ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 8, August 2016

High Field Electrical Conduction and Breakdown in Solid Dielectrics

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ABSTRACT: Insulator is an important part of the high voltage equipments. Various types of insulating materials are used in high voltage electrical power system to protect all power system equipments. For the safety, reliability and efficiency, the insulating materials must be in a healthy condition during its operation. Most of the insulating materials are in impure form due to presence of air bubbles (cavity) or other impurities present inside the solid insulating materials. The local electrical breakdown occurring in solid dielectric is called as partial discharge (PD) which takes place due to the high voltage field stress. Due to the occurrence of PD the dielectric property of insulating materials deteriorates. Because of this reason detection of PD becomes one of the important tasks for high voltage engineers in order to keep the high voltage equipment in healthy condition. In this experimental model is used to study partial discharge and breakdown phenomena. For experimentation purpose sample of Acrylic material with cylindrical cavity is taken as a solid insulating material for creating partial discharge inside the solid dielectric by applying high voltage. In this study, partial discharge signal is captured with experimental setup at different high voltages which are further used for study and PD analysis.

KEYWORDS: Insulators, Partial Discharge, High Voltage, Cavity.

I. INTRODUCTION

Partial Discharge occurs inside the cavities present in a solid dielectrics, or bubbles inside the liquid dielectrics [13]. Since the discharge is named as partial discharge so it is limited only in the cavity portion inside the insulation. Partial discharges partially bridge the gap between the two electrodes. Boundary between two insulating materials can also lead to the occurrence of partial discharge. Cavities or bubbles present in insulating medium contain gas inside it due to which partial discharge occurs in a medium [1]. Because the dielectric strength of the gas inside the cavity or bubble is less than the surrounding dielectric medium, the electric field stress acting across the cavity or bubble is considerably higher than that across the complete dielectric [12]. If the voltage applied across the cavity or bubble is raised above the corona inception voltage for the gas present inside it, then PD activity will initiate within the void. This PD causes deterioration and degradation of insulating materials, ultimately leading to reduction of dielectric strength or dielectric property this will lead to final breakdown and complete damage of dielectric materials. PD can be avoided by designing an insulation medium careful and by proper material selection. In high voltage equipment manufacturing industry the insulation system is tested to detect the presence of cavity by monitoring PD. Periodically equipment's are tested by using on- line partial discharge measurement devices for detection of PD. Prevention and detection of PD is necessary to insure reliable and long-term operation of high voltage equipment. Many errors occurs in power system equipments are related to failure of insulation system or partial discharge which deteriorate the dielectric strength, majority of the faults occurs due to insulation failure [16]. Detection and identification techniques of PD are essential for removing errors in insulation system of high voltage equipments. Researchers are working for detection and identification of partial discharges. Localization of PD can be done by proper modelling and simulating PD mechanism. In this paper detection and identification of PD is done.

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II. PARTIAL DISCHARGE MECHANISM

As per IEC Standard 60270, Partial discharge is defined as a localized electrical discharge that partially bridges the insulation gap between the two conductors and which may or may not occur adjacent to a conductor. Concentration of local electrical stress in an insulation system or on the surface of insulation system results in occurrence of partial discharge. Such electrical discharges appear in the form of sharp impulses of various forms of voltage magnitude and current magnitude having short duration less than a sec. Generally PD occurs in high voltage equipments like transformer, insulators, cable etc. PD mainly occurs within cavities or voids inside a solid dielectric. It also occurs at interface between solid and liquid dielectric mediums, or in bubbles or air pockets inside liquid dielectrics. This discharge is limited to only over a portion of the insulation; the discharge partially bridges the gap between the two electrodes. PD can also take place along the insulation boundary between two insulating materials.

A. CLASSIFICATION OF PARTIAL DISCHARGE

Partial discharge phenomenon is divided into following two categories:

(a) External partial discharge

The partial discharge which takes place outside the high voltage equipment is called as external partial discharge. Such type of discharge generally occurs in overhead transmission lines or on armature of machines.

(b) Internal partial discharge

The partial discharge which mainly occurs inside a system is called as internal partial discharge. The discharge occurring inside cavity is belonging to such type of partial discharge. Partial discharge includes several types of discharges like corona discharge, surface discharge, cavity discharge, Treeing and tracing phenomenon.

(i) Surface discharge: It takes place on interfaces of two different dielectric materials such as gas and solid interface due to high electric stressed in gas than solid material. This type of discharge may takes place in high voltage bushing, high voltage cable end, on insulator surface between electrodes.

(ii) Cavity discharge: Generally cavities are formed in solid or bubbles in liquid insulating materials. The cavity is filled with gas or air medium. Such discharge takes place when the gas within the cavity gets over stressed.

(iii) Corona discharge: It takes place due to non-uniform electric field distribution on the edges of conductor supplied with high voltage. Gas or air or liquid insulation is supplied for such type of discharge.

(iv) Treeing and tracing: High intensity electric fields are produced in an insulating material at its surfaces or edges which deteriorates the insulating material. This is responsible for the production of continuous discharge called as Treeing and tracking phenomenon.

B. EFFECT OF A PARTIAL DISCHARGE IN INSULATING SYSTEM

Occurrence of PD is the main cause for degradation of insulating material and responsible for electrical breakdown. Repetition of partial discharge phenomenon is the main reason for mechanical and chemical degradation or deterioration of the insulating material. The effect of this discharge is severe on insulation of high voltage power equipment. Insulation damage occurs due to formation of partial discharge. The conductivity of the insulating material is zero under normal operating condition but it rises due to chemical changes in the dielectric.

Dielectrics are classified into two types:

- Inorganic dielectric and
- Organic dielectric.

Generally immunity of organic dielectrics is less. Porcelain, glass, mica are belonging to inorganic type of dielectric. Polymer dielectrics are belonging to organic dielectrics category.

Partial discharge generally produces energy in the form of heat. Heat energy is the main cause for degradation of the insulating medium. The effect is termed as thermal effect. For high voltage equipments deterioration of the insulation can be identified by monitoring the partial discharge activities. It can be monitored time to time by the high voltage engineer at the time of high voltage equipment manufacturing.

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C. PD MEASURING CIRCUITS ACCORDING TO IEC 60270

Fig.1 shows the equivalent circuit diagram for the measurement of PD(partial discharge) as per IEC 60270. This setup consists of high voltage source, test object as per a-b-c model and measuring instrument.

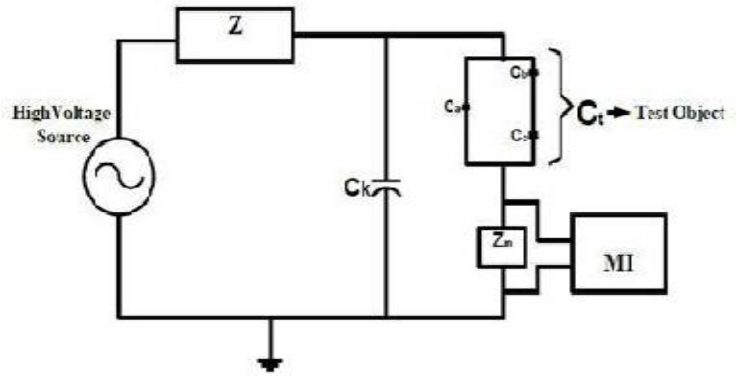

Fig: 1: Equivalent circuit diagram used for PD measurement

There are various methods used for the measurement of partial discharge based on both electrical and non-electrical phenomena. Methods which have been popularly used for the measurement of partial discharges are:

- Optical method of detection
- Acoustic method of detection
- Chemical method of detection
- Electrical method of detection

D. FACTORS AFFECTING THE DIELECTRIC STRENGTH OF INSULATING MATERIAL

Several studies are carried out to check whether the dielectric strength of insulating material is affected by some factors or conditions. The dielectric strength of any insulating material depends upon the temperature, impurity; spacing between two electrodes etc. and some other factors which are also responsible for it. In high voltage equipments the strength of liquid dielectric decreases to 70 % because of the presence of impurity content like suspended particles. Impurity includes solid particles of carbon, wax, and fiber. Presence of impurity contents creates imperfections in the insulation system.

III. NECESSITY OF DETECTION OF PARTIAL DISCHARGE

Most of the dielectric materials are in impure form from the origin. Due to the presence of impurity air bubbles are created within the insulating material. It minimizes the insulation property and responsible for the occurrence of partial discharge. The reason behind the formation of PD is the dielectric constant of the gas inside the cavity is less than that of surrounding medium. This results in insulation failure of high voltage equipments. Partial discharge generally occurs in cavities. This type of electric discharge has low magnitude but they are responsible for degradation of insulation. Due to formation of discharge, failure occurs in the insulation medium. Because of all above reason detection and measurement partial discharge is important for predicting life of insulation in high voltage equipments.

IV. MODELING OF CIRCUIT FOR PD MEASUREMENT

The characteristics of internal discharges occurring inside the dielectric medium can be represented using most accepted a-b-c model. Fig.2.a represents the physical model of insulator with cavity inside it and fig.2.b represents a-b-c model of insulator with cavity in the form of capacitors. The values of capacitors can be determined by using following formulae.

Assuming that a cylindrical cavity is filled with a gas of relative permittivity ε_c, the capacitance of portion c is given as

$$C_{ic} = \frac{\varepsilon_0 \varepsilon_c A}{h_c}$$

The capacitance of portion b of relative permittivity ε_i is given as

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$$C_{ib} = \frac{\varepsilon_0 \varepsilon_i A}{h_i - h_c}$$

Similarly, the capacitance for portion a can be determined.

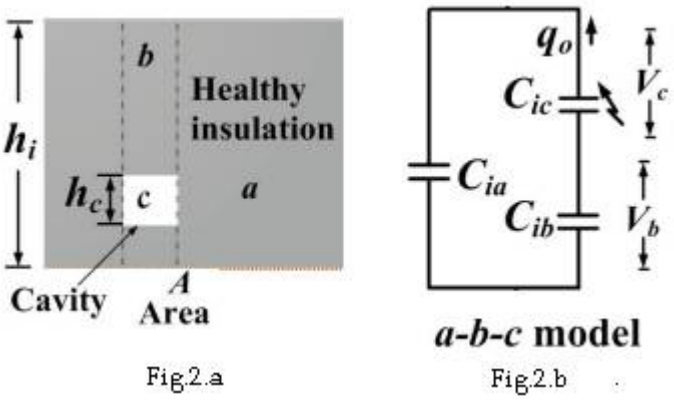

Fig. 2: a) physical representation of insulator with cavity & b) a-b-c model representation of insulator with cavity

V. EXPERIMENTAL SETUP

Fig.3 & Fig.4 shows overall experimental setup for detection and measurement of partial discharge. Fig.3 shows 100kV High voltage AC testing set, point-plane electrode arrangement, solid (Acrylic sheet of 100mmx100mmx5mm) dielectric sample with cylindrical cavity of 2mm diameter, discharge current sensor. By using HV control panel we can change the magnitude of high voltage applied to dielectric. With the help of meters mounted on HV panel we can monitor the magnitude of applied high voltage and leakage discharge current.

Fig. 3: Point-Plane Electrode Sample with 5mm gap

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Fig.4 shows Tektronix make TDS 2014B DSO, PC with Open Choice Desktop and Tekvisa software. Current sensor senses the changes in current which can be monitored on DSO as well as PC. This current signal is used to study the partial discharge occurring at different magnitude of applied voltage.

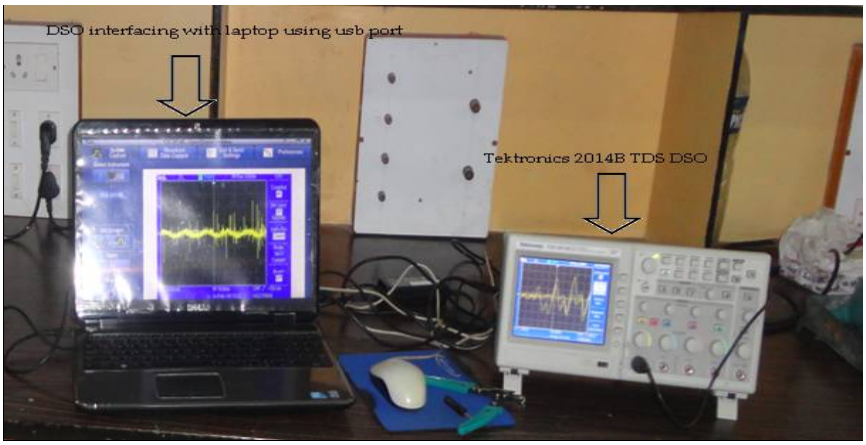

Fig. 4: Experimental set for measurement and detection of Partial Discharge (PD)

VI. RESULTS & DICUSSION

Fig.5 shows the current signal captured with the help of experimental setup on TDS 2014B DSO. The partial discharges occurring due to presence of cavity in dielectric sample are represented in the form of spikes in current waveform. Single cycle of current signal is captured.

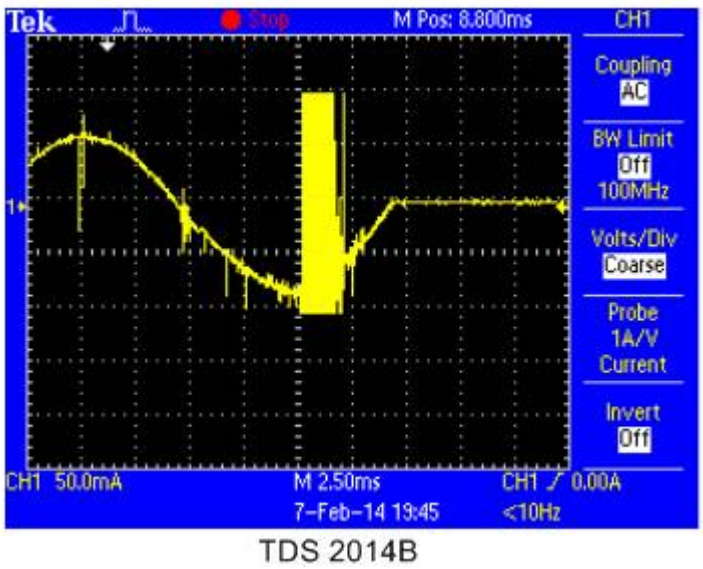

Fig. 5: Current Signal with partial discharges captured on TDS 2014B DSO

Fig. 6 shows the wavelet decomposition of the breakdown current signal processed in MATLAB environment upto decomposition level 6. The experimental results are obtained in statistical and graphical form for the study of partial discharge and breakdown characteristics formed in solid insulating material. From the experimental setup partial discharge and breakdown signal can be captured. It is observed that when high voltage is applied through the source to sample the amplitude of the partial discharges are detected in the solid insulator Acrylics in the form of sudden spikes

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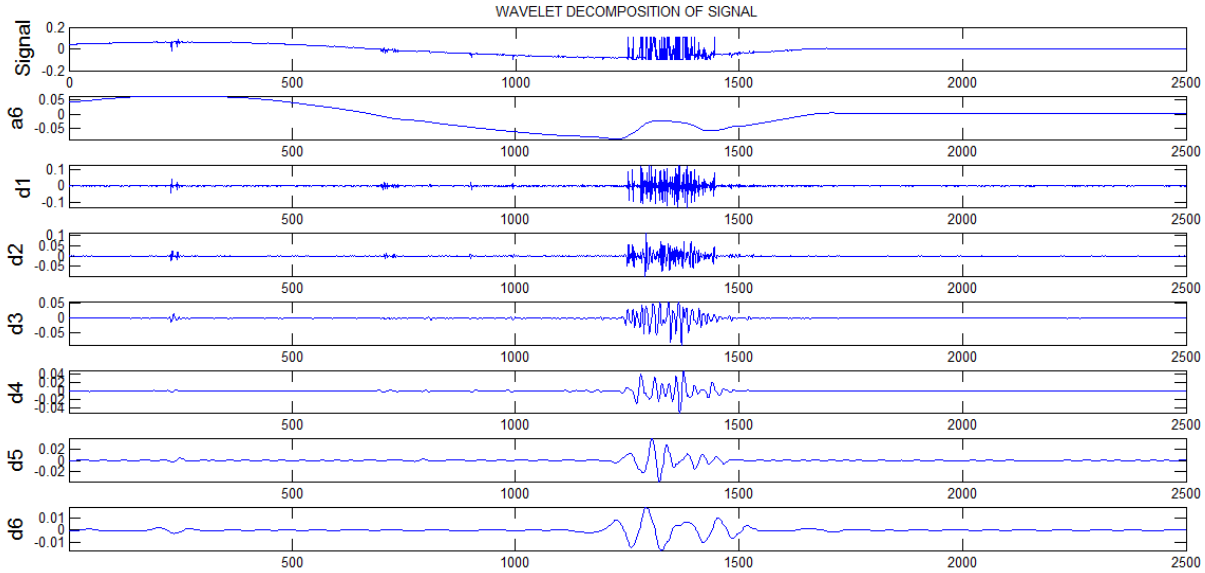

Fig.6: DWT apllied to the breakdown signal upto the level 6

Table 1 shows the statistical parameters by applying the db6 & sym6 wavelet for wavelet decomposition of captured signal at various levels.

Parameters	For db6 At Level 6	For sym6 At Level 6
Mean	-0.003473	-0.003473
Median	0.0032	0.0032
Mean	0.004883	0.004883
Maximum	0.103	0.103
Minimum	-0.1	-0.1
Range	0.203	0.203
Standard Deviation	0.04538	0.04538
Median Abs. Dve.	0.032	0.032
Mean Abs. Dev.	0.0351	0.0351
L1 Norm.	85.44	85.44
L2 Norm.	2.275	2.275
Maximum Norm.	0.103	0.103

Table 1: Statistical Parameters of the captured breakdown waveform

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VII. CONCLUSION

This paper addresses the phenomenon of partial discharge and breakdown occurring in high voltage equipment insulation system. While designing insulation system for high voltage equipment engineer has to pay attention on formation of cavity in dielectric. If any cavity is formed in the dielectric then detection of such cavity is necessary as it creates partial discharge and breakdown takes place. This partial discharge degrades the insulation. Hence, detection and measurement of partial discharge is done by monitoring discharges occurring in dielectric under service condition. It is necessary to keep all equipments in healthy working condition throughout their operation. The work presented in this paper is based on experimental studies carried out for partial discharge measurement and detection using discharge current sensor and 2014B TDS Tektronics make DSO. The amplitude and frequency of partial discharge occurrence can be easily measured from the captured waveform.The life of dielectric material can be predicted with the help of partial discharge signal captured.

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