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Identification of Acoustic Signals of Internal Electric Discharges on Glass Insulator under Variable Applied Voltage

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ABSTRACT

A Partial Discharge (PD) is an unwanted phenomenon in electrical equipment. Therefore it is of great importance to identify different types of PD and assess their severity. This paper investigates the acoustic emissions associated with Internal Discharge (ID) from different types of sources in the time-domain. An experimental setup was arranged in the high voltage laboratory, a chamber with an electrode configuration attached to it was connected to a high voltage transformer for generating various types of PD. A laboratory experiment was done by making the models of these discharges. The test equipment including antennas as a means of detection and digital processing techniques for signal analysis were used. Wavelet signal processing was used to recover the internal discharge acoustic signal by eliminating the noises of many natures.

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1. INTRODUCTION

Outdoor insulation represents an important component of electric power transmission and distribution systems, given that a single insulator failure can result in an excessive outage of the power system. Different insulator designs and materials are employed by power corporations and their behaviours are investigated and tested in laboratories and field tests as well as during service conditions. Specimens (rods and plates) are also tested when researchers focus on investigating certain phenomena of surface activity or material performance without being influenced by the insulator design [1]. The performance of insulators is strongly linked to local conditions, especially to the accumulation of pollutants and the wetting mechanisms present.

The weak parts of the insulation are the cavities, since the gas breakdown strength is lower than that of the solid insulation. On the other hand, the electric field in the cavities is much stronger than in the big insulation parts due to lower gas permittivity [2]. Hence, the PD is limited inside the cavities and does not penetrate through the solid material to reach the electrodes. Initiation of a PD in a cavity needs two major conditions; essentially the cavity electric field should be more than that of the gas, a condition called the inception voltage level. To start an electron avalanche, a free electron must be present in the cavity [3]. The extinction voltage level may depend on the actual voltage at which a discharge starts, since presumably a higher inception voltage yields a higher initial temperature in the streamer channel. In this study, the adaptability of the Daubechies wavelets of orders 2 has been evaluated, and results have shown the superiority. It is befitting to select a suitable number of breakup levels based on the nature of the signal.

Based on acoustic signal features, it is seen that six levels of decomposition is the best choice, because it has described the SD acoustic signal in a more mindful and symptomatic way. This decision is mainly due to the low frequency band (approximation), which is the most valuable part of the acoustic signal [4].

2. ACOUSTIC SIGNAL ANALYSIS USING WAVELET TRANSFORM

Wavelet Transforms (WT) has been introduced into signal processing by Mallet. WTs employ orthonormal basis function with finite support (local in time). WTs can provide nearly distortionless reconstruction of signals transitions. The multi-resolution concept underlying WTs has in general led to new solutions and insights in diverse applications such as speech processing, acoustic target identification, weak signal detection and numerical analysis. The intent here is to demonstrate the value of the WT as a tool to generate and extract unique feature vectors of acoustic signals [5, 6].

2.1. The Wavelet Transform

Wavelets are used extensively in many varied technical fields. They are usually presented in mathematical formulae, but can actually be under-stood in terms of simple comparisons or correlations with the signal being analysed. A wavelet is a waveform of limited duration that has an average value of zero. Unlike sinusoids that theoretically extend from minus to plus infinity, wavelets have a beginning and an end [7]. Sinusoids are smooth and predictable and are good at describing constant-frequency (stationary) signals. Wavelets are irregular [8], of limited duration, and often non-symmetrical. They are better at describing anomalies, pulses, and other events that start and stop within the signal.

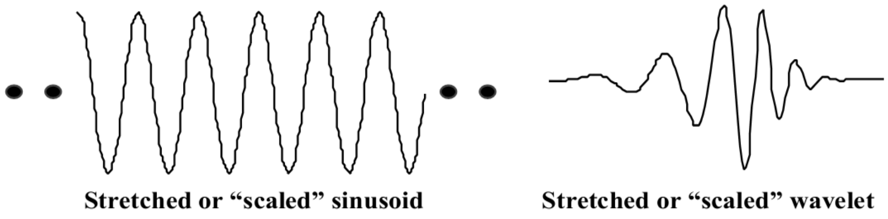

Figure 1. The infinitely long sinusoid is stretched (scaled in wavelet terminology) and is now at lower frequency [7]

As can be seen from Figure 1, wavelets come in various shapes and sizes. By stretching and shifting (“dilating and translating“) the wavelet, it is possible to “match” it to the hidden event and thus discover its frequency and location in time [9]. In addition, a particular wavelet shape may match the event unusually well (when stretched and shifted appropriately).

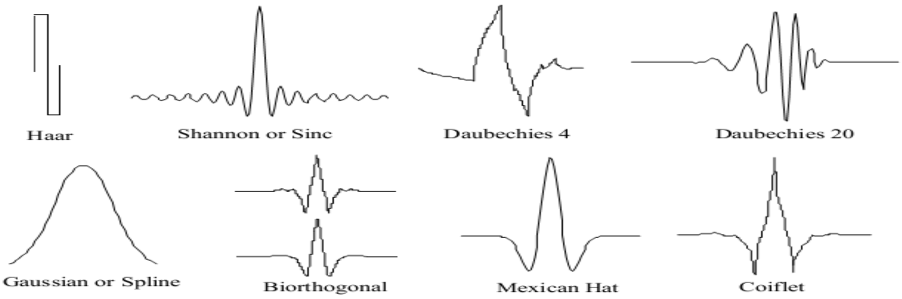

Figure 2. Examples of types of wavelets [7]

Some examples of wavelet family are presented in Figure 2. It probably looks like the wavelet to obtain such a good match or correlation. For example, the Haar wavelet would match an abrupt discontinuity while the Db20 would match a chirp signal [10].

2.2. Suitable Selection of the Mother Wavelet

To best characterize the PD spikes in a noisy signal, careful selection of the mother wavelet is very important to better approximate and capture the transient spikes of the original signal. The mother wavelet will not only determine how well the original signal is estimated in terms of the shape of the PD spikes, but also affect the frequency spectrum of the de-noised signal [11]. The choice of mother wavelet can be based on eyeball inspection of the PD spikes or it can be selected based on correlation γ between the signal of interest and the wavelet de-noised signal [12], or based on the cumulative energy over some interval where PD spikes occur. Being well aware of this issue, a number of mother wavelets have been examined and it was finally found that the Daubechies wavelet was the most suitable for treating PDs.

3. METHODOLOGY

The test setup consists of two main parts: the circuit loop (AC source, transformer, connections and insulator), and the measurement and acquisition system (earthing resistor, wideband antennas). Figure 3 shows the experimental set-up for generating various types of discharges as well as detecting the consequent acoustic signal due to the PDs. The test cell was connected across a high voltage source. The test cell was designed to generate various types of PD. It is an airtight cylindrical chamber made of glass in which the electrode configuration is fitted. The electrodes are made of stainless steel in a point-to-plane configuration. Figure 3 shows a picture of the chamber taken in the high voltage laboratory. Figure 3.1 shows the experimental setup for generating PD. The chamber is made airtight in order to produce the contaminated humidity and at the same time to lower the effect of field noise, which can interrupt the original PD signal. This chamber is designed for multipurpose use, where it can be used to test the PD under gas. The test cell consists of a plexiglass cylindrical tube attached to two aluminium top and bottom flanges which are connected to the high voltage supply and ground potential respectively [13]. These flanges can be removed easily to position the electrode configuration. The top and bottom flanges are connected with a semi-cylindrical piece of insulating material made of PVC to which the specimen is attached to generate the PD. The earth terminal is also provided in the bottom flange. The test cell has a height of 800 mm and weighs 12 kg; it can withstand AC voltage up to 100 kV and a D.C impulse voltage up to 145 kV.

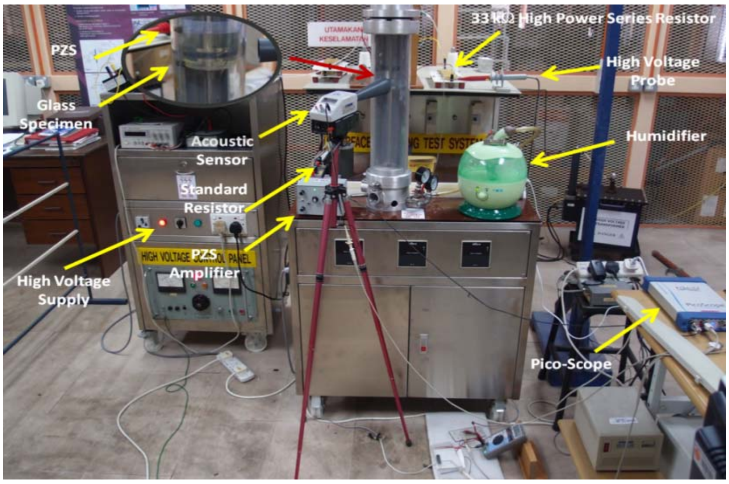

Figure 3. Experimental setup for generating ID

4. INTERNAL DISCHARGE GENERATION

To generate a cavity or internal discharge, a plastic container was used to place the specimen inside it and the container was filled with transformer oil in order to avoid any other type of PDs and to focus exclusively on internal discharge [14]. Figure 4 reports the setup for generation of internal discharge in oil. A plane-to-plane electrode configuration was used to create cavity discharge in oil. The specimen is placed within the two electrodes planes and pressed firmly in order to avoid any air between the electrode surface and the glass.

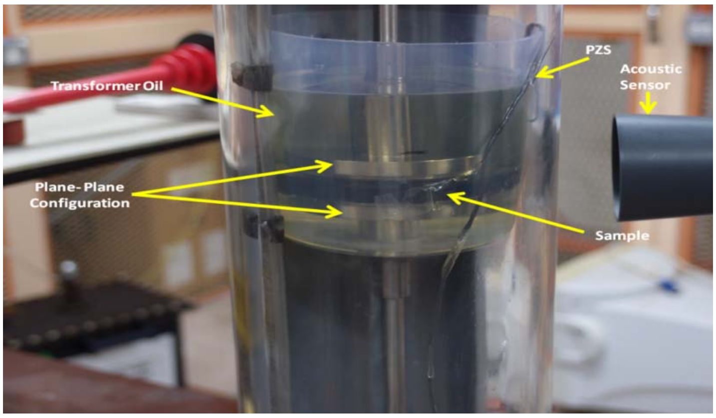

Figure 4. Setup for the generation of internal discharge

5. CAVITY FORMATION IN GLASS

In order to generate an internal discharge, three pieces of circular glass of equal dimensions were used; a hole diameter of 0.5 mm and a depth 4 mm was drilled in one of the pieces and the three pieces were attached firmly together and glued, sandwiching the piece with the hole as can be seen in Figure 5. A cross-section along the symmetry axis of the cavity is shown in Figure 6.

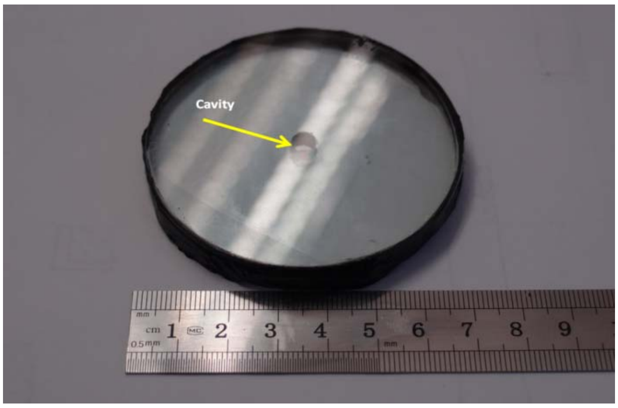

Figure 5. Cavity in the glass to create internal discharge

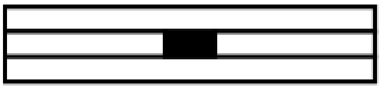

Figure 6. Test object with cylindrical cavity

6. RESULTS AND DISCUSSION

Measurements were carried out using a PD detector which is considered to be a reliable electrical technique to capture the PD. This equipment is not greatly affected in electrically noisy environments [15], so the patterns it captures are considered to be genuine, reliable and free of noise. Consequently, all the comparisons are made based on these patterns.

Internal discharges are generated using a plane-to-plane oil-dipped electrode configuration within a sample of glass consisting of a cavity [14]. This is a typical void found in solid sheet material and some cast components. The discharges occur in advance of the voltage peaks on both the positive and negative halves of the waveform, as seen in Figure 7. Discharges are of the same amplitude and same number on both sides of the ellipse, although a difference is same in magnitude from one side of the display to the other which is normal. It is normal to notice a degree of random variation in amplitude or location with time. There is little or no variation in magnitude with increases in voltage, and the discharge extinction voltage is equal to or slightly below the discharge inception voltage [15].

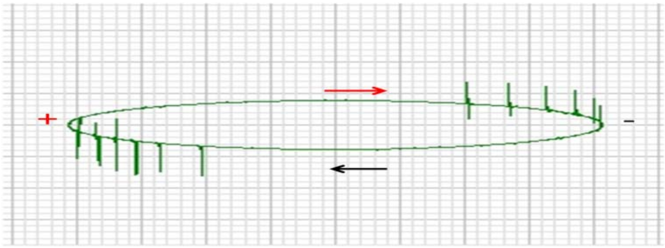

Figure 7. Typical discharges from a plane-to-plane configuration (internal discharge)

Figure 8 shows the captured internal discharge PD signal under applied voltage of 5 kV; no contamination levels are used for this type of discharge since it is dipped in oil. Here two types of sensors were used, the acoustic and the piezo-electric sensor. The real PD signal due to internal discharge is very noisy, and it is difficult to distinguish between partial discharge pulses and noise, even by visual inspection and knowledge of internal discharge patterns. Thus PD due to internal discharge cannot be distinguished due to the heavy noise as shown in Figure 9 and 10, where the pattern captured under operating voltage of 10 kV and 15 kV respectively.

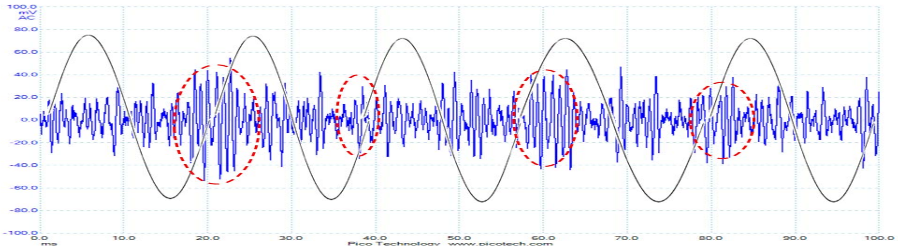

Figure 8. Internal discharges at 5 kV

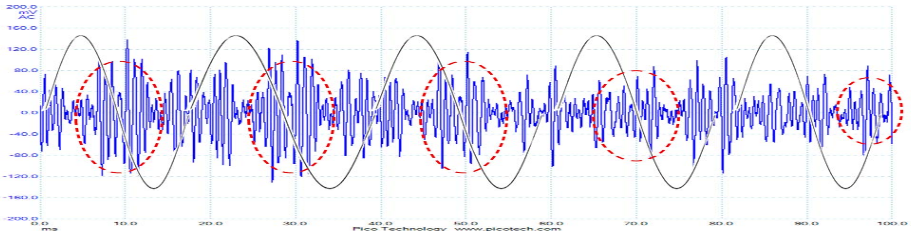

Figure 9. Internal discharges at 10kV

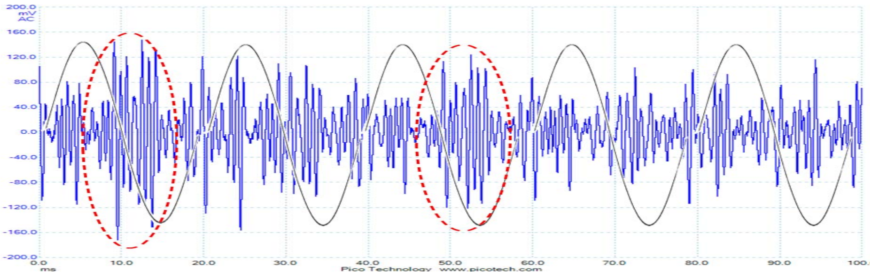

Figure 10. Internal discharges at 15 kV

Internal discharges occur within the insulation ground-wall, inside small voids, since they are cavity discharges so no contamination is used in this discharge. Internal partial discharge activity is characterized by symmetry in the maximum amplitude and in the number of discharge pulses, as identified when the activity occurring in both voltage half-cycles is compared. Discharges occur in advance of the voltage peaks and are often similar in number and magnitude, as shown by the red indicators in Figures 8, 9 and 10. It can be seen from figure that the internal discharges occur exactly in advance of the positive and negative half-cycle of the sinusoidal wave, which has rather the same phase information as the reference pattern shown in Figure 7. This confirms that the detected acoustic signal is an internal discharge signal, although a lot of background noise is masking the original PD signal. After the pre-processing procedure, this will be further confirmed.

6.1. Internal Discharge De-noised Signal

After de-noising the acoustic internal discharge PD signal, the result can be revealed in Figures 11, 12 and 13. The DWT successfully eliminated the noise, keeping the main structure of the internal discharge signal, where the low energy noisy signals were suppressed. Discharges occur in advance of the voltage peaks and are often similar in number and magnitude.

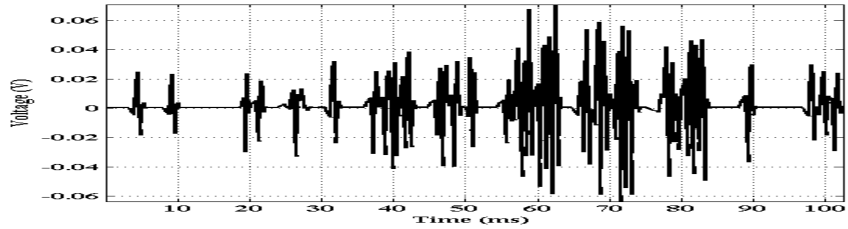

Figure 11. De-noised internal discharge PD signal at 5kV

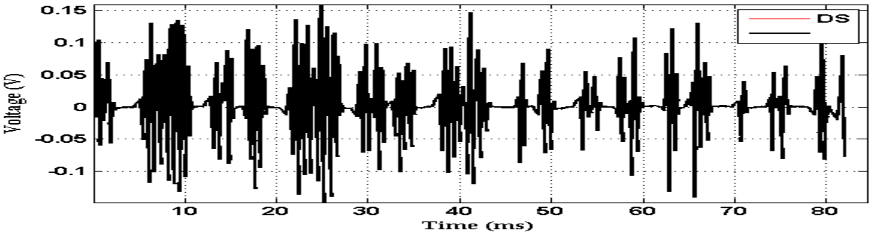

Figure 12. De-noised internal discharge PD signal at 10kV

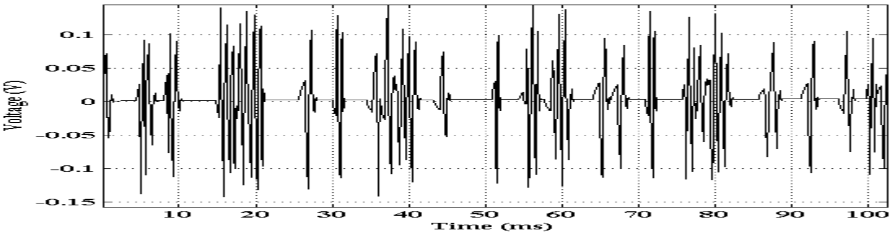

Figure 13. De-noised internal discharge PD signal at 15kV

7. CONCLUSION

From the results obtained, it was shown that the study of internal discharge provides information leading to a better understanding the behavior of the insulators subjected to different levels of operating voltage. Due to the pre-processing of the data by using wavelet transform gave the model high rate of classification accuracy. Hence, if the data contains a lot of noise it may lead to false detection. So we can identify faults before the development of failures, because once present the damage caused by PD always increases leading to asset failures, outages and protection system fail, disaster and a huge amount of energy loss. Interpreting of the signal properties could be used for early failure detection. The model is quite versatile for a wide range of applications in the field of power system analyses. As future work three types of partial discharges will be generated in a high-voltage laboratory, namely corona discharge in the air, floating discharge in oil, and surface discharge in the air, at different applied voltages will be recorded and a feature vector will be extracted by using wavelet transform, which will be used to train the RegPSO-RBF-NN.

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