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Using a new generation of piezoelectric sensors for partial discharge detection

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ABSTRACT

In this paper, we present the application potential for the on-line detection of partial discharges of a new generation of piezoelectric sensors (High Temperature Ultrasonic Transducers, HTUTs). Such a sensor was recently developed by Canada's Industrial Materials Institute (IMI). Given its inherent features, it can be considered as an excellent economic alternative for partial discharge detection. A breadboard was designed to produce a specifically localized partial discharge source. Partial discharge measurements were taken simultaneously with piezoelectric sensors and with a standard detection circuit equipped with a capacitive coupler. This paper presents the correlation between the two measurement types.

1. Introduction

A significant problem affecting high-voltage electrical equipment continuity is damage to their insulation system due to the effect of partial discharge activity [1,2]. This effect has been known since the early work of Franklin and Lichtenberg in the 18th century, and continues to be the subject of research on both its theoretical and physical foundations and detection technique.

To ensure that the insulation system of a high-voltage piece of equipment can safely withstand the service voltage and assess its reliability in operating conditions after a given number of years in service, non-destructive and on-line techniques must be used to detect and diagnose defects in order to determine whether a preventive maintenance action is required, and ultimately to prevent a service failure. Enormous material losses can thus be prevented while improving equipment reliability, safety and availability.

Given the fact that a partial discharge can be both an indicator and a primary cause of insulation system degradation, its measurement and diagnosis is a very effective way of monitoring high-voltage equipment condition [3,4]. In recent years, there has been a growing trend towards developing new methods for detecting and recognizing partial discharge patterns in various areas of physics and in different electrical engineering applications. From a fundamental perspective, much research has been undertaken for several decades to identify and understand the physical mechanisms behind partial discharge phenomena [5,6]. Extensive literature exists on various partial discharge signal recognition and classification techniques [7–9]. For example, Cavallini et al. published a study in 2008 on the recognition of partial discharges from artificial defects created in a paper-oil insulation system to improve the effectiveness of partial discharge measurement for the diagnosis of power transformers [10]. In 2009, Kuo proposed an artificial partial discharge recognition system based on measuring acoustic emissions in dry-type transformers [11]. Also in 2009, Wang et al. proposed a diagnostics tool for monitoring (on-line and off-line) high-voltage transformers based on dissolved gas analysis by using a

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combination of artificial neural network algorithms and expert systems [12].

In order to obtain information on the condition of high-voltage equipment insulation, these different studies have attempted to examine the different aspects of partial discharges, such as detection, measurement, recognition and data interpretation. However, the strategic significance of the problem and the complexity of partial discharge measurement, resulting from electromagnetic interferences and noise [13,14], still spur researchers to continue developing other reliable solutions for detecting and locating of on-line discharge sources [15,16].

2. A new generation of piezoelectric BIT/PZT sensors

Piezoelectric sensors operating at a very high frequency (High Temperature Ultrasonic Transducers or HTUTs) have recently been developed by Kobayashi et al. [17,18]. Fig. 1 illustrates nine films of these piezoelectric ceramics.

These sensors are made from a mixture of BIT (Bismuth Titanate) and PZT (Lead ZirconateTitanate) in a 1:3 ratio, deposited on a metallic substrate using a sol–gel spray technique, and poled using the corona discharging technique. For more information, see references [17,18].

The success of this new technology is attributable to a number of inherent advantages. Their light, miniature, and malleable structure (with thickness of 40–120 μm) makes them greatly flexible and capable of sticking to various surface types. They can be used under harsh operating conditions. Also, they have a broadband frequency response that gives them the ability to detect a great part of PDs frequency spectrum. Moreover, they offer a significant temperature operating margin (−150 °C to 400 °C) and a large value of the relative dielectric constant $\varepsilon_r \approx 90$. Finally, they are very affordable and require no coupling.

3. Using piezoelectric BIT/PZT sensors to detect PDs

Given the interesting features offered by this new piezoelectric technology, applying it to the problem of partial discharge detection appears to have significant potential. It could provide a simple and economical solution that can be easily implemented in support tools that are used in electrical equipment preventive maintenance. The subject of the investigation presented in this paper is to demonstrate empirically the consistency of its PD measures.

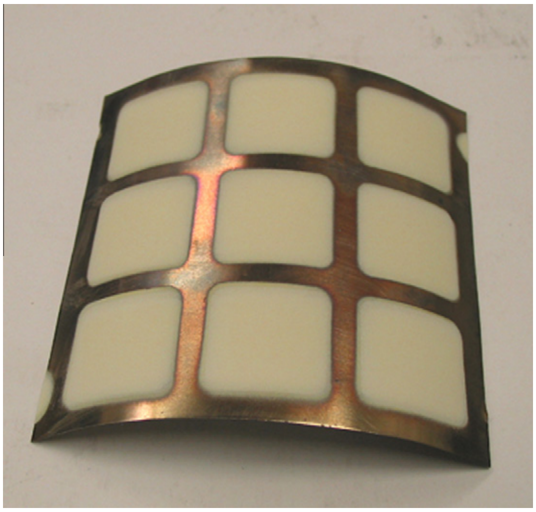

Fig. 1. Piezoelectric HTUT sensors.

3.1. Breadboard

Fig. 2 illustrates the test bench used in this investigation. A high-voltage AC source is connected to a configuration of tip-plane electrodes placed in a PMMA case equipped with several piezoelectric BIT/PZT sensors on different sides.

These sensors are directly connected, without any coupling, to the channels of a digital oscilloscope (Tektronix3014B). To validate results, a 1 nF capacitive coupler is set up in parallel to the system. Partial discharges are created by a configuration of tip-plane electrodes, and the distance between the two electrodes can be adjusted through a screw and nut transmission. In the design, the pre-drilled holes on the top cover of the case allow a predetermined positioning of the discharge area.

The signals collected by the oscilloscope are recorded in a data acquisition system and later processed to extract the useful partial discharge signal by removing the background noise, 60 Hz sine wave and any other interference superimposed on it. Fig. 3 presents the experimental set-up used, as well as the equivalent electric circuit. The transfer function of the equivalent circuit is represented by:

$$\frac{\mathbf{V}}{\mathbf{e}} = jRc_k\omega \frac{1}{1 + jR(c + c_k)\omega} \qquad (1)$$

With, $c_k \cong 0.13$ pF: Representing the coupling capacity between the high voltage and the piezoelectric sensor's counter electrode. $c = c_p + c_2$: Represents the equivalent capacity of the piezoelectric $c_p \cong 6.37$ nF and the coaxial cable $c_2 \cong 1.66$ nF. R: Represents the oscilloscope's impedance measurement of 1 MΩ or 50 Ω.

3.2. Discussion of results

Fig. 4a shows a typical signal detected by one of the sensors when partial discharges occur within the test

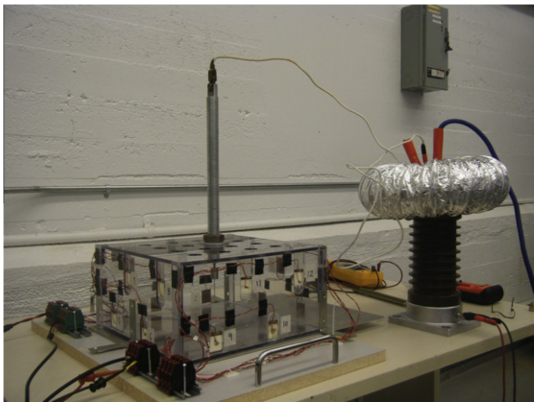

Fig. 2. Set-up, a PMMA case with HTUTs mounted above.