ISSN 2229-5518

# Partial Discharge Detection in Solid Dielectrics

Kannan M, Prof. P. Sreejaya

**Abstract**—Partial Discharge (PD) measurement and characterization provide vital information on insulation condition, different aspects of insulation ageing useful for equipment integrity verification and diagnosis. The work demonstrates standard test methods which employs capture of PD parameters with the aid of discharge detector. This paper investigates on the voltage amplitude at which PD of a specified magnitude commence and determines the apparent charge, discharge energy and power dissipation for discharge quantity at a specified voltage. PD detection and measurement procedures suitable for use on Current Transformers, Insulators and Air Break (AB) switches are examined.

**Index Terms**— Apparent Charge, Coupling Capacitor, High Voltage, Insulation, Partial Discharge Detection, Pattern of PD, Void.

## 1. Introduction

ONE common factor, which in different forms, runs throughout the entire electrical industries, is the requirement for insulation which gives necessary mechanical, thermal, electrical properties and sustainability needed for particular application. The insulation health of high voltage apparatus is a major concern for the proper operation and smooth functioning of the system. However the inevitable void inclusions, introduced in the manufacturing processes, creates operational problem.

When the insulation system is subjected to a voltage stress, the weak points occluded, results in local over stressing and undergo partial discharge activity. The magnitude of such discharges is usually small, but once prevalent they represent the dominant mechanism of degradation and leads to reduction in the equipment life. Partial discharges are localized discharge process, confined to insulation system, in which distance between two electrodes is only partially bridged.

Over the years, the level of investigative effort in the PD field has varied considerably both as regards to the type of electrical apparatus under consideration as well as the type of discharge behavioral aspect being examined [1]. Many models and test set-ups have been made to describe the PD activity with in a dielectric occluded void [2]. A critical review of the past shows tremendous technological developments in the field of PD activity [3-10].

Earlier, quality of insulation was judged, mainly by insulation resistance measurements, dissipation factor measurements and breakdown tests by overstressing the insulation with high ac or surge voltages, which suffered the drawback that during the process of testing the equipment may be damaged, if the insulation is faulty [11].

This paper focuses on the examination of partial discharge activity for insulators, air break switches and current transformers. The objective behind the work is to check whether the test object exhibit PD and if so, determine the voltage amplitude at which PD exists and commence with increasing voltage. It also finds the apparent charge, discharge energy and power dissipation for the same.

The paper is organized as follows. In section II, breakdown in solid dielectrics due to void is summarized. In section III and sub sections, basic PD test circuit, PD detection methods and measurement are presented. Section IV, covers results obtained and discussion. Conclusion is drawn in section V.

## 2. Breakdown in Solid Dielectrics Due to Voids

The major factors which lead to the breakdown of insulation in solid dielectrics are by intrinsic, electromechanical / chemical, thermal, treeing / tracking phenomenon's and the presence of voids. The breakdown of solid dielectrics not only depends upon the magnitude of voltage applied but also on the time, for which voltage is applied.

Practical solid insulating materials contain voids or cavities. The voids are usually filled with a gaseous or a liquid medium of lower breakdown strength than that of the solid. Also, the dielectric constant of the void medium is lower than that of the insulation. This result in a higher electric field stress in the voids compared to that in the solid. Thus, under normal working stress of the insulation, the field in the voids may exceed their breakdown value-causing breakdown of


- *Kannan M, Assistant Professor, Department of Electrical and Electronics Engineering, LBSITW, Trivandrum. E-mail: mylightmain@gmail.com*
- *P. Sreejaya, Associate Professor, College of Engineering, Trivandrum. E-mail: psreejaya@gmail.com*

the voids. It is possible to calculate the voltage across the dielectric, which will initiate discharge in a gaseous cavity in a dielectric of thickness d. The cavity is assumed to be of thickness t as shown in figure 1. Figure 2 shows the electrical equivalent circuit.

The insulating medium and the void may be represented by three capacitances- Cc, the capacitance of the void; Cs, the capacitance of the dielectric, which is in series with the void; Cr, the capacitance of the rest of the dielectric.

Thus,

$$C_c = \frac{\varepsilon_0 A}{t} \quad \text{.......} \quad (1)$$

$$C_s = \frac{\varepsilon_0 \varepsilon_r A}{d - t} \quad \text{.......} \quad (2)$$

where A is the cross- sectional area of the cavity disc and $\varepsilon_r$ is the relative permittivity of the solid [12].

If a voltage V is applied across the dielectric, then the voltage across the void $V_v$ is given by

$$V_v = \frac{C_s V}{C_s + C_c} = \frac{V}{1 + \frac{1}{\varepsilon_r}\left(\frac{d}{t} - 1\right)} \quad \text{.......} \quad (3)$$

If the gaseous cavity has breakdown strength of $E_c$, then the break down voltage across the cavity $V_c$, should be $E_c t$ and the dielectric voltage $V_d$ required to cause breakdown of the void is obtained by putting $V = V_d$ and $V_v = E_c t$ in equation (3). Thus,

$$V_d = E_c t \left\{1 + \frac{1}{\varepsilon_r}\left(\frac{d}{t} - 1\right)\right\} \quad \text{.......} \quad (4)$$

So, when a voltage more than $V_d$ is applied across the dielectric, breakdown of the gas in the void occurs. As $V_v$ reaches the value of $V_c$, a discharge takes place; the voltage $V_v$ collapses and spark gets extinguished. The voltage across the void then starts increasing again until it reaches $V_c$, when a new discharge occurs. Similarly, in the negative half cycle of $V$, discharges in the void take place as $V_v$ reaches $-V_c$.

In this way the discharge process is repeated in the void and it gives rise to positive and negative current pulses. Heat produced in the discharge will carbonize the surface of the void and cause erosion of the material. The erosion roughens the surface and penetrates the insulation and a tree-like channel may grow in the insulation. Ultimately, the insulation will breakdown even under normal voltage application.

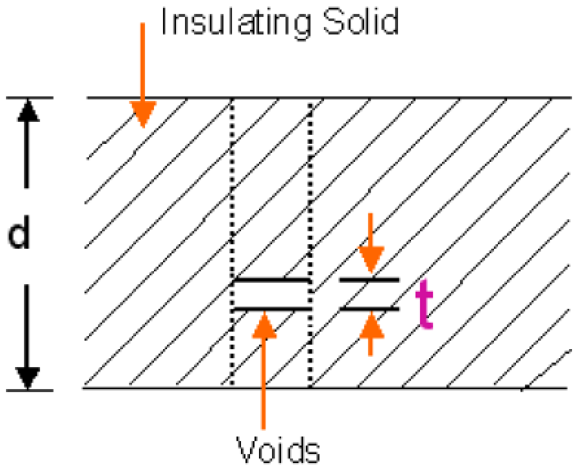


Fig 1: Void in the solid dielectric of thickness *d* and cavity of thickness *t*

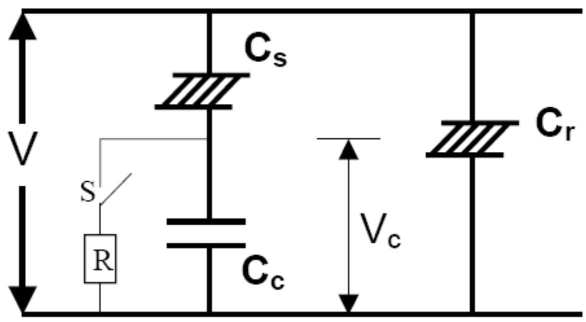


Fig 2: Electrical equivalent circuit of Dielectric with void

## 3. PD DETECTION

Today's Test Systems measure the test voltage at the moment of PD event, the PD inception voltage and the apparent charge. Partial Discharges in insulation can be measured by optical, acoustic, chemical and electrical methods [13]. The most modern and most accurate methods are the electrical methods. PD detection consists of converting PD pulse current from sensor to voltage signal via detection impedance, which yields signal amplitude proportional to the apparent charge transfer, in each discharge [14].

### 3.1 Basic PD Test Circuit

The basic PD test circuit is shown in figure 3. The test object is always connected to a voltage source and a coupling capacitor.

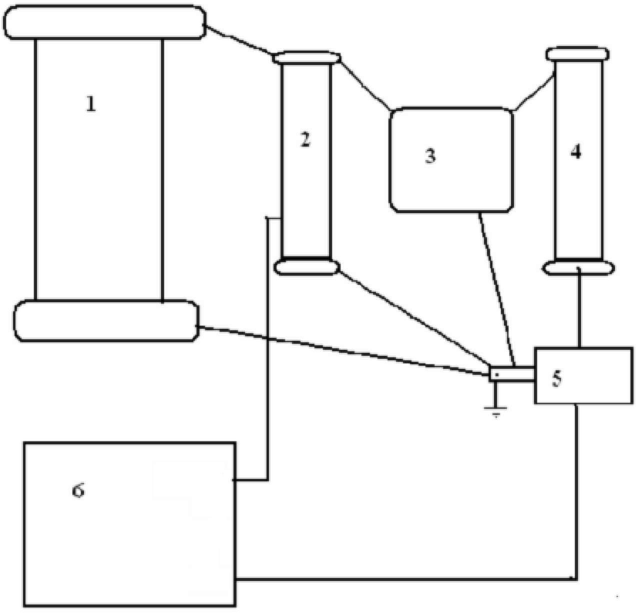


Fig: 3 Basic PD test circuit 1) High voltage transformer 2) Measuring Capacitor 3) Test object 4) Coupling Capacitor 5) Detection Impedance 6) Measuring Instrument

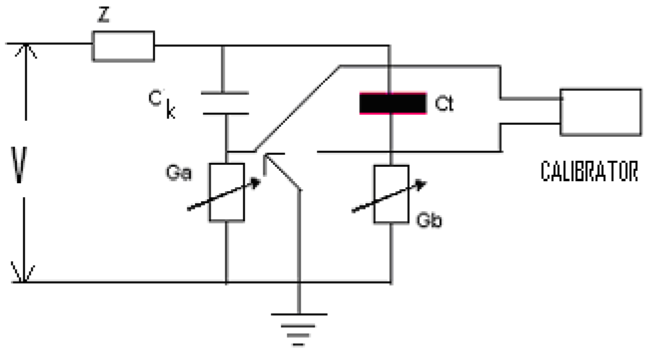


Fig: 4 Balanced detection method. Ga and Gb- measuring impedances,
$C_k$- coupling capacitor $C_t$- test object, Z-Filter.

## 3.2 PD Detection Methods

There are two types of detection methods used for the measurement of PD namely the straight detection method and bridge/ balanced detection method [15].

### *3.2.1 Straight Detection Method*

The test-setup used for straight detection method is shown in figure 3 in section 3 subsection *A*. To the test object place, the specimen to be tested, is connected. Following a discharge, a pulse with a fast rise time is produced in the circuit. The voltage developed across the detection impedance is fed into a CRO through an amplifier. The detection impedance consists of RLC circuits with interchangeably input units to match specimens of varying capacitance so that the circuit is tuned to the midband frequency of the band pass amplifier to obtain maximum sensitivity.

The magnitude of any given discharge may be determined by direct comparison with a known size of pulse, which is produced by the calibrator. For calibration purpose, proper input unit is connected according to specimen capacitance and adjusted to concerned charge with the use of pulse generator.

The coupling capacitor bypasses the power frequency components and allows only the PD pulses to reach the measuring impedance.

### *3.2.2 Balanced Detection Method*

Figure 4 shows a bridge circuit for partial discharge measurement. If the sample capacitance is very high to that of the coupling capacitor, the sensitivity of the measurement comes down in straight detection method.

To improve the sensitivity of measurement, bridge/ balanced detection is used. The circuit mainly consists of two balanceable measuring conductances Ga and Gb which are inserted into the ground conductors of coupling capacitor and test object. The bridge is balanced by calibration generator when it is not energized.

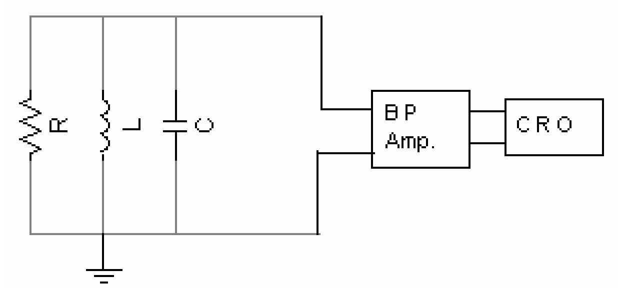


Fig: 5 Wide band PD measuring circuit

According to international standards the level of partial discharges is judged by quantity of apparent charge measured. The apparent charge is obtained by integration of circular current. This operation is carried out on the PD pulses using wide band and narrow band measuring systems. The wide band is of bandwidth 40 to 220 kHz and narrow band has variable centre frequencies from 600 to 2400 kHz and bandwidth 9 kHz. These are band pass filters with amplifying action [16]. The frequency spectrum of the exponentially decaying pulse current shows why band pass filters are suitable for integrating PD pulse currents. The wide band circuit shown in figure 5, employing the coupling impedance is a parallel combination of R, L and C whose quality factor is low [17-21].

ISSN 2229-5518

### 3.3 Concept of Apparent Charge

Consider the figure 2 in section II. The sample is charged to a voltage *V*, but the terminals are disconnected from the voltage source. When the switch is closed, the capacitor $C_c$ discharges and charge is lost in the system. This will cause a voltage drop of $\delta V_c$ across the cavity and $\delta V$ across the terminals. Hence, $C_c\delta V_c = \delta V\left(C_r + C_s\right) - C_s\delta V_c$ ............................. (5)

$$\delta V = \frac{C_s\delta V_c}{C_r + C_s} \qquad (6)$$

Since $C_c << C_s$

This voltage $\delta V$ does not give any information of the charge discharged which is

$$\delta q_c = C_c\delta V_c \qquad (7)$$

When the test sample is connected to the voltage source, during the short interval of cavity discharge, the coupling capacitor only replenishes the charge. Thus it acts as a storage capacitor during this time period of PD phenomenon. It releases a charge to the test specimen which tries to cancel the voltage drop $\delta V$ across terminals.

The charge transferred by coupling capacitor is given by

$$q \approx \left(C_r + C_s\right)\delta V \qquad (8)$$

Combining equation (6) and (8)

$$q = C_s\delta V_c \qquad (9)$$

The charge q supplied by the coupling capacitor is called the apparent charge.

## 4. RESULTS AND DISCUSSIONS

The test procedure is conducted with a coupling capacitor of 1000pF, measuring capacitor of 100pF, high voltage PD free transformer, and discharge detector in wide band mode. The magnitude of PD is measured in pico coulombs (pC). The partial discharge detector provides display of PD pulses on a CRO, which shows pulses on an elliptical time base.

Using the two detection methods, for the cases of current transformer, air break switches and insulators, the partial discharge intensity as charge in Pico coulombs is measured from the test circuit for different input voltages.

To test the discharge level of a pin insulator with balanced method, it is connected in the place of test object and calibration is done with 50pC charge level. The experimental results obtained are shown in figures 6, 7and 8 respectively.

From figure 6 it can be inferred that as voltage is increased the discharge intensity increases and when the breakdown voltage of cavity is exceeded it leads to ultimate breakdown.

Figure 7 shows a plot of PD intensity vs Discharge energy giving the idea, how much quantity of energy is released, at a particular discharge. The measure of discharge energy is done by equation (10).

$$W = 0.707 q_a V_{i(rms)} \qquad (10)$$

$q_a$ = apparent charge and $V_i$ = input voltage.

Even a small discharge whose magnitude is 15pC, at an inception voltage of 0.8kV, will release energy of 8.48 x 10$^{(-9)}$ joules.

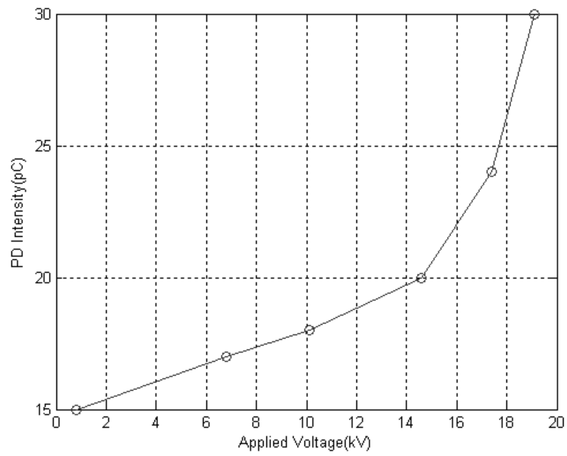


Fig: 6 Variation of PD intensity as a function of applied voltage

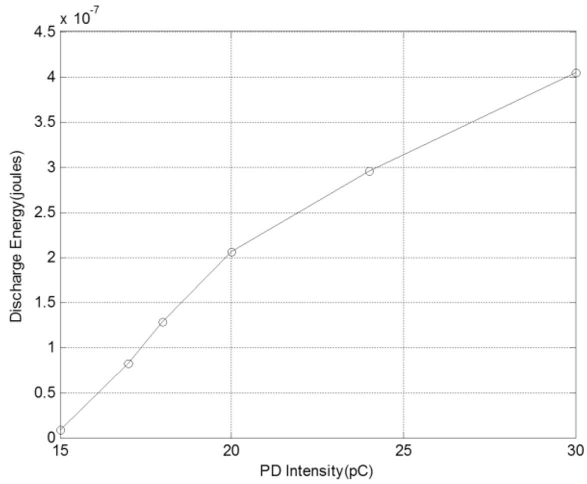


Fig: 7 Variation of Discharge energy (joules) as a function of PD intensity

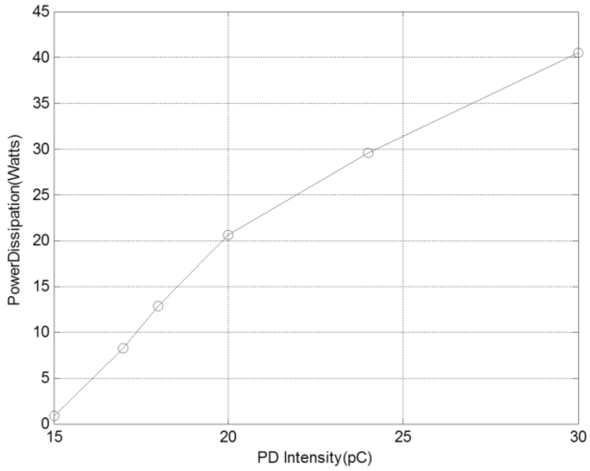


Fig: 8 Variation of Power Dissipation (watts) as a function of PD intensity

The results obtained from Figure 8 plays the vital role. The energy is released at 0.8kV in a small duration, of about 10nanoseconds. Thus, power is quantitatively about 0.848 watts which increases to around 40.5 watts at an intensity of 30pC at 19kV. This causes heating within the insulation, which leads to the premature failure of the insulation system.

The effect of partial discharge thus can be summarized as an (i) increase in the loss component of the charging current taken by the capacitive sample, (ii) increased dielectric power loss, (iii) radiation of energy in the form of sound, light or ultraviolet radiation, (iv) changes in pressure and (v) chemical changes in the dielectric material.

Partial Discharge measurement, a nondestructive test, thus forms a quality assurance test for the insulation system.

To test the discharge level of an AB switch, with straight detection method, it is connected to the test set up and calibration is done with the intensity level to get display of PD pulses, if present.

Calibration is effected by injecting pulses of known charge contents. Calibrating pulse and PD pulse magnitude and characteristics must be comparable. The PD pulses are tapped from the analog output terminal and displayed on the built-in oscilloscope. The results obtained are shown in fig 9, 10 and 11 respectively.

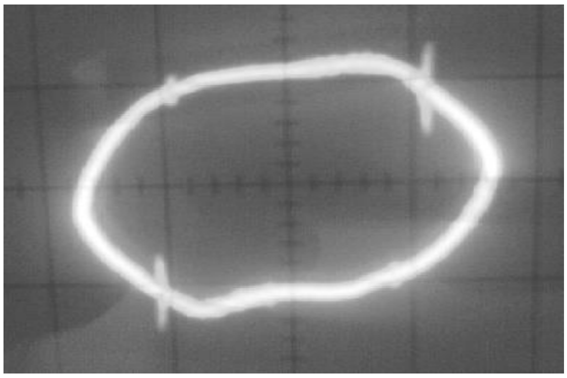

Fig: 9 Pattern obtained in CRO for AB switch when applied voltage given is 0.8 kV

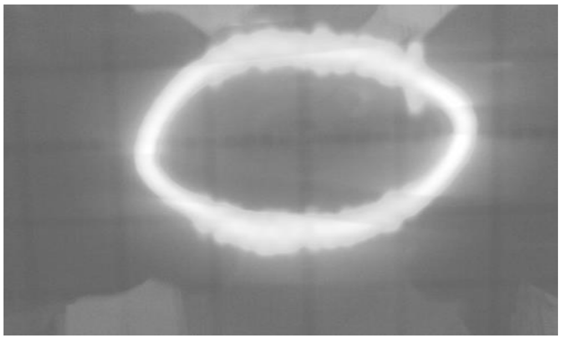

Fig: 10 Pattern obtained in CRO for AB switch when applied voltage is increased to 2 kV

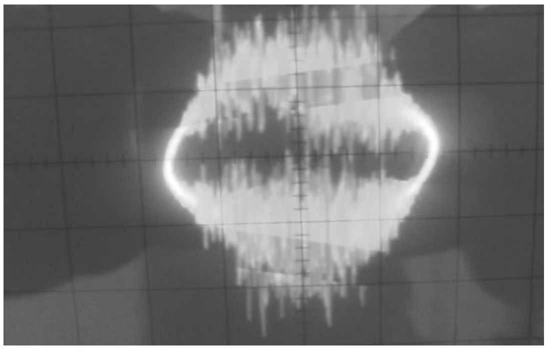

Fig: 11 Pattern obtained in CRO for AB switch when applied voltage is increased beyond 2 kV

From figures 9, 10 and 11 it can be inferred that the insulation system has failed prematurely since, for application beyond 2 kV the waveform showed severe distortion indicating high intensity of partial discharge.

Similar procedure is repeated for current transformer. The test circuit is arranged as shown in figure 12.

For transformers, under the application of power frequency voltage, the discharge magnitude greater than $10^4$ pico coulombs are considered to be severe. The result obtained is shown in figure 13. The PD intensity level showed a magnitude of 30 pC for 0.8kV which is found to be satisfactory when compared to the specified magnitude of $10^4$ pico coulombs.

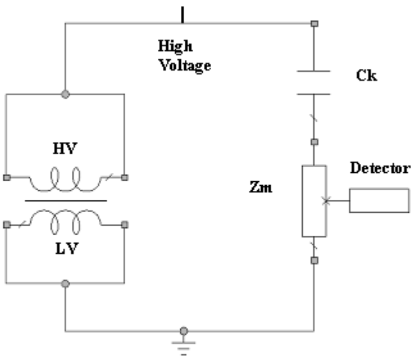


**Fig: 12 Connection circuit for PD test on current transformers Ck- coupling capacitor, Zm- detection impedance**

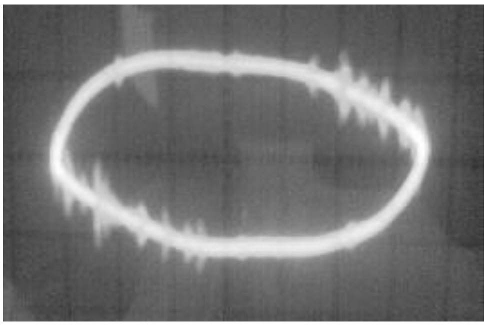

**Fig: 13 Pattern obtained in CRO for Current Transformer when applied voltage is 0.8 kV**

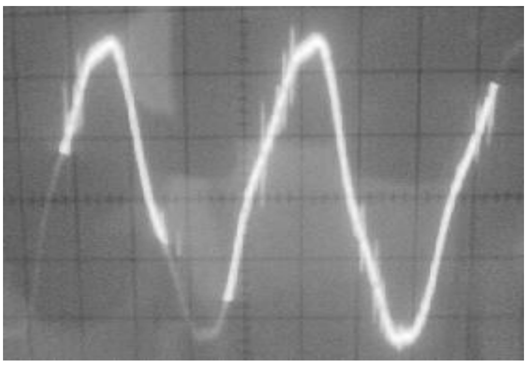

**Fig: 14 Pattern obtained in CRO with sinusoidal time base for Pin Insulator when applied voltage is 0.8 kV**

## 5. CONCLUSION

The underlying principles of partial discharge detection have been elucidated. The PD test for the three equipments namely Pin Insulator, AB Switches and current transformer are done and their PD intensity levels are investigated. The result conveys that breakdown due to partial discharges will occur after prolonged voltage application and leads to premature failure of the insulation system.

Noise continues to be a large issue in PD testing. High sensitivity levels are particularly difficult to achieve with high capacitance specimens. The two factors, noise and sensitivity level can be made satisfactory with balanced detection method.

The PD measurement finds application as a design test, quality assurance test and condition assessment test for high voltage equipments.

## 6. ACKNOWLEDGMENT

The authors wish to gratefully acknowledge the support provided by Prof. G. L. Valsala, Head of the department, Prof. Chandramohan, former P G Coordinator and Prof. K. M. Lizy, P. G. Co-ordinator, of Department of Electrical Engineering, College of Engineering, Thiruvananthapuram during the research work.

## 7. REFERENCES

[1] R. Bartnikas, “Partial Discharges: Their Mechanism, Detection and Measurement”, IEEE Trans. Dielectrics and Electrical Insulation, Volume 9, Number 5, Pages 763-808, October 2002.

[2] R. Bartnikas, “A commentary on partial discharge measurement and detection”, IEEE Trans. Electrical Insulation, Volume EI-22, Number 5, Pages 629-653, October 1987.

[3] Walter S. Zaengl, Kurt Lehman, Manfred Albiez, “ Conventional PD Measurement Techniques used for Complex HV Apparatus” IEEE Trans. Electrical Insulation, Volume 27, Number 1, Pages 15-27, February 1992.

[4] Peter H.F. Morshuis, “Degradation of solid dielectrics due to internal partial discharge: some thoughts on progress made and where to go now” IEEE Trans. Electrical Insulation, Volume 12, Number 5, Pages 905-913, October 2005.

[5] T. Brosche, W.Hiller,E.Fauser,W.Pfeiffer, “ Novel Characterization of PD Signals by Real Time Measurement of Pulse Parameters” IEEE Trans. Dielectrics and Electrical Insulation, Volume 6, Number 1, Pages 51-59, February 1999.

[6] M.A.Pecorelli, “Miniature Partial Discharge Calibrator Synchronized by Capacitive Coupling”, IEEE Trans. Electrical Insulation, Volume 27, Number 1, Pages 181-183, February 1992.

[7] R. Bartnikas,J.P.Novak, “ On the Character of Different Forms of Partial Discharges and their Related Terminologies”, IEEE Trans. on Electrical Insulation, Volume 28, Number 6, Pages 956-968, December 1993.

[8] K.Wu, Y. Suzuoki,T. Mitzutani,H.Xie, “ A Novel Physical Model for Partial Discharge in Narrow Channels”, IEEE Trans. Dielectrics and Electrical Insulation, Volume 6, Number 2, Pages 181-190, April 1999.