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Partial Discharge Analysis of a Solid Dielectric Using MATLAB Simulink

C Sunil kumar[1], Harisha K S[2], Gouthami N[3], Harshitha V[4], Madhu C[5]

Assistant Professor, E&E Department, PESCE, Mandya, Karnataka, India [1]

UG Student, E&E Department, PESCE, Mandya, Karnataka, India [2, 3, 4, 5]

Abstract: Insulators plays an important role in the high voltage power equipment. Various types of insulators are used in high voltage (HV) electrical power system to protect the power equipment. For the purpose of safety and better efficiency, insulators should be kept in a healthy condition during its operation [1]. As the insulators are always in impure form due to presence of impurities inside the insulators, the local electrical breakdown known as partial discharge (PD) takes place due to the HV stresses. The magnitude of these discharges though small, but can cause progressive deterioration and ultimate failure and hence it is essential to detect these discharges as nondestructive control test to keep the high voltage power equipment in healthy condition. In this work, an electrical circuit model of an epoxy resin as an insulator with a cylindrical void as an impurity is taken for the analysis of actual PD activity inside the insulator with respect to the application of high voltage using MATLAB Simulink software [3].

Key words: PD (partial discharge), Void, HV, C_a, C_b, C_c.

INTRODUCTION

The insulation plays a vital role in high voltage power system equipment. One of the major problems in HV power system is PD which may leads to breakdown of insulation. Due to PD the efficiency of power system engineering equipments deteriorates. For the better efficiency, the insulators should be kept in a healthy condition during its operation. As the insulators are always in impure form, the local electrical breakdown which bridges the insulation between electrodes called PD will takes place due to the high voltage stresses. Due to PD, failure of insulation arises and the properties of such insulators deteriorate enormously [3]. Finally, the breakdown will take place and entire power system is collapsed. Thus most effective way to assess the insulation condition of HV equipment is PD monitoring .In this work, an electrical circuit model of an epoxy resin (i.e., an insulator) with a cylindrical void(i.e., an impurity) is taken for the analysis of actual PD activity inside the insulator with the application of high voltage using MATLAB Simulink software. In this study, the maximum amplitude of PD, PD pulses at different applied voltages, number of PD's with respect to phase angle and apparent charge transfer for different applied voltage is studied [3].

PARTIAL DISCHARGE

According to IEC (International Electro technical Commission) Standard 60270**, Partial discharge is a localized electrical discharge that only partially bridges the insulation between conductors and which may or may not occur adjacent to a conductor** [1].

Types of Partial Discharge

Electrical discharges which do not bridge electrodes are called partial discharges [1]. Between the discharger and one or both electrodes, a sound dielectric is present in form of a solid, liquid or gaseous Insulator. These discharges may be in cavity of a solid dielectric or from an electrode to the surface of a solid insulating material or discharges may be around a sharp point at HV. These discharges are known as Internal, Surface and corona discharges as shown in Fig1.

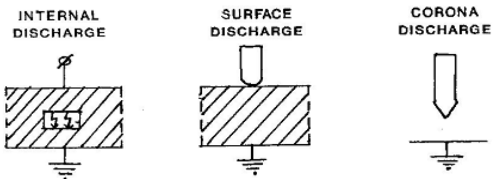

Fig1: Different Discharge Phenomena

Sequential Breakdown under Sinusoidal Alternating Voltages: [4]

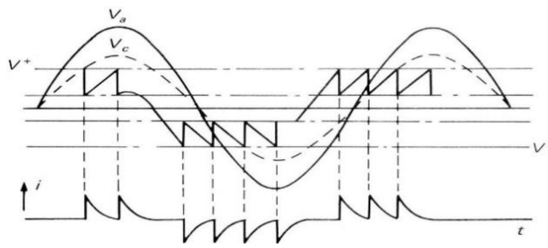

Fig2: Discharge current and voltage waveforms

V_a - voltage across the healthy part, V_c - voltage across the void, v^+ - Inception voltage$^-$ - extinction voltage.

Sample preparation:
An epoxy resin insulator with void inside is considered having dimensions 100mm, 40mm and 50mm. The void having dimensions of 20mm and 10mm. As the electrical circuit model consists of three capacitors the values of these capacitors are calculated by following equations.[8]

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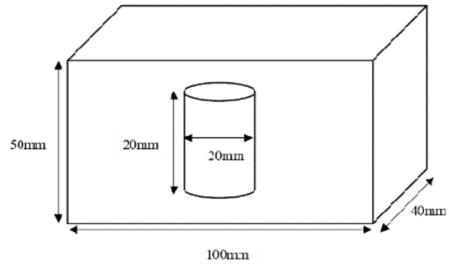

Fig3: Void model of epoxy resin insulator

$$C_a = \frac{\varepsilon_0 \times \epsilon_r \times (a - 2b) \times b}{c}$$

$$C_b = \frac{\varepsilon_0 \times \epsilon_r \times r^2 \times \pi}{c - h}$$

$$C_c = \frac{\varepsilon_0 \times r^2 \times \pi}{h} \quad [3]$$

Where ε_0 = absolute permittivity

ε_r = relative permittivity

C_a=4.9582*10^{-13}, C_b=3.2451*10^{-13}, C_c=1.3907*10^{-13}

Simulation Model of Experimental setup:

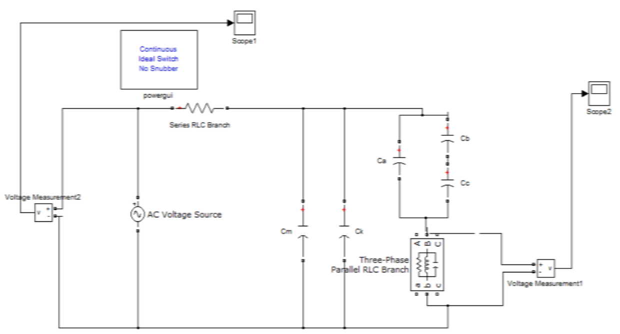

Fig4: Simulink model

The calculated capacitance values are required to get desire partial discharge characteristics. Here an equivalent circuit of solid insulator having a cylindrical shape void is taken to evaluate the partial discharge characteristics. Generally (C_a>>C_b>>C_c). The Simulink model for detecting partial discharge characteristics is shown in figure4.

C_a, C_b and C_c together constitutes test object. Where capacitor C_C represents capacitance of the void in the test object. Capacitor C_b represents capacitance of the healthy part connected in series with the void. Capacitor C_a represents the capacitance of the healthy part leaving C_c and C_b. Cm refers to the measuring capacitor and Ck refers to the coupling capacitor.

The model drawn in Fig.4 is simulated using MATLAB. When high voltage is applied across the test object, voltage across the dielectric Va is increased thereby the voltage Vc across the cavity also increases. When Vc reaches breakdown voltage, discharge in the void occurs. The voltage across the sample at which discharges begin to occur is called **Inception voltage.**

In Fig. 4 the partial discharge pulses in µv are seen in scope2 which is connected through voltage measurement 1 across matching impedance. The applied input voltage is measured through voltage measurement 2 and witnessed in scope 1.

In this study the value of void model and the other HV equipment for the measurement of PD inside the solid insulation is taken as depicted in table1

Table1: Parameters used for simulation

Sl. No	Parameter	Symbol	Value	Dimension
1	HV measuring capacitor	C_m	1000	pF
2	Coupling capacitor	C_k	1000	µF
3	Permittivity	ε_o	8.85X 10^{-12}	F/m
4	Relative permittivity	ε_r	3.5	-
5	Resistance	R	50	Ω
6	Inductance	L	0.60	mH
7	Capacitance	C	0.45	µF

RESULT AND DISCUSSIONS

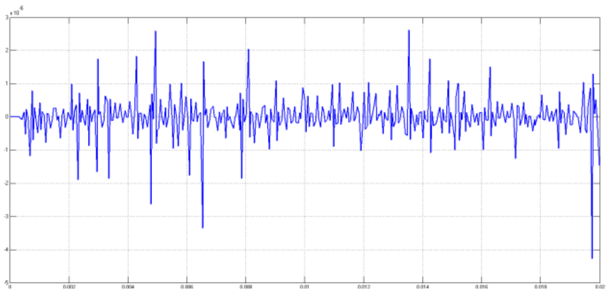
Fig5: observed partial discharge pulse at 5kV

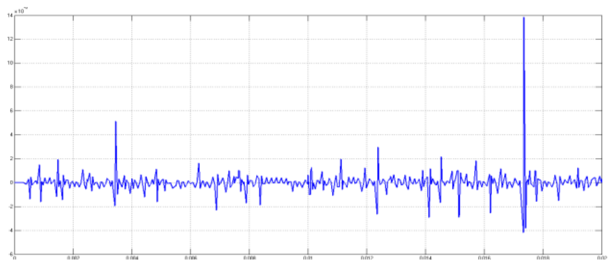
Fig6: observed partial discharge pulse at 10kV

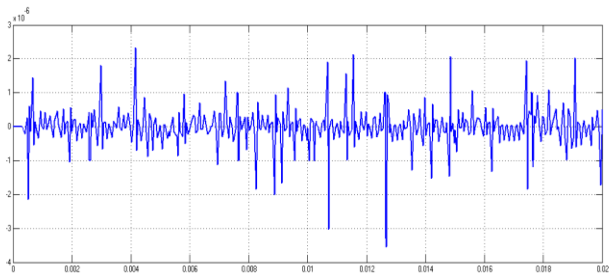
Fig7: observed partial discharge pulse at 15Kv

Figures 5, 6 and 7 shows the PD characteristics for the applied voltage of 5kV, 10kV and 15kV respectively.

When 3kV supply is applied across the test object, it is observed that between time period 0.01 to 0.012 sec, the amplitude of PD pulse corresponds to 3.66 µv.

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When 8kV supply is applied across the test object, it is observed that between time period 0.014 to 0.016 sec, the amplitude of PD pulse corresponds to 3.64 µv.

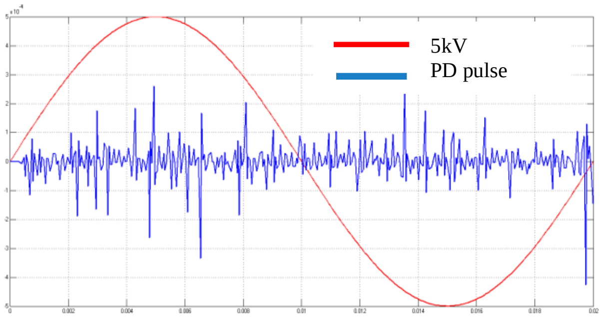

Fig8: merged input and output PD pulse at 5kV

An increasing voltage of 0-9 kV is applied across the solid insulation to observe the maximum amplitude PD pulses. The corresponding data found is depicted in Table 2 and graph has been plotted as shown in figure 9. From the graph it is observed that maximum amplitude of 15.71 µV is obtained at 9 kV of applied voltage.

TABLE2: Max PD values with different applied voltages

Sl. No	Applied voltage In kV	Max.PD amplitude in **µv**
1	1	3.39
2	2	1.59
3	3	3.66
4	4	2.79
5	5	2.621
6	6	2.55
7	7	2.31
8	8	3.64
9	9	15.71

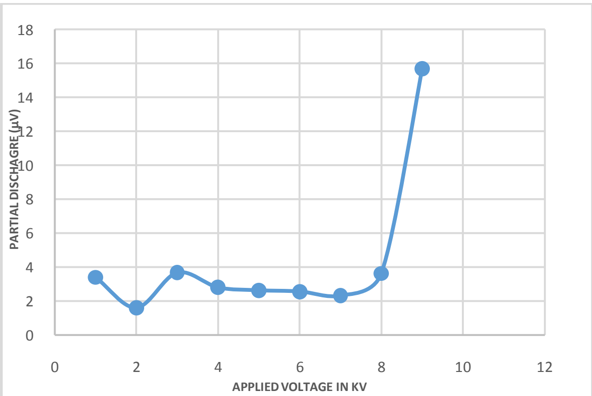

Fig9: Max PD Amplitude with different applied voltage

The partial discharge pulses are analyzed by dividing single applied sinusoidal cycle of 50 Hz into eight equal parts. Each part has 45^0 phase angle interval. The number of PD pulses for each interval is plotted for different applied voltages. Figures (10, 11 &12) shows graph for number of PD pulses v/s different phase angle for different applied voltages (i.e, 5kV, 10kV and 15kV). The partial discharge phenomenon is random in nature so the number of PD pulses is not constant for every cycle

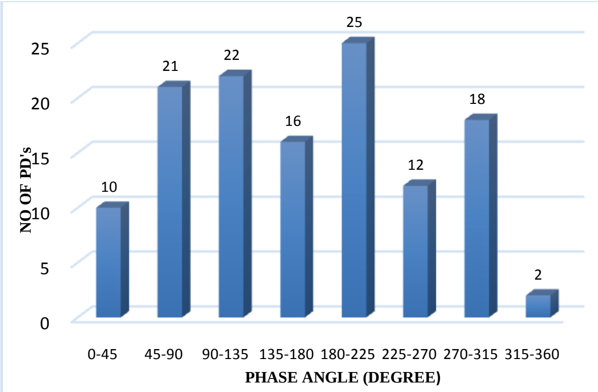

Fig10: PD pulses at different phase angle with applied voltage of 5kV

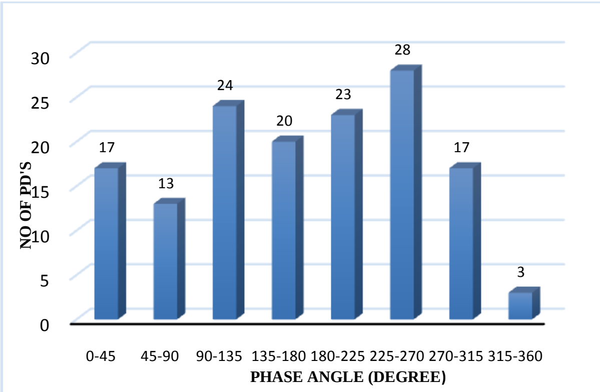

Fig11: PD pulses at different phase angle with applied voltage of 10kV

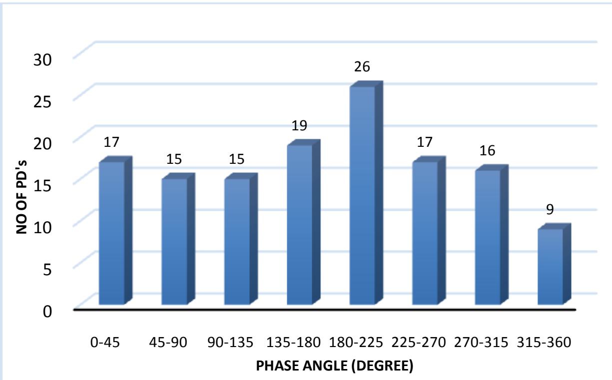

Fig12: PD pulses at different Phase angle with applied voltage of 15kV.

TABLE 3: Number of Partial discharge at different applied voltages at phase angles

SL. NO	PHASE ANGLE IN DEGREE	5KV	10KV	15KV
1	0-45	10	17	17
2	46-90	21	13	15
3	91-135	22	24	15
4	136-180	16	20	19
5	181-225	25	23	26
6	226-270	12	28	17
7	271-315	18	17	16
8	316-360	02	03	09

Further the partial discharge pulses with different phase angle for different applied voltages ranging from 5-10 kV are tabulated in table3.

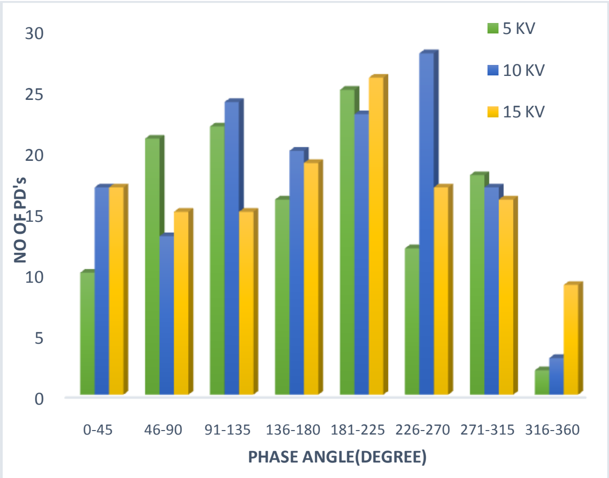

Figure 13: Partial discharge pulses at different phase angle with different applied voltage

Voltage across the test object (V_c) is measured and applied to a subsystem in MATLAB simulink created as per the formula below.

Voltage across the cylindrical void Cc is given by

$$V_c = \frac{V_a \times C_b}{C_a + C_b} \qquad [3]$$

The apparent charge transferred is calculated by

$$Q = C_a \times V_c \qquad [3]$$

TABLE4: Apparent charge transfer at different applied voltage

Applied Voltage(KV)	Apparent Charge(pC)
1	0.40
2	0.81
3	1.22
4	1.63
5	2.04
6	2.45
7	2.86
8	3.26
9	3.67
10	4.08
11	4.49
12	4.90
13	5.31
14	5.72
15	6.12

The obtained apparent charge through Matlab subsystem is tabulated and graph is plotted against applied input voltages. It is observed that as the applied voltage increases, the apparent charge transferred increases linearly.

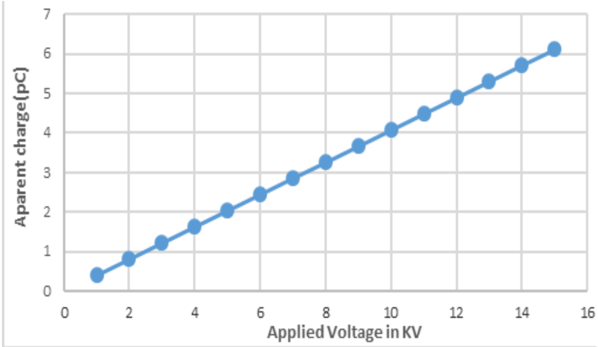

Fig14: Charge Transfer with respect to applied input voltage

CONCLUSION

Partial discharge is the main problem in high voltage power equipment system. Therefore, detection and measurement of partial discharge is necessary to keep the equipments in healthy condition during their operation. In this work an epoxy resin is taken as a solid insulation material and MATLAB Simulink based model has been adopted to observe the partial discharge activity inside the solid insulation. It is found that with increase in applied voltage across the void, partial discharge increases. This study is employed to find out the maximum partial discharge, Charge transfer with respect to applied voltage, Number of PD pulses with respect to phase angle, Number of PD pulses for different applied voltage. Based on the SIMULINK model partial discharge characteristics are plotted.

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BIOGRAPHIES

C Sunil Kumar completed his Engg. from STJIT, Ranebennur and Masters from NIE Mysore, presently pursuing Ph.D. in University of Mysore, Mysore. Working as Asst. Professor in PESCE, Mandya, Karnataka, India from 2006.

Harisha K S was born on 5th April, 1993. Currently pursuing B.E degree in Electrical and Electronics Engineering in PESCE, Mandya, Karnataka, India

Gouthami N was born on 8th December, 1994. Currently pursuing B.E degree in Electrical and Electronics Engineering in PESCE, Mandya, Karnataka, India.

Harshitha V was born on 15th February, 1995 Degree in Electrical and Electronics Engineering in PESCE, Mandya, Karnataka, India.

Madhu C was born on 9th February, 1993. Currently pursuing B.E degree in Electrical and Electronics Engineering in PESCE, Mandya, Karnataka, India.