1.5, less than 2.0 and higher than 3.0, for each sample, for the 240 Hz and 180 Hz harmonic components ratio are shown in Table I.

The results from Table 1 show that only insulator samples with holes (side hole and top hole) have ratios between the frequencies of the 240 Hz and 180 Hz bigger than 3.0 on the majority of the processing periods. This is a clear indication that this feature can be used to identify these types of defects. Also, if the ratio is less than 1.5, it can indicate that the specimen under inspection is in good condition.

Tab. I: Percentage of processing periods matching the ratio conditions (less than 1.5, less than 2.0 and higher than 3.0) for the ratio between 240Hz and 180Hz harmonic components for all tested samples.

Ratio	Insulator Sample			
	Clean	Contaminated	Side Hole	Top Hole
Less than 1.5	86%	0%	0%	0%
Less than 2.0	90%	98%	0%	0%
Higher than 3.0	0%	2%	100%	100%

To distinguish between a clean insulator and a dirty insulator when the ration is less than 2, another information can be used, which is the amplitude of the acquired ultrasound signal.

These features can be used to automate the inspection routine, in a simple logical decision process in a programming ambient like LabVIEW, providing an easy to use tool for the inspection technician.

CONCLUSIONS

It was developed a methodology for detecting defects in insulating systems, like insulators, emplying an ultraound inspection instrument and a notebook PC running LabVIEW. The developed interface indicates to the inspection technician whether an insulator needs to be replaced or not, and the type of defect. The main feature used to identify and classify the defects is the differences between the frequencies ratios of the harmonic components of the acquired signal.

Similar methodology could be developed to other types of insulating devices and/or profiles.

The methodology was tested on laboratory only, with controlled conditions, but is going to be tested on the field as next step.

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REFERENCES

[1] E. Kuffel; W.S. Zaengl; J. Kuffel, High Voltage Engineering Fundamentals. 2 ed. 2000, p. 281-365.

[2] R.S. Gorur; E.A. Cherney; J.T. Burnham, Outdoor Insulators, Phoenix: R. S. Gorur. 1999, p. 262.

[4] G. Madruga; F. Scarpini; L.H. Meyer; F.H. Molina, 2013, A Practical Approach for Detection of Incipient Failure of Ceramic Insulators, IEEE Conference on Solid Dielectrics, Bologna, Italy.

[5] S.F. Stefenon; L.H. Meyer; F.H. Molina, 2014, Analysis of the Ultrasound Emitted from Defective Insulators, International Conference on Condition Monitoring and Diagnosis, CMD2014, Jeju Island, Korea.

[5] A.V. Oppenheim; A.S. Willsky, Signals & Systems, Massachusetts Institute of Technology, Prentice-Hall, 2 ed., International Edition.