

Review on Partial Discharge Detection Techniques Related to High Voltage Power Equipment Using Different Sensors

MA AlSaedi^{*a,b}, MM Yaacob^a

^aInstitute of High Voltage and High Current, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia.

^bDepartment of Electrical, Faculty of Engineering, University of Misan, Iraq
maliksaady@yahoo.com

Abstract— There is a high risk of insulation system dielectric instability when partial discharge (PD) occurs. Therefore, measurement and monitoring of PD is an important preventive tool to safeguard high-voltage equipment from wanton damage. When operating an equipment or a power system at high voltage, problems associated with PD can be tracked down to electromagnetic emission, acoustic emission or chemical reactions such as the formation of ozone and nitrous oxide gases. High Voltage equipment and High Voltage installation owners have come to terms with the need for conditions monitoring process of PD in equipment such as power transformers, gas insulated substations (GIS) and cable installations. This paper reviews the available PD detection methods (involving high voltage equipment) such as electrical detection, chemical detection, acoustic detection and optical detection. Advantages and disadvantages of each method have been explored and compared. The review suggests that optical detection techniques provide many advantages from the consideration of accuracy and suitability for the applications when compared to other techniques.

Index Terms— PD detection methods, power transformer, high voltage equipment, sensors

1 INTRODUCTION

Stability of any power system network is determined mainly by the high voltage equipment used [1]. Failure of this equipment is normally related to partial discharge (PD) activity which deteriorates the system performance and can lead to breakdowns, fires or irreparable damage to the system. PD detection is necessary as precautionary measures to ensure that high voltage equipment insulation is not exposed to any unnecessary hazards. A good understanding of PD mechanisms, characteristics and its development processes is essential for power systems designer and power systems installation maintenance engineer.

There is a high risk of insulation system dielectric instability when PD occurs. Therefore, measurement and monitoring of PD is an important preventive tool to safeguard high-voltage equipment from wanton damage. Techniques for detecting PD depend on what different physical properties which accompany the occurrence of PD, are measured. Known physical properties which have been used in the measurement include electromagnet-

ic emission (in the form of radio wave, light and heat), acoustic emission (in the audible and ultra-sonic ranges), ozone formation and the release of nitrous oxide gases. The measurement level indicates the quantity and magnitude of partial discharge. Popular methods of PD detection in high-voltage power equipment utilizes electrical, chemical, acoustic or optical measurements. Measurement of an electrical quantity is convenient and can give precise recording of PD variations in the laboratory. However, it can give an inaccurate recording for conditions at on-site (for example to monitor in-service transformers). The inaccuracy is due to the various disturbances and interferences which can result in high environmental noise level.

Two electrical quantity measurement methods are available. They are the Ultra High Frequency (UHF) method and Pulse Capacitive Coupler method. The UHF method is based on the measurement of electrical resonance at the frequency range of up to 1.5 GHz due to PD excitation. This method is capable of detecting as well as locating a PD source [2][3]. UHF method has inherent advantages such as low noise levels due to shielding effect of the transformer and very low signal attenuation. UHF method can also avoid local interference throughout the 100 MHz of its operating measurement frequency band which nestles in the whole UHF band range between 300 MHz-1500 MHz. This method has immunity against external noise as the UHF sensor is connected inside the transformer. The connection between UHF sensor and power transformer is non-electrical and hence there is reliability and safety against any induced current at the power

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- MM Yaacob is with the Institute of High Voltage and High Current Faculty of Electrical Engineering, Universiti Teknologi Malaysia
- Malik Abdulrazzaq Al-Saedi is with the Faculty of Electrical Engineering, Universiti Teknologi Malaysia, and Johor, Malaysia
- Corresponding author. Tel.: +61-07- 5535695; fax: +61-07- 5578150. E-mail address: maliksaady@yahoo.com

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The Pulse Capacitive Coupler method collects and measures the PD induced current at the detection coil which has a connection loop through some impedance to the earth line [4]. Quantitative measurement has good sensitivity and great implementation simplicity. However, it is prone to false alarm due to this high sensitivity and it is therefore not suitable for long - term monitoring of transformers.

The chemical measurement techniques for detecting PD in high voltage transformer is based on the collection and some chemical measurement of oil and gas samples released during the PD process. Two chemical measurement techniques are used at the present moment. They are the High Performance Liquid Chromatography method (HPLC) and the Dissolved Gas Analysis method (DGA). HPLC analyses PD expelled byproducts such as degraded forms of glucose induced by degradation of insulation[5][6]. While DGA analyses the accumulated volume of gas produced by the PD. For chemical measurement techniques, sufficient expelled byproducts or gas has to be collected before analysis can begin. Hence there is some time delay between collection and analysis. Chemical measurement techniques are therefore not suitable for real time monitoring. Chemical as well as electrical approaches are incapable of locating the exact position of PD sources.

Acoustic method detects and locates the position of PD by studying the amplitude attenuation or phase delay of the acoustic waves propagated from the PD. This mechanical wave (acoustic wave) is caused by the mechanical energy explosion due to the vaporization of material inside the transformer tank creating a form of pressure field [7][8][9][10][11]. Acoustic wave in the transformer oil can be detected using acoustic sensors (Piezoelectric Transducers – PZT) . When PZT is mounted outside, on the transformer wall, it will capture interferences from the very noisy environment and this can make PZT sensors' usefulness limited. The PZT sensor can be placed inside the oil tank of the transformer to reduce noise and attenuation of signal[12]. Location of PD can be estimated by measuring the time of arrival of acoustic wave and position information is ascertained by using sensors at multiple locations . This makes acoustic emission sensing a more preferable measuring tool in real time. Measurement using the acoustic approach has an additional advantage of possessing better noise immunity for online real time applications. Occasionally , acoustic method experiences difficulty in locating the exact origin of PD due to interference/degradation of signals from environmental noise [13][14]. Here, sensitivity is certainly compromised.

Optical method that uses optical fiber sensor which is small in size, highly sensitive and light weight, and possesses high frequency response and significant immunity against electromagnetic interference , can measure a wide range of chemical and physical parameters at ease. Apart from PD detection and assessment[15], optical fiber acoustic sensors have been used successfully in applications such as underwater hydrophones , construction non-destructive diagnosis, material property analysis [16]traffic monitoring and vehicle detection. Functionally , optical detection technique is based on fiber optic intrinsic interferometers such as Michelson interferometers, Mach-Zehnder interferometers, multimode fiber and fiber optic extrinsic such as Fabry-Perot interferometric sensors. The Michelson interferometers,

Mach-Zehnder interferometers sensors suffer from fringe fading problems due to random polarization rotation. Fabry-Perot interferometric sensors are compact in size compared to Michelson and Mach-Zehnder fibre sensors, and therefore achieve virtually single-point measurement. Due to measurements sensitivity , optical method has restricted use for PD detection.

2 SENSORS FOR THE DETECTION OF PD PHENOMENON

2.1 The Sensors for electrical quantity measurement

PD is an electrical discharge or spark that partially bridges a small section of insulation when two conducting electrodes emerge from the separation of distinct high concentration of positive and negative charges. It is a random localized discharge formed by transient gas ionization in an insulated system when the stress voltage exceeds a certain critical value. PD often occurs when electric field strength exceeds the breakdown strength of insulation, and can lead to a flashover. PD phenomenon causes gradual deterioration of the insulating materials, sometimes over a period of several years, leading perhaps to eventual failure.

Locating and detecting PD in power transformers is vital both in industries and utilities to avoid damage of high-voltage equipment. Fig. 1 (a) shows UHF sensor to detect PD in GIS. This type of sensor has been proven effective not only for laboratory test but also for on-site PD. Fig. 1 (b) shows a direction coupler UHF sensor for PD detection in a cable joint. The sensor has successfully been used in quality control applications for checking the right assembling work in power cable accessories. Fig. 1 (c) shows UHF sensor to test power transformer for usage on DN50/DN80 gate valve. The sensor allows alternative ways to estimate PD , the configuration shown is known as bushing-tap which is suited for measurements made on galvanic connected decoupling. Fig. 1 (d) shows an inductive UHF sensor set up for measurements on power cable termination[17]. Fig. 2 shows three types of UHF sensors which can be used to characterise PD on power transformer and GIS . They are the disc-type, monopole-type and spiral-type. The disc-type, monopole-type and spiral-type sensors can provides the greatest energy accumulation in laboratory test, which indicates that the sensors have high sensitivity for detecting radiated signals[18]. Fig. 3 shows a capacitive coupler for partial discharge detection in high voltage cable. The 40 mm tin tape wrapped around the exposed cable acts as a coupler for the capacitive sensor. The capacitive sensor coupler does not interfere with the measurements on the insulation of the cable because at UHF the capacitive coupler is effectively connected and work as power frequency ground[19].

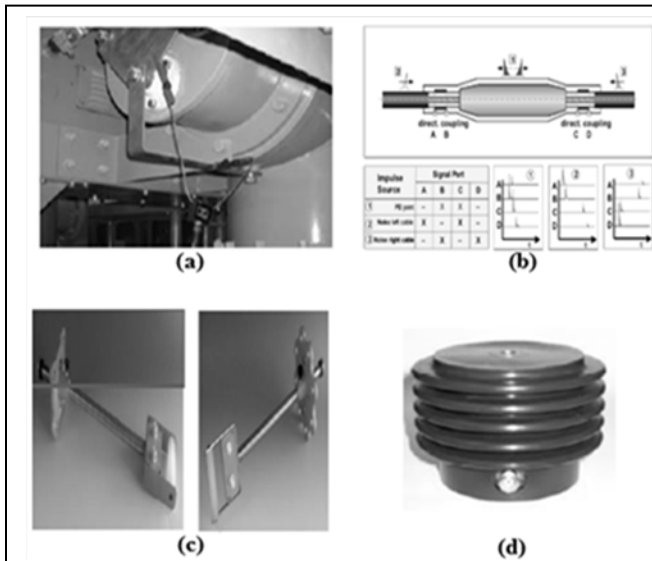


Fig. 1 (a) UHF sensor adapted to a GIS grounding bar. (b) Directional coupler implemented in a cable joint. (c) Oil valve sensor for power transformer reactor e.g. left side for usage on DN 50 gate valve right side for DN 80 gate valve. (d) Inductive UHF sensor for power cable termination.

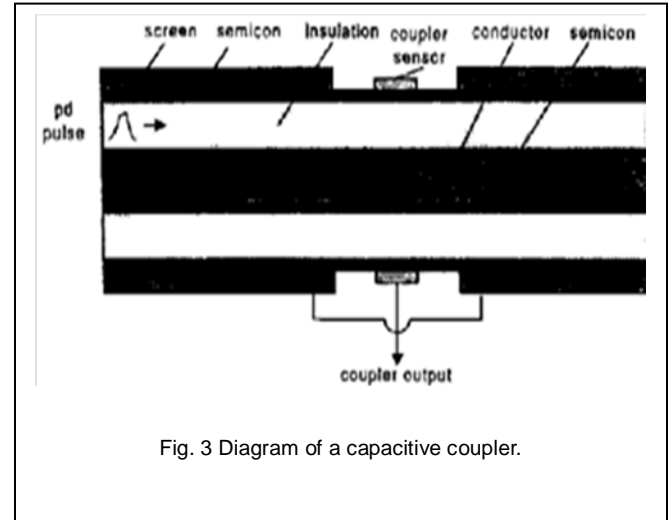


Fig. 3 Diagram of a capacitive coupler.

2.2 The Sensors for Acoustic Detection

The acoustic technique which uses a highly sensitive piezoelectric film sensor shown in Fig. 4(a) and conFig.d as in Fig. 4(b) have applications in the measurements of PD for high-voltage equipment such as power transformers and HV cables. At low resonant frequencies the piezoelectric sensor film is a crystal which is in the form of a disc, for which resonances can be calculated easily [20]. discharge detection in GIS[22] while Fig. 6 (a),(b) shows extrinsic Fabry-Perot interferometer sensor and extrinsic microelectro-mechanical system sensor which have applications in the measurement of PD of oil cooled high voltage transformers[23].

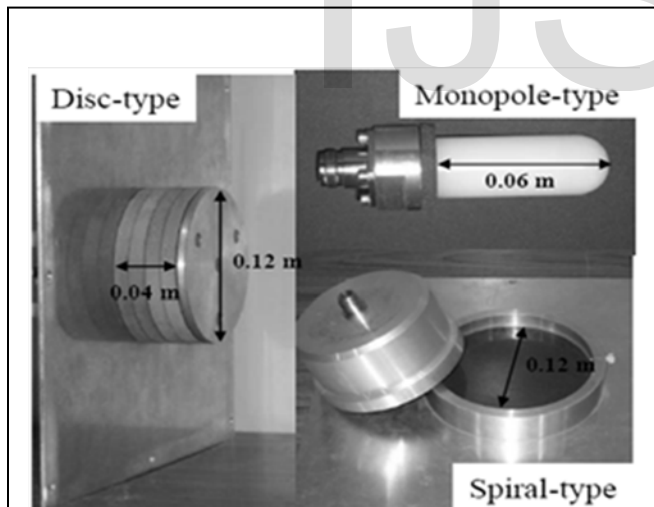


Fig. 2 Three types of UHF sensors: disc-type, monopole-type and spiral-type.

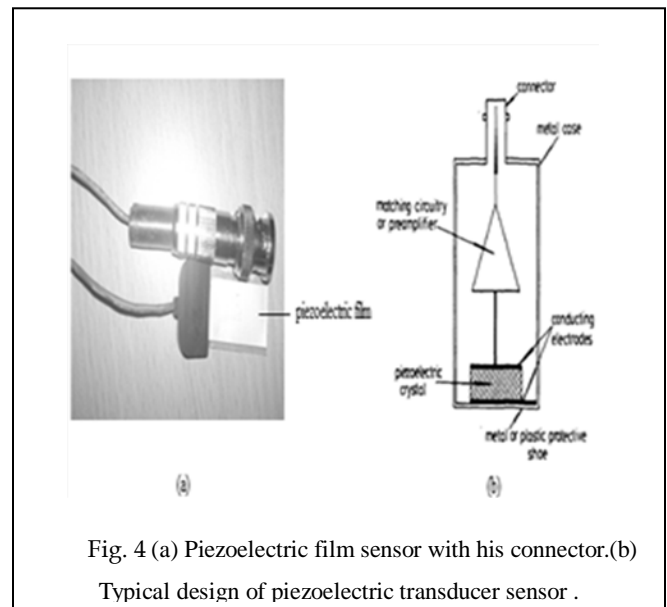
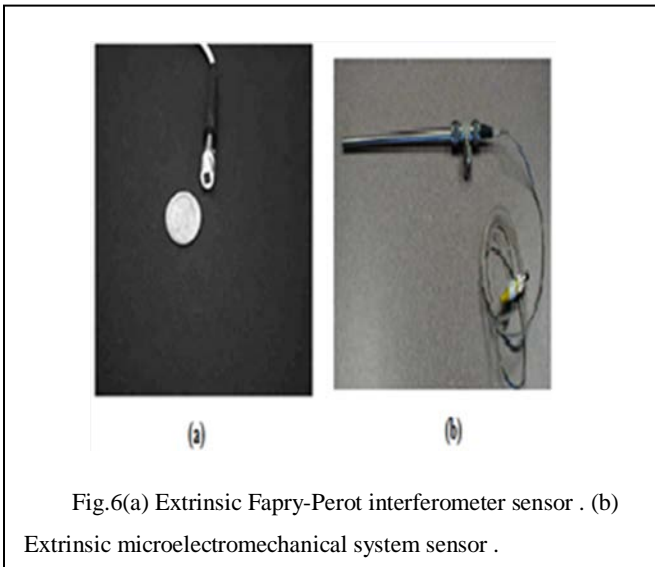
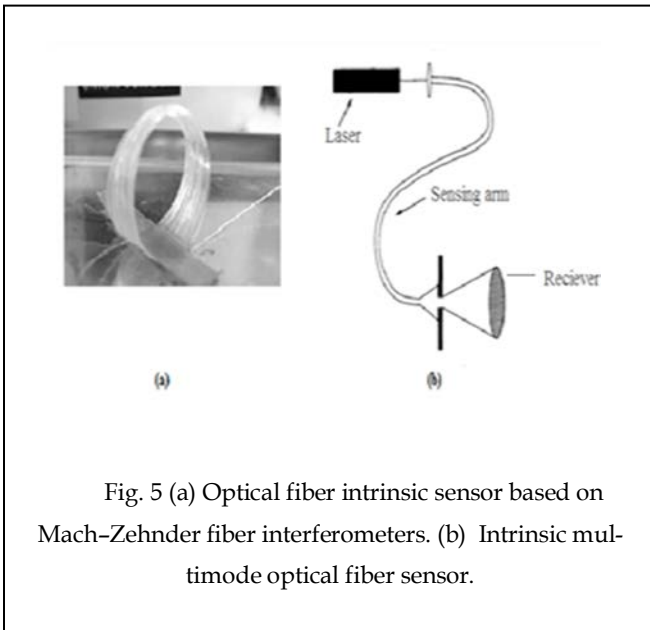


Fig. 4 (a) Piezoelectric film sensor with his connector.(b) Typical design of piezoelectric transducer sensor .



2.3 The sensors for optical detection

Currently, the most popular method for detecting PD in high voltage transformer and other equipment such as GIS is the optical detection method which uses fibre intrinsic sensor coil, the detail of which is as shown in Fig. 5 (a) . Fibre intrinsic sensor coil is made by winding 8 m of fibre around a former into a coil of 25 mm in diameter. The single mode optical fiber intrinsic sensor is based on Mach-Zehnder fiber interferometers and is normally immersed in the oil within the walls of the transformer whose PD characteristics are being measured[21] . Fig. 5 (b) shows multimode optical fiber sensor for partial discharge detection in GIS[22] while Fig. 6 (a),(b) shows extrinsic Fabry-Perot interferometer sensor and extrinsic microelectro-mechanical system sensor which have applications in the measurement of PD of oil cooled high voltage transformers[23].

3 conclusion

The problems associated with PD for High Voltage equipment and High Voltage power systems have not been ignored and will never be ignored by High Voltage system designers and High Voltage system maintenance engineers. When it comes to High Voltage, PD identification and PD monitoring make economic sense now and many years to come. How reliable, how quick PD can be measured and what sensors to use have become hot issues. This paper has gone to some lengths to present the many different ways in which PD can be measured. With technical progress, it is now possible to put suitable sensors directly into H.V. electrical equipment. Online PD monitoring system for H.V. electrical equipment can be used to detect occurrences before breakdown happens. At the present state of technology, it does appear that optical detection techniques have more advantages than non-optical ones. The optical detection and measurement method for PD may be considered as the future technique which will give a more precise prediction of preventive measures which can avoid time and money losses when operating H.V. power equipment and systems.

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