Localization of Acoustic Wave Using Leakage Current and Fiber Optic Sensor Techniques

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Malik Abdulrazzaq Alsaedi*, JR Rashed, AM Dakhil, and SF Atyah

***Abstract*—**The Electrical discharge (ED)phenomenon is very harmful for electrical appliances and its early detection could be a cost effective approach for the industry. Although many techniques are used for ED detection yet no technique has presented widely acceptable solution. Still the subject needs parallel study of the detection techniques. In this study, partial discharge signal has been captured by the three techniques using fiber optic sensor (FOS), Piezoelectric Sensor (PZT), leakage current(LC) techniques. In these experiments, FOS shows good sensitivity in the range of applied high voltage > 5 kV. The sensitivity and noise level of ED signal was different in these two experiments. The location of a ED was demonstrated in a 500 gallon water tank using convolution method**.**

***Keywords*—**Acoustic emission, Electrical discharge, Piezoelectric Sensor, optical fiber sensor, multimode optical fiber, Leakage current sensing method, oil-insulation transformer

I. Introduction

Electrical energy is an important item in life around the globe and the devices used in the distribution of electricity needs proper caring. These devices consist of high voltage transformers, insulators and high voltage cables. A reliable and up-to-date condition evaluation system could therefore contribute much to prevent expensive repair and compensation costs. Condition based maintenance (CBM) is getting more popular these days. Service work can be planed and organized and therefore the total operational costs can be lowered, the service life prolonged and furthermore the outage times can be reduced to a minimum in general. For the implementation of this maintenance strategy, accurate information about plant status and equipment condition is absolutely necessary. Partly, this information could be gained with the usage of ED measurement. As parameters, the quantity, the amplitude (apparent charge) and the phase position of ED impulses can be determined for example. Based on these parameters it is possible to make conclusions like yes/no decisions about equipment maintenance[1]. Partly, these parameters could be determined with the so-called conventional ED-measurement technique, which is basically an electrical measurement and they are described standardized in the IEC 60270 or in miscellaneous IEEE standards [2]. Besides the conventional ED-measurement and techniques there are several other methods for ED detection. In detail, these are optical, chemical and acoustical methods. The different techniques have been explored to measure partial discharge activities in different apparatus. One of them is to detect the weak light produced by partial discharge. Advance in optical fiber technology and interference-free feature have attracted many researchers to examine the optical technique carefully in order to find out its potential in specific apparatus such as transformers[3]. Optical fiber has been used as a sensor for a long time because of its many advantages such as: safety from electrical spark, resistance to chemical corrosion, response capability to a wide range of measurements , ability to stand high temperature, small size, large bandwidth and high sensitivity. Optical detection is based on fractional changes on optical parameters such as wavelength, intensity, polarization and phase. Hence , it is possible to get four types of optical sensors ; namely spectrum based sensor, intensity based sensor, polarization based sensor and interferometeric based sensor. Fiber optic acoustic sensor includes optical fiber intrinsic sensor such as Michelson interferometers, Mach–Zehnder interferometers, multimode fiber and fiber optic extrinsic such as Fabry–Perot interferometric sensors. The fiber optic acoustic sensor combines the acoustic and optical method. The detection process of this method is based on photo elastic effect of silica fiber. The acoustic wave that is incident on the optical fiber will cause distortion of optical fiber structure. This distortion will change fiber length and fiber refractive index. This change can create a modulation effect on a laser beam which passes through the fiber. Due to the low photo elastic effect of the silica fiber, the sensitivity needs to be increased.

In this study, partial discharge signal has been captured by the three techniques using fiber optic sensor, pizo electric film sensor and leakage current techniques. The sensitivity and noise level of ED signal was found different in these three experiments. The results of these experiments have been discussed and some peculiar characteristics of fiber optic sensitivity have been observed.

II. Detection Strategy Of Acoustic Emission Phenomenon

AE near the high voltage discharge zone provides the variables in the detection of ED. The modulating effect of AE on laser light source (850 nm) provides the signals for FOS and PZT sensors as shows in. A photo detector is used in this technique to convert optical signal into electrical signal. The optical fiber picks the AE modulated laser optical signal (850 nm) which then becomes input to the photo detector. A simple and inexpensive signal detection configuration to measure AE is adopted. It consists of multimode fiber in combination with broad band light source, photodiode, amplifier and high speed signal processing apparatus [4],[5]. The detection system consists of (850 nm) LED, low noise optical receiver (photo

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detector), multimode fiber linking the light source and the optical receiver unit. In this system, laser light source (850 nm) is used and a photo detector is used to convert the optical signal into electrical signal. When high voltage discharge is produced between two electrodes AE signal is generated. This is picked up by the multimode fibre. The optical signal from the LED source gets modulated by refractive index variation at the microbends due to induced energy from AE [6] . Physically, AE generates dynamic mechanical strain which produces linear variation on the photo-elasticity of the multimode fibre [7]. This changes the fibre's refractive index and alters the propagation properties of light and consequently vary the polarization and the phase shift.

III. Experiment-1: In Situ Ed Detection By Fos And Leakage Current Technique

In this work, two sensors, LC and FOS, were used for ED detection as in. High Voltage discharge which simulates ED produces acoustic emission between two steel electrodes which creates interference in the light passing through the optical fibre connected to multichannel oscilloscope. The simulated ED is generated using 5kV, 10 kV and 15 kV power sources in two steel electrodes having 5 mm gap. A light source from LED (wavelength 850) and output power 0.01mW is sent through an optical fiber. Output from FOS is picked up by the photo detector (ED1) which is connected to the optical fiber by means of a fiber adapter. The optical fiber used is a multimode graded index fiber having core diameter of 50 µm. The cladding diameter of multimode fiber is 125 µm with coating layer plus soft coating such as acrylate based elastomers. The acrylate material has narrower band pass sensitivity to ultrasound of AE which gives good result in transformer ED detection. FOS is connected to a photo detector which converts light to electrical signal which is enhanced using low noise amplifier. The LC technique has been done to detect ED signal. The High voltage source applied to two steels electrodes (needle – plan), the plan electrode was connect to ground, 100 Ω resistor connected in series to ground finally output from the resistor connected to oscilloscope.

IV. Results And Discussion Of Experiment-1

This experiment provides a comparison of ED produced signal data obtained by two sensors LC and FOS which is shown in figure 1. It was observed that LC signal is much better than FOS signal in the high voltage range 5-10 kV but FOS signal is much better than LC for the high voltage at applied voltage 15 kV. It was also observed that the no of peaks in the LC data are more than the FOS signal and intensity of peak is high in range 5-10 kV while the FOS shows good sensitivity at 15 kV. Interestingly, both sensors have peaks at the same position with time but some peaks of data are observed to be reversed at the same position such as peak no 6, 8 etc. It is worth mentioning that FOS has quite good sensitivity with high intensity peaks in the data observed at 15 kV as compare to LC observed data. The reason of this good sensitivity may be due to the effect of frequency band of FOS material. The second reason is the intensity of the shockwaves produced due to ED is quite enough to pass through the FOS material.

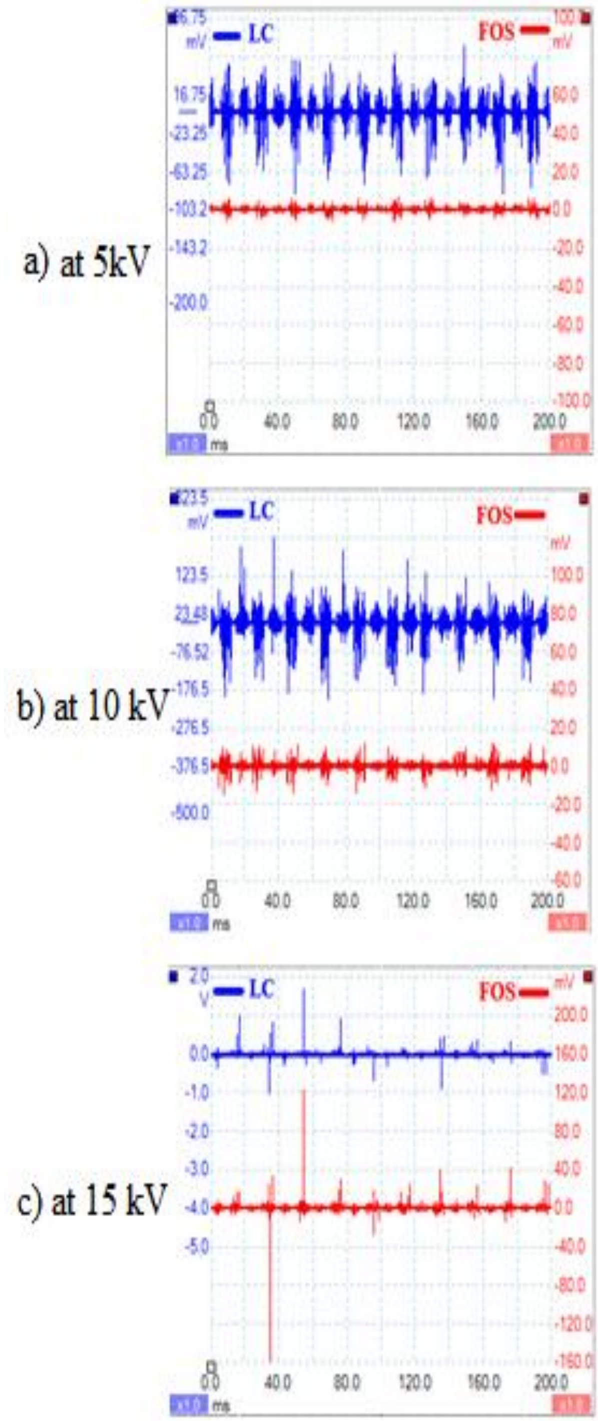

Fig. 1 Results of signals has been capture from FOS and LC.

V. Experiment-2: In Situ Ed Detection Under Insulation Oil By Two Sensors Fos And Pzt

The schematic diagram of complete experimental setup to generate partial discharge and its acoustic emission is described in Figure 2. The tank was filled with insulation oil so that the steel electrodes remain immersed completely in the middle of the tank. Two sensors, multimode optical fiber and

PZT were mounted on the top at the same distance 8 cm from ED source. The electrodes having 5 mm gap were connected to 5 kV high voltage source to produce ED under insulation oil. The acoustic emission produced by ED was then sensed by two sensor The partial discharge generates electromagnetic emission between two electrodes which creates interference in the light passing through the OF connected to the oscilloscope.

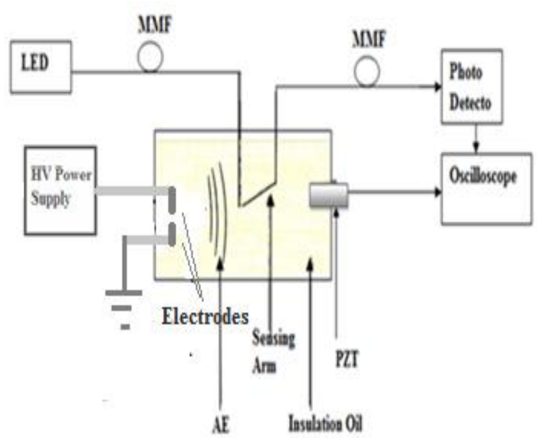

Fig. 2 High voltage produced ED and AE signal insulation oil.

VI. Results And Discussion Of Experiment-2

The data of AE signal output of both sensors of both sensors was recorded by four channel digital Lecory oscilloscope. The typical spectra of acoustic signals detected by both sensors PZT and FOS. These results show that acoustic signal generated by ED comprises sinusoidal pulses in which have gradually decreasing trend in their intensity. Although the shape and peaks of signal output of both sensors follow the same oscillatory pattern. It was also observed that PZT sensor has a noisy signal due to multi reflections which cause degeneration of the received signals. In case of PZT, it is difficult to determine exactly that how long a ED will last while FOS gives a clear picture of acoustic wave.

VII. 5. ED Location

A. Positioning Al gorithm of ED location

The algorithm for locating a ED source is a hyperbolic position fixing solution based on the time difference of arrival (TDOA). When a number of spatially separated sensors capture the emitted signals and the time difference is determined, the emitter location can be calculated. The range between the source and the sensor can be expressed as

r12 = (x – x1) 2 + (y–y1) 2 + (z–z1)2 (3)

where (x, y, z) are the coordinates of the source and (x1, y1, z1) are the coordinates of the sensor. For each sensor in an array, one of thesespherical equations can be written and asystem of nonlinear equations is created.

B. Results of ED location

The experimental setup has already been mentioned in Section-4, in which four sensors were used for the detection of acoustic emission source. The coordinate systems of the four sensors and the acoustic source, with x, y and z values (in millimeter) for sensor #1 of (410.9, 200.1, 306.0), sensor #2 of (710.7, 450.4, 404.6), sensor #3 of (380.0, 650.6, 392.7), sensor #4 of (189.1, 440.5, 302.5) . Convolution functions basically as an integrator or a low pass filter. If the signals were identical and we consider only the additive white Gaussian noise channel, convolution functions as a matched filter. The output from the matched filter will reach maximum when the delay between the two signals is zero. Using this method we can determine the time delays for the four different sensors. Using the TDOA routine, we can thus determine the ED location. Figure 3 shows the positioning results of ED location.

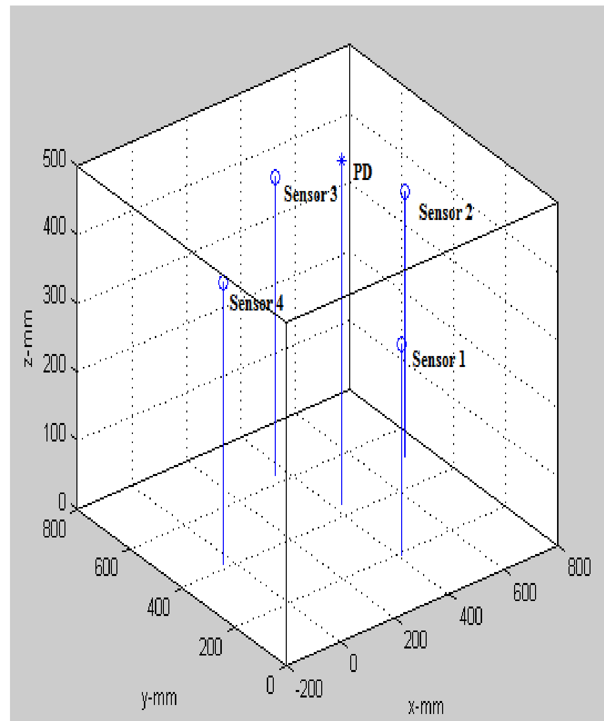

Fig. 3 positioning results of ED location

VIII. Conclusion

The experimental (1) shows that the FOS has quite good sensitivity with high intensity peaks in the data observed at 15 kV as compare to LC observed data. From experimental (2) we can conclude the sensitivity of multimode FOS and PZT for acoustic sensing were ascertained and measured. The data of both sensors were analyzed in time domain and compared through peak analysis. The results suggest that the multimode optical fiber was able to act as acoustic sensor with large wide band of signals. The time domain analyses show that FOS has been successfully used to capture acoustic signal with less noise. The location of a ED was demonstrated in a 500 gallon water tank. The convolution method , was used to precisely determine the TDOA . The cross correlation method was confirmed to be more robust than the convolution method. Finally it is demonstrated that 94.48% of the position data of ED signal are bounded by a (420.9, 418.7, 390.6) with a sensing range of 810 mm in a 500 gallon water tank.

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