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Corona-type partial discharge detection in power transformers using fiber bragg gratings

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We present a Fiber Bragg Grating (FBG) based scheme for sensing corona discharges in a power transformer. The corona-induced acoustic emissions detected using the FBG sensor pasted in a test cell is found to be correlated to the signals detected by HFCT sensor. A detailed spectral analysis of the detected signals is presented and the influence of electrode gap on the acoustic spectrum is investigated.

Keywords: *Corona, partial discharge, power transformer, fiber bragg gratings 1.0*

1.0 INTRODUCTION

Power transformers form an integral part of the high voltage power distribution system. Failure of these high voltage equipment can result in huge repair costs and long service durations. Since insulation failures are the most common cause of failure of transformers, it is imperative to keep monitoring the health of the insulation. Partial discharges are one of the effective tools in this regard as they are generated in regions of weak insulation [1], [2]. One of the common types of partial discharge in power transformers is the corona type discharge, which originate near the sharp protrusions on either the conductors or on the tank surface. These discharges are found to generate acoustic bursts which propagate through the oil medium towards the transformer tank walls [3]..

Among the various sensors available for picking up acoustic emissions, Fiber Bragg Grating (FBGs) based optical sensors have attracted a lot of attention over the past few decades [4]. FBGs are excellent alternative to the conventional piezoelectric sensors as they are immune to electromagnetic interference, in addition to being small, lightweight and amenable to array sensing [5].

FBGs have been used for partial discharge detection in various interferometric and direct configurations previously [6]–[8]. In this paper, we describe a simple approach of using FBG sensors to capture the acoustic emissions generated from a corona discharge using the tunable laser based interrogation.

2.0 EXPERIMENTAL SET UP

The following section describes the experimental setup used for the detection of PD using FBGs. The FBG sensor was pasted on the wall of the test cell. A needle-plane electrode configuration was chosen to create the corona discharge when the test cell is connected to high voltage supply. The needle was kept at three variable distances (1 cm, 1.25 cm and 1.5 cm) from the ground electrode. AC High Voltage unit capable of producing upto 20 kV (300 V/s ramp rate) was used for the experiment. A HFCT (High frequency Current Transducer) sensor was also included in the ground section of the HV unit, to detect the presence of PD current pulses.

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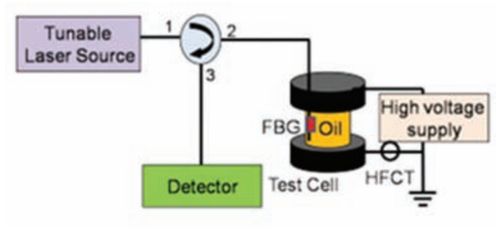
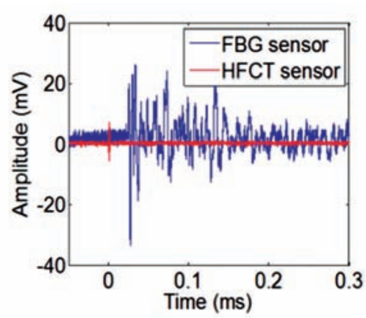


FIG. 1. EXPERIMENTAL SETUP

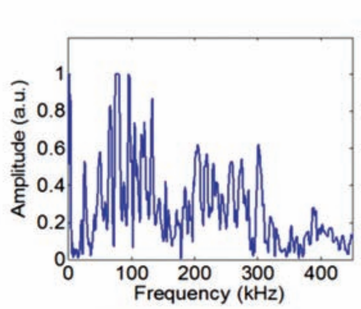
The optical section consists of a Tunable Laser Source (OEQuest), a circulator and a switchable gain photodetector (Thorlabs Detector PDB450C) as shown in Figure 1. The tunable laser is tuned to the reflection slope of the FBG so that any change in its Bragg wavelength is converted into a corresponding change in the intensity of light reflected from the FBG. The detector used to capture these intensity variations is set at a gain of 10^6 with a bandwidth of 0.3 MHz. The output of the detector is observed on an oscilloscope, whose trigger level was set just above the noise floor.

3.0 RESULTS AND ANALYSIS

A sample time domain signal obtained for a gap distance of 1 cm when 13 kV of voltage was applied is shown in Figure 2 (a), while its corresponding frequency spectrum is shown in Figure 2 (b). The acoustic signal is a bit delayed in time compared to the signal picked up by the HFCT sensor. This may be explained as follows. The HFCT sensor measures the current pulses generated from the partial discharge, so it instantaneously measures the current. However the acoustic waves generated from the discharge would travel to the wall of the test cell and would be detected by the FBG sensor a little later. The delay in this case measured to be around 26 µs corresponds to the radius of the test cell.



(a) Time domain



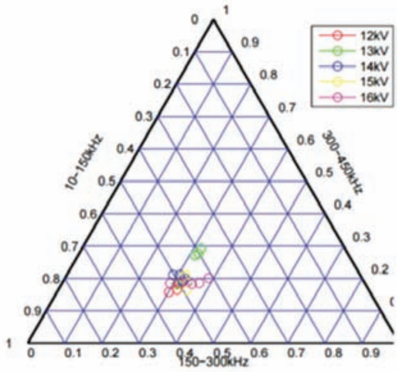
(b) Frequency domain

FIG. 2. SIGNALS CAPTURED BY FBG SENSOR FOR AN ELECTRODE GAP OF 1 CM IN BOTH (A) TIME AND (B) FREQUENCY DOMAINS

The acoustic spectrum signature is found to be spread over the entire frequency range of 450 kHz. In order to study the relative power content of various frequencies for different gaps, ternary diagrams were plotted by dividing the frequency spectrum into three different ranges, 10-150 kHz, 150-300 kHz and 300-450 kHz. The diagrams for different gaps at various voltages as indicated are shown in Figure 3.

The voltage at which discharges start appearing in the sensor increases as the gap is increased. For 1 cm gap discharges appear at around 12 kV, while for 1.5 cm gap the discharges occur around 15 kV. This is expected as larger gap would mean higher breakdown strength, which would require a larger voltage for initiating the discharges.

As evident from the ternary plots, the gap influences the spectrum of the acoustic signals generated from the discharge. It may be observed from Figure 3 (a) that for an electrode gap of 1 cm, discharges at different voltages show a lesser concentration of spectral energy in the 10-150 kHz



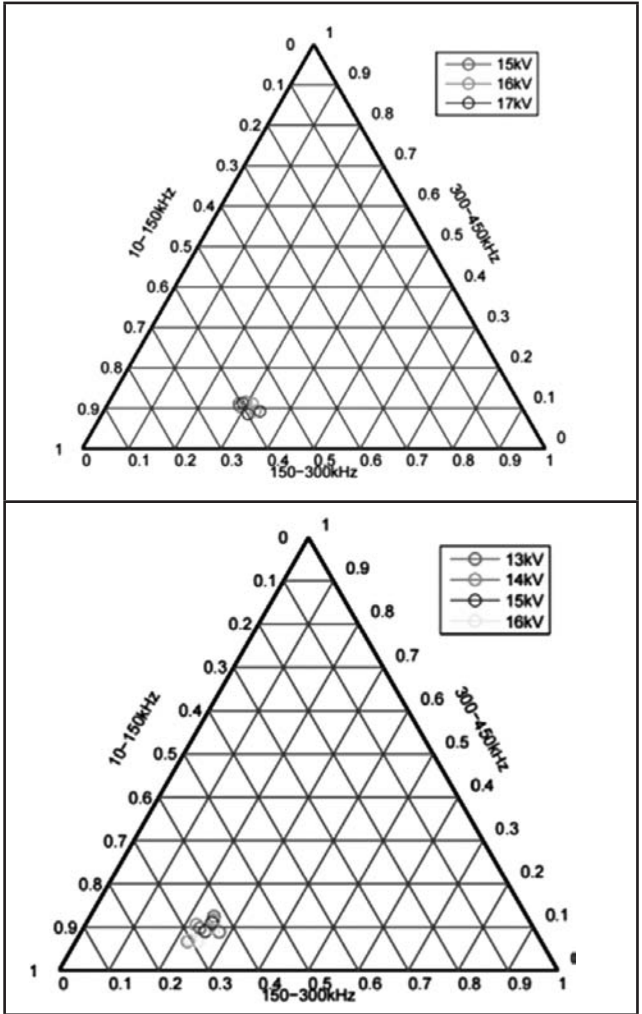


FIG. 3. TERNARY PLOTS PLOTTED FOR DIFFERENT VALUES OF ELECTRODE GAP (A) 1 CM (B) 1.25 CM AND (C) 1.5 CM

However, when the electrode gap is increased in Figure 3 (b) and (c), it may be observed that energy content in lower frequency range tends to increase. Thus, increasing the electrode separation results in the generation of more lower frequency components in the discharge.

4.0 CONCLUSION

Acoustic emissions from partial discharges can indicate the severity of insulation degradation in power transformers. In this paper, the use of FBG sensors in capturing acoustic signals from corona PD is demonstrated. Spectral analysis is used in conjunction with ternary plots to show the spectral dependence on the gap of the electrodes. The proposed technique has considerable potential in a power transformer environment primarily due to the large immunity to EMI possessed by this sensor. The ongoing work is concentrated on establishing the correspondence with electric charge and improvements in sensitivity which would enhance the opportunities for a practical implementation.

The main conclusions are

- The acoustic emissions detected by FBG sensors are in good correlation with the signals detected by the HFCT sensor. The time delay between the onsets of signals in both sensors is attributed to the definite propagation time of the acoustic signals involved.
- Electrode gap is found to influence the spectral characteristics of the acoustic emissions. Lower electrode gaps result in generation of higher frequency components in the acoustic signal.

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