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Simulation and Mathematical Analysis of Partial Discharge Measurement in Transformer

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***Abstract*—Partial discharge is a tiny spark of electricity that occurs within the insulation of electrical equipment. This discharge travels through the dielectric material and connects the energized conductors inside the casing. It is important to note that PD activity can occur anywhere within the dielectric, where the breakdown strength of the material is no longer adequate to counter strength of the electric field generated in the system. Information on PD position can be used by plant Monitors to diagnose the cause of PD and can help to identify type and severity of an insulation fault for maintenance strategies. The acoustic PD detection system, with great advantages relative to other methods, contains inaccuracies in PD localization, such as the multipath interferences due to reflections within transformer tank, improper acoustic coupling between sensor and tank surface, mechanical vibrations and inherent sensor inaccuracies, which can severely limit the accuracy of the positioning system and make locating the exact positions of PD difficult. There are numbers of advantages of acoustic emission method over the electrical measurement method. The acoustically emitted waves due to PD tend to propagation along various paths before being detected by the sensors. The analyses the results obtained from theoretical analysis of various propagation paths. Theoretically determine the time difference between direct path and indirect path acoustically emitted signal and the shortest time needs to be computed.**

Keywords— ***Acoustic Emission, Modeling of Partial Discharge, Partial Discharge, Propagation Path***

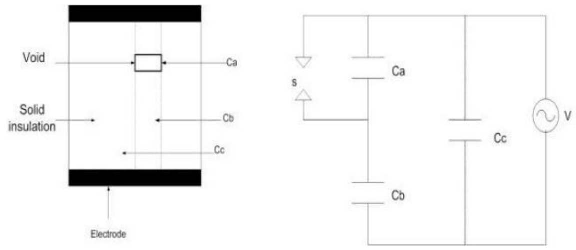
I. INTRODUCTION

According to International Electro technical Commission Standard 60270, Partial discharge is an electrical discharge which partially connects the insulation between conductors and which may also possible to other adjacent conductor. In general, due to the local electrical stress concentrations in insulation or on insulation surfaces, the PD occurs. Such types of discharges are come into view like impulses. For examples-various forms of voltage impulses and current impulses, the duration of these impulses very much less than 1sec. PD is usually noticed in high rating power transformer, high voltage cable and bushings, other power equipment.

A partial discharge is short release of current caused by the build-up of electric field intensity in a finite region. In high voltage equipment like power transformers, Partial discharges can be indicative of problems like an insulation defect and floating components within the device.

For judging the quality and condition of manufacturing devices like transformer the PD detection is used as a tool at the time of manufacturing. In addition, as the transformers ages, faults in the device can be created. Overtime, electrical and mechanical stresses can damage materials within the transformer, including the winding and the paper insulation lining the walls of the transformer tank. Now a day in a modern power system, PD detection is used to examine the health of a transformer in service. PD detection is also helps plant managers to schedule maintenance of devices.

II. FUNDAMENTAL OF PARTIAL DISCHARGE IN SOLID CAVITY



(a) Physical modelling of void (b) Equivalent circuit of PD

Fig.- 1: PD Model[8]

V = applied voltage at power frequency
S = spark gap representing discharge of Ca
Ca = capacitor representing the cavity
Cb= capacitor representing insulating material around cavity
Cc = capacitance of the remaining insulating material

A capacitor with a void inside the insulation (Ca) series with the rest of the insulation capacitance (Cb). The remaining void free material is represented by the (Cc). When the voltage across the capacitor is increased, and it will reach across the capacitor Ca (more than insulation withstand capacity) a discharge occurs through the capacitor it represented by the closer of the switch [3][8].

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III. CLASSIFICATION OF PARTIAL DISCHARGE

Partial Discharge phenomenon is divided into two types:

1) External Partial Discharge: External Partial discharge is the process which takes place outside of the power equipment. Such type of discharges occurs in overhead lines, on armature etc.
2) Internal Partial Discharge: The PD which is occurring inside of a system. PD measurement system gives the information about the properties of insulating material uses in high power equipment.

Type of Typical Partial Discharge:

- *Corona Discharge:* PD around a conductor in free space is called corona discharge [3]. Corona discharge takes place due to non-uniform field on sharp edges of the conductor subjected to high voltage. The insulation provided is air or gas or liquid.

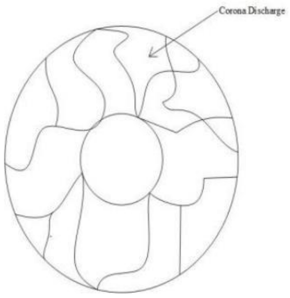

Fig.- 2: Corona Discharge

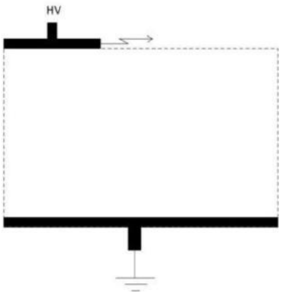

Fig.- 3: Surface Discharge

- *Surface Discharge:* Surface discharge takes place on interfaces of dielectric material such as gas/solid interface as gets over stressed times the stress on the solid material.
- *Cavity Discharge:* The cavities are generally formed in solid or liquid insulating materials. The cavity is generally filled with gas or air. When the gas in the cavity is over stressed such discharges are taking place.

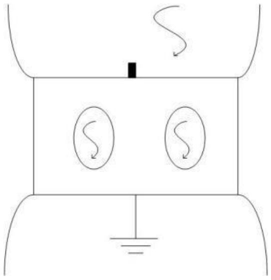
Fig.- 4: Cavity Discharge

IV. PARTIAL DISCHARGE DETECTION METHODS

Over time, the insulation within an HVT begins to break down due to mechanical, thermal and electrical stress. Because partial discharges are both symptomatic of insulation breakdown and a mechanism for further insulation damage, PD detection is used to evaluate the condition of and diagnose problems with the HVT insulation [2]. For detection of PDs within HVTs, several methods have been developed and these can be divided into four categories: chemical, electrical, acoustic and optical detection. Optical detection is not widely used in current systems and is difficult to implement in HVTs due to the opaque nature of mineral oil. The techniques are described below.

1) Chemical detection: Partial discharges can be detected chemically because the current streamer across the void can break down the surrounding materials into different chemical components. Now a days, there are two chemical tests are used by power companies are dissolved gas analysis (DGA) and high performance liquid chromatography (HPLC). The DGA test identifies gas levels which are produced due to breakdown of mineral oil in the transformer. The test is performed by taking an oil sample from the tank and determining the levels of different dissolved gases, which include acetylene, methane, hydrogen carbon dioxide, and ethylene [4]. This test indicates the presence of PDs as well as provides additional diagnostic information because different levels of each of the gases can be correlated to a specific type of fault within the HVT using extensively developed tables. Although this test is widely used, there is some debate as to whether or not the levels of dissolved gas really correlate to a specific type of fault. Chemical testing has disadvantages that it does not provide any information about the position of the PD or the extent of the insulation damage and chemical testing cannot be performed online. In most cases, the transformers must be taken out of operation to obtain the oil sample.

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2) Electrical detection: The detection of electrical pulses produced by partial discharges tends to be more convenient and sensitive then non-electrical methods [1]. The electrical pulse created by the current streamer in the void is required for electrical detection. This method or system is more convenient, standardized, accepted, sensitive and simple to apply compared to other methods. This system is able to measure the internal discharge, surface discharge and corona discharge.

3) Acoustic detection: Acoustic emissions from the electrical discharge source were detected as early as 1939. PD activity is associated with instantaneous release of energy along with other micro and macroscopic processes. A fraction of the released energy heats the material adjacent to the PD location creating a small explosion, which excites a sound wave. High frequency Acoustic Emission sensors mounted on the walls of the container pick up these vibrations of the surface wave and convert in to electrical signals, which could then be captured by appropriate instrumentation and analyzed by a processing system. More recently, These technique is gaining increased popularity due to certain distinct advantages like Non-destructive and non-invasive in nature, Easier and quicker instrument set up at site, No disruption of power system operation is required, Possibility of localization of acoustic source [1].

4) UHF detection: In recent year, there has been a fast development in UHF detection technology. Discharge can be understood as electromagnetic events which are extremely fast, transient pulses. The disturbance, being of the order of nanoseconds, causes a pulsed radiation, having measurable energy levels in the gigahertz range. PD is detected by means of the electromagnetic transients radiated within the frequency range 300-3000 MHz (UHF). UHF sensors measure these signals which can be further analyzed and processed. The UHF frequency range in particular is adopted in gas insulated system.

V. SIMULATION MODEL OF PD

The PD circuit that has been used in this project came from a conventional circuit proposed by Gemant & philippoff in 1932. The circuit is also known as 3 capacitance model. The model was then reconstructed in order to consider the addition electric field generated by preceding discharges, as can be seen in Fig 5.

Table I
Value of Circuit Component In Ac Source For Simulation

<table>
<tr><td colspan="2" rowspan="4">AC V in(kV)
50Hz</td><td>10</td></tr>
<tr><td>20</td></tr>
<tr><td>30</td></tr>
<tr><td>40</td></tr>
<tr><td colspan="2">Rin</td><td>5kΩ</td></tr>
<tr><td colspan="2">C_1</td><td>10pF</td></tr>
<tr><td colspan="2">C_2</td><td>20pF</td></tr>
<tr><td colspan="2">C_3</td><td>15pF</td></tr>
<tr><td colspan="2">C_4</td><td>1pF</td></tr>
<tr><td colspan="2">R_1</td><td>10kΩ</td></tr>
<tr><td colspan="2">R_2</td><td>5kΩ</td></tr>
<tr><td rowspan="2">Breaker Timing (second)</td><td>Open</td><td>1/60</td></tr>
<tr><td>Close</td><td>1/50</td></tr>
</table>

The capacitor C_4 is charged from the capacitor C_1 during the PD process until the two voltages are equal. A consecutive discharge occurs only if the voltage reaches the ignition voltage of the spark gap. The value of components in the circuit for the simulation is described in Table I. This circuit was implemented with Simulink application in MATLAB software. The spark gap in the Fig 5 has been changed with the breaker in simulation circuit as shown in Fig 6; this breaker is set with certain time value to represent PD occurring time.

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The circuit developed in Simulink application in MATLAB for the experiment is shown in Fig scope 4 is used to observe discharge current, voltage discharge waveform, input voltage. We chose ode23tb with low accuracy to solve the stiff problem.

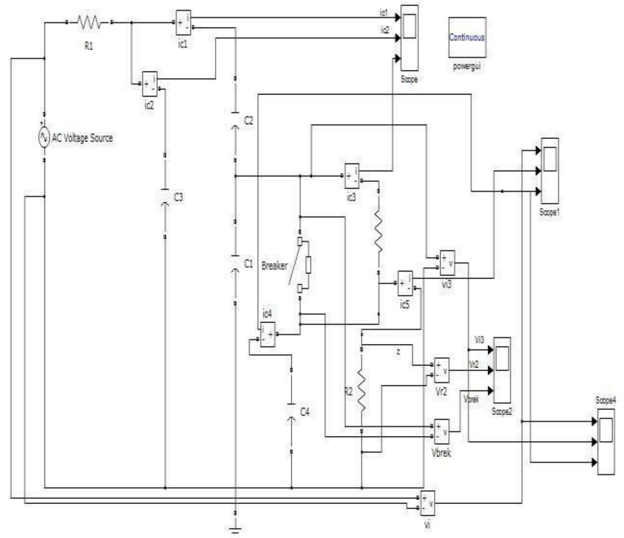

Fig.- 6: Simulation Circuit of PD [9]

VI. RESULTS AND DISCUSSION

The simulation was run for 0.06 second. The applied voltage frequency was set to 50Hz. The results of the simulation are shown in Fig. 6 for each applied voltage (30, 60,90,120,150 and 180kV respectively) which were observed from scope 1 to 3 respectively. From the results, discharges vary at every input voltage. For an increasing AC source, the amplitude of waveform in sampling resistance increased, as well as the single discharges waveform in a void. We observed that the discharge current is proportional with the input voltage. All discharge currents and discharge voltages occurred in nano-seconds. The discharge occurred once because of the non-repetitive switching mode of the breaker .To make the switching more frequent, it is necessary to replace the breaker with a circuit appropriate for repetitive switching.

Table II
Current Discharge Corresponding With Applied Input Voltage

Applied input voltage (kV)	Current discharge(amp)
30	46.5
60	93.0
90	136.5
120	217.5
150	237
180	286.5

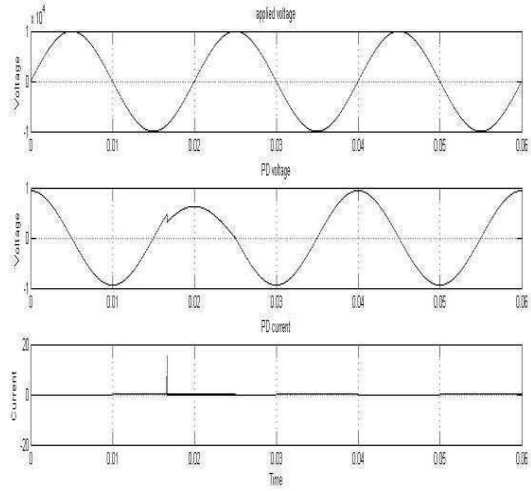

Fig.- 7: Result of Simulation of Applied Voltage 30kV

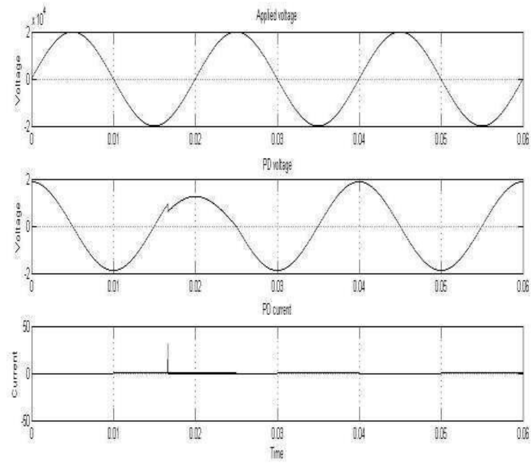

Fig.- 8: Result of Simulation of Applied Voltage 60kV

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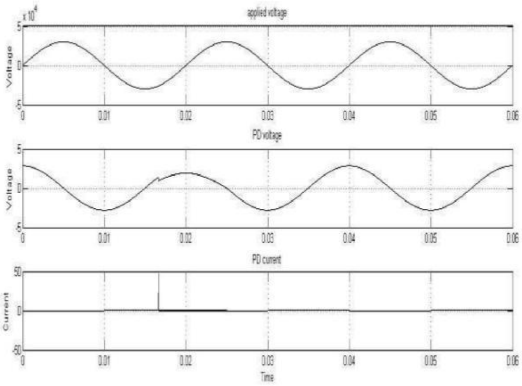

Fig.- 9: Result of Simulation of Applied Voltage 90kV

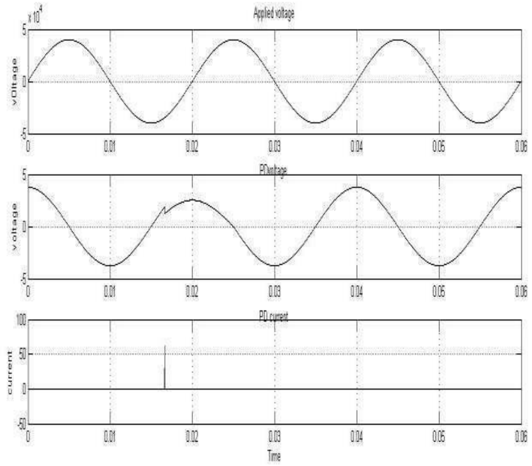

Fig.- 10: Result of Simulation of Applied Voltage 120kV

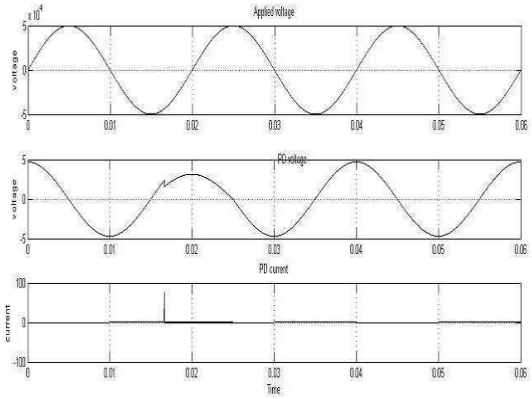

Fig.- 11: Result of Simulation of Applied Voltage 150kV

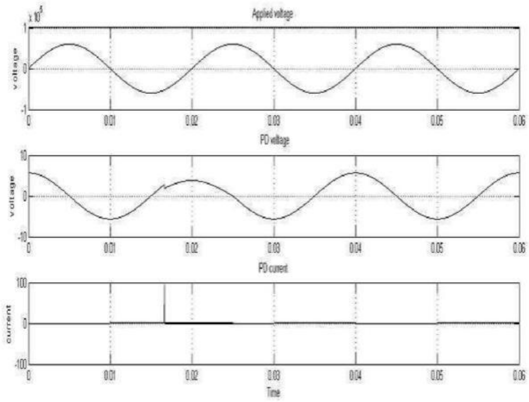

Fig.- 12: Result of Simulation of Applied Voltage 180kV

VII. PRINCIPLE OF ACOUSTIC PD DETECTION

The wave propagates through material media enclosing the region of emission, before reaching the enclosure of the electrical equipment. High frequency acoustic emission sensors mounted on the walls of the container pick up these vibrations of the surface wave and convert it into electrical signals, which could then be captured by appropriate instrumentation and analyzed by a processing system. The shape of the detected signal depends on the source, the propagation media, the detection equipment, and the acoustic emission sensors [1].

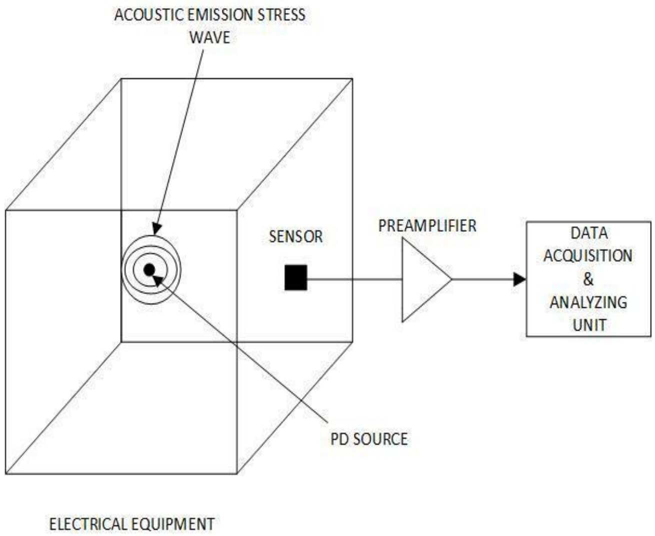

Fig.- 13: Principle of Acoustic Emission Technique

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VIII. ANALYSIS OF ACOUSTIC PROPAGATION PATH

A transformer tank is 100 cm X 100 cm X 100 cm. A transformer tank is made up of steel. Acoustic sensor mounted on the tank. Speed of the waves traveling in transformer oil (1415 m/s) and In transformer tank metal or steel (5900 m/s)[1].

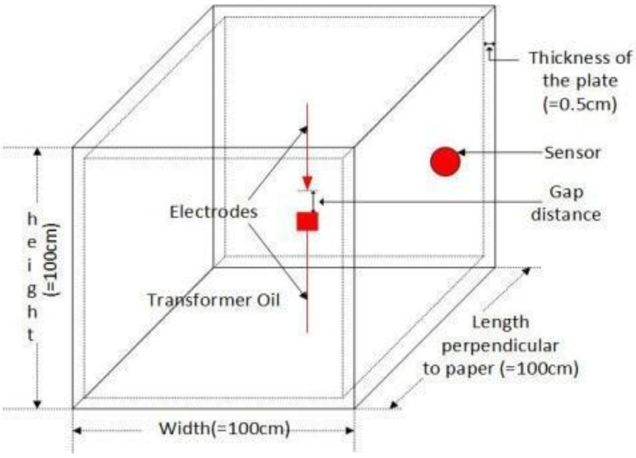

Fig.- 14: Schematic Diagram of The Experimental Model

IX. DIRECT PATH

It is defined as the path in which the acoustic signals travel along a direct, straight line route from the source to the sensor. Direct path mainly comprises of the distance travelled in the oil and a relatively very small distance travelled in the tank metal.

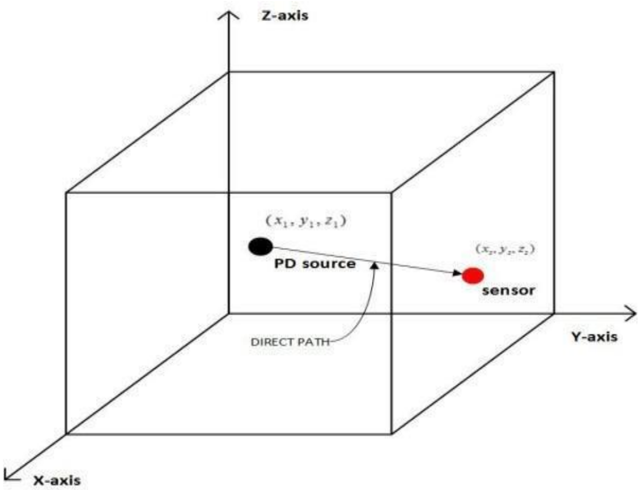

Fig.- 15: Illustration of Direct Path

If the coordinates of the sensor are (x_s , y_s , z_s) and the coordinates of the PD source are (x_1 , y_1 , z_1) and the direct path distance is „dd"; then, from (Figure 15) the direct path distance between the sensor and the source of PD is given by:

Direct Path Distance:

The time taken by the shortest path acoustic emission signals is given by:

Time taken: $dd = \sqrt{(x_{s1} - x)^2 + (y_{s1} - y)^2 + (z_s - z_1)^2}$ cm.......(1)

$$T_{direct} = \frac{dd}{141500} \text{ sec}$$

Where the velocity of the wave in oil is 141500 cm/s

X. INDIRECT PATH

It can be seen from that the acoustic waves hitting the nearby tank wall create an alternate propagation path via the tank walls to the sensor. As the acoustic wave hits the tank wall, its frequency characteristics remain the same, but its mode of propagation and propagation speed change. Indirect path comprises of the structure borne path as well as the path travelled in the oil. In majority of the cases the structure-borne path is larger than the oil borne path. As the speed of the wave in the tank metal is greater than that in oil, the wave traveling along the structure-borne path arrives at the sensor earlier than the wave traveling along the direct acoustic path in most of the cases.

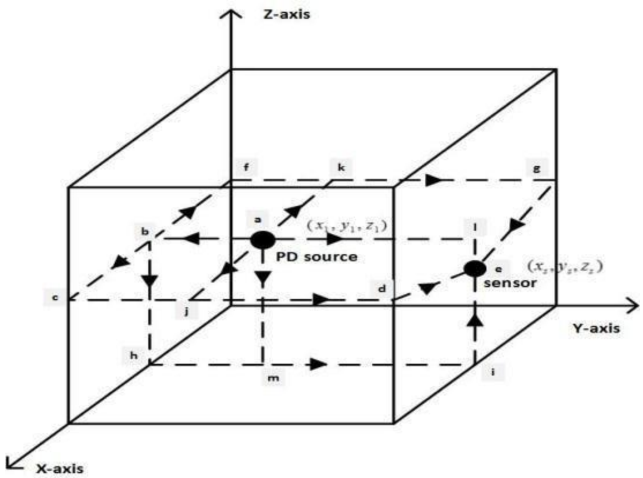

Fig.- 16: Possible Propagation Paths

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To determine the shortest time path for indirect path acoustic emission signals it should be understood that the signals can impinge on any one of the tank surface and follow the structure borne path. Thus, the equations are given for sensor (x_s,y_s,z_s) and the coordinate of PD source are (x_1,y_1,z_1) Then, the equation to determine the path for shortest time are given by Equation Set 1, which consists of (2),(3),(4),(5),(6),(7),(8)[6].

Equation Set 1,

For path 11 (abcde):

$$T_{11} = \left(\frac{y}{141500}\right) + \left(\frac{x_1 + 100 + \sqrt{(x_1 - x_s)^2 + (z_1 - z_s)^2}}{590000}\right)$$

For path 12 (abfge):

$$T_{12} = \left(\frac{y}{141500}\right) + \left(\frac{(100 - x_1) + 100 + \sqrt{(100 - x_s)^2 + (z_1 - z_s)^2}}{590000}\right)$$

For path 13 (abhie):

$$T_{13} = \left(\frac{y}{141500}\right) + \left(\frac{z_1 + 100 + \sqrt{(z_1 - z_s)^2 + (x_1 - x_s)^2}}{590000}\right)$$

For path 2 (ajde):

$$T_{2} = \left(\frac{x}{141500}\right) + \left(\frac{(100 - y_1) + \sqrt{(x_1 - x_s)^2 + (z_1 - z_s)^2}}{590000}\right)$$

For path 3 (akge):

$$T_{3} = \left(\frac{100 - x}{141500}\right) + \left(\frac{(100 - y_1) + \sqrt{(100 - x_s)^2 + (z_1 - z_s)^2}}{590000}\right)$$

For path 4 (ale):

$$T_{4} = \left(\frac{100 - y}{141500}\right) + \left(\frac{\sqrt{(x_1 - x_s)^2 + (z_1 - z_s)^2}}{590000}\right) \text{sec} \ldots\ldots(7)$$

For path 5 (amie):

$$T_{5} = \left(\frac{z}{141500}\right) + \left(\frac{(100 - y_1) + \sqrt{(z_s)^2 + (x_1 - x_s)^2}}{590000}\right)$$

The acoustic sensor position is fixed at (16,10,50)cm. The PD source is varied along (x,y,z) coordinates and the corresponding indirect paths for shortest time computed theoretical from equation. The acoustic sensor positions are fixed (48 cm, 60 cm, 30 cm). The PD source is varied and (60,100,50) corresponding time and distances are computed analytical by following methods mentioned in Table III.

TABLE II
THEORETICAL RESULT

PD point (x_1,y_1,z_1)	Indirect Path (m)	Direct Path (m)	Indirect path time (s)*10^{-04}	Direct path time (s)*10^{-04}
(16,10,50)	1.42	1.03	3.80	7.34
(16,60,50)	0.92	0.65	2.96	4.64
(40,60,50)	0.68	0.48	3.30	3.45
(50,60,70)	0.66	0.48	3.28	3.45
(60,10,60)	1.02	0.90	3.64	6.42
(68,20,50)	0.80	0.80	4.16	5.65
(60,50,50)	0.58	0.50	3.67	3.57

XI. CONCLUSION

In this paper given theoretical background of PD and its detection method and their comparison also their advantages and disadvantages. The simulation conducted showed that the PD equivalent circuit was able to represent the behavior of PD in solid dielectric. This circuit is more accurate because the local discharge accumulation generated by preceding discharge. There is a slight difference of voltage waveform and current discharge in the void from the original model. This is due to the timing mode of the breaker. Breaker cannot simulate the perfect timing for PD to occur. The value of discharge current is dependent on the input voltage. If the input voltage increased that the discharge current will be increase. The paper analyzes behavior of acoustic propagation path in direct path and indirect path. In which direct path and indirect path shortest time of path given for any mode of propagation.

REFERENCES

[1] T. S. Ramu, H. N. Nagamani, "Partial discharge based condition monitoring of high voltage equipment" New Age International Publishers, Delhi, 2010.

[2] G. C. Stone, "Partial Discharge - Part VII: Practical Techniques for Measuring PD in Operating Equipment," in IEEE Electrical Insulation Magazine, vol. 7, 1991, pp. 9-19.

[3] M. S. Naidu, V. Kamaraju, "High voltage engineering", McGraw Hill Companies, Ninth reprint, 2011.

[4] I. J. Kemp, "Partial discharge plant-monitoring technology: Present and future Developments," IEE Proc.-Sci. Meas. Technology, vol. 142, pp. 4-10, 1995.

[5] M. Duval, "Dissolved Gas Analysis: It Can Save Your Transformer," in IEEE Electrical Insulation Magazine, vol. 5, 1989, pp. 22-27.

[6] Prathmesh Dhole, Tanmoy Sinha, Sumeet Nayak, Prasanta Kundu, N.K.Kishore, "Analysis of propagation paths of partial discharge acoustic emission signals", Fifteenth National Power Systems Conference (NPSC), IIT Bombay, December 2008.

[7] http://www.partial-discharge-academy.com/ - accessed on Feb 17, 2014.

[8] Mr. N.J.Patel, Prof. K.K.Dudani, Prof. A.K.Joshi, "Partial discharge detection-An Overview", Journal Of Information, Knowledge And Research In Electrical Engineering, vol. 02, issue-02.

[9] Y.Z.Arief, W.A.Izzati, Z.Adzis, "Modeling of Partial Discharge Mechanisms in Solid Dielectric Material", International Journal of Engineering and Innovative Technology (IJEIT), Volume 1.Issue 4, April 2012.

[10] Prasanta Kundu, N.K.Kisore and A.K.Sinha "Simulation and Analysis of Acoustic Wave Propagation due to Partial Discharge Activity"**.** Department of Electrical Engineering, Indian Institute of Technology, Kharagpur, India. Annual Report Conference on Electrical Insulation and Dielectric Phenomena.

[11] Su-Yeon Choi, Dae-Won Park, II-Kwon Kim, Chan-Yong Park and Gyung-Suk Kil, "Analysis of Acoustic Signals Generated by Partial Discharges in Insulation Oil", International Conference on Condition Monitoring and Diagnosis, Beijing, China, April 21-24,2008

[12] Prathmesh Dhole, Tanmoy Sinha, Sumeet Nayak, Prasanta Kundu, N.K.Kishore, "New Approach Of Sensor Positioning for Optimizing Source Location of Partial Discharge", in IEEE 2011