

# Comparison of PD Activity in Cylindrical and Cubical Void using MATLAB Simulink

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**Abstract:** Insulators play an important role in high voltage power equipments as they protect the equipments and ensure their reliable operation. The insulator has certain impurities in it such as voids and cracks as no insulator can be completely free from impurities. The insulator when subjected to high voltage degrades in terms of its performance due to the imperfections present in it such as voids. It is linked to occurrence of partial discharge. Partial discharge is nothing but localized electrical discharge that only partially bridges the insulation between conductors and which may or may not occur adjacent to a conductor [1]. It indicates the presence of an imperfection within the insulation. The magnitude of these discharges though small, can cause progressive deterioration and ultimate failure. Considerable efforts have been made so as to analyze PD pulse patterns, PD pattern recognition and charge transfer [5]. Thus while diagnosing insulator for its desired performance partial discharge is an important phenomenon that has to be considered. In this work an electric circuit model of an epoxy resin with void of cylindrical and cubical shape is considered for realization of partial discharge activity inside the insulator with the application of high voltage using MATLAB Simulink environment. The results obtained with cylindrical and cubical void as an impurity is compared and analysed.

**Keywords:** Partial discharge (PD), void, High voltage (HV),  $C_a$ ,  $C_b$  and  $C_c$ .

## 1. INTRODUCTION

The reliability of power system can be increased by improving the performance of insulation provided to it. We know that a good dielectric should possess high mechanical strength, low dielectric losses and also it should be resistant to thermal and chemical deterioration [2]. The suspended impurities, moisture and gaseous inclusions in dielectric have harmful effect on these properties.

The void present creates a weak zone as the dielectric constant of the medium in the voids is lower than that of insulation. This paves path to the occurrence of partial discharge. Heat will be dissipated in each discharge in the void which causes chemical degradation thereby increase in the electric stresses which tends to accelerate the process of breakdown. Partial discharge will not cause immediate insulation failure instead it leads to ageing, progressive deterioration and ultimate failure [3][4].

The monitoring and measurement of partial discharge is extremely necessary for ensuring reliable operation of insulation and prediction of breakdown in insulation. In this work, an electrical circuit model of an epoxy resin (i.e., an insulator) with a void (i.e., an impurity) that is of cylindrical and cubical shape is taken as shown in figure 1 and 2 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, apparent charge transfer for different applied voltages and frequency content of the observed PD pulse is studied. Also the results obtained is compared and analysed.

### **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].

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.

### **Sample preparation:**

As the electrical circuit model consists of three capacitors the values of these capacitors are calculated by following equations. [3][5].

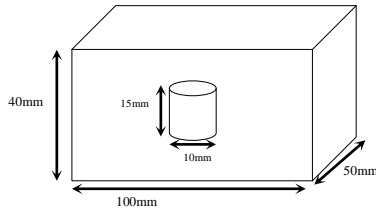


Fig 1: Void model of epoxy resin insulator with cylindrical void

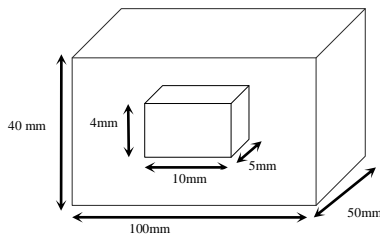


Fig 2: Void model of epoxy resin insulator with cubical void

Formulas for Cylindrical void:

$$C_a = \frac{\epsilon_0 \times \epsilon_r \times (a - 2r) \times b}{c}$$

$$C_b = \frac{\epsilon_0 \times \epsilon_r \times r^2 \times \pi}{c - h}$$

$$C_c = \frac{\epsilon_0 \times r^2 \times \pi}{h} \quad [3]$$

Formulas for Cubical void:

$$C_a = \frac{\epsilon_0 \times \epsilon_r \times A}{d}$$

$$C_b = \frac{\epsilon_0 \times \epsilon_r \times A}{d - t}$$

$$C_c = \frac{\epsilon_0 \times A}{t} \quad [1]$$

Where  $\epsilon_0$  = absolute permittivity  
 $\epsilon_r$  = relative permittivity

Calculated capacitance	Cylindrical void	Cubical void
$C_a$	$3.098 \times 10^{-12}$	$3.8736 \times 10^{-14}$
$C_b$	$3.8941 \times 10^{-13}$	$4.3040 \times 10^{-14}$
$C_c$	$1.854 \times 10^{-13}$	$1.1067 \times 10^{-13}$

**2. EXPERIMENTAL SETUP**

The calculated capacitance values are required to get desire partial discharge characteristics. Here an equivalent circuit of solid insulator having a cylindrical shape void and cubical shape void is taken to evaluate the partial discharge characteristics. The Simulink model

for detecting partial discharge characteristics is shown in figure 3.

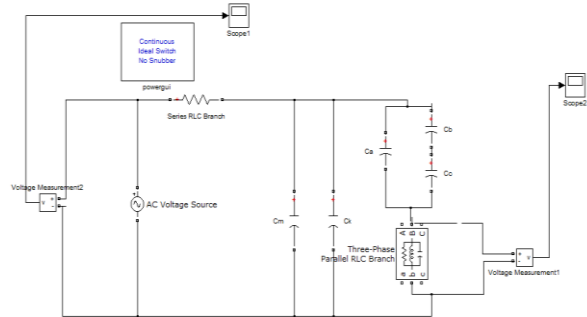


Fig 3: Simulink model [4]

$C_a$ ,  $C_b$  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  $C_b$ .  $C_m$  refers to the measuring capacitor and  $C_k$  refers to the coupling capacitor.

The model drawn in figure 3 is simulated using MATLAB. When high voltage is applied across the test object, voltage across the dielectric is increased thereby the voltage across the cavity also increases. When reaches inception voltage, discharge in the void occurs. The voltage across the sample at which discharges begin to occur is called **Inception voltage** [4].

In figure 3 the partial discharge pulses in  $\mu V$  are seen in scope2 which is connected through voltage measurement1 across matching impedance. The applied input voltage is measured through voltage measurement 2 and witnessed in scope 1.

In this study the values of HV equipments used for the measurement of PD inside the solid insulation is taken as depicted in Table1[5].

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	$\mu F$
3	Permittivity	$\epsilon_o$	$8.85 \times 10^{-12}$	F/m
4	Relative permittivity	$\epsilon_r$	3.5	-
5	Resistance	R	50	$\Omega$
6	Inductance	L	0.60	mH
7	Capacitance	C	0.45	$\mu F$

**3. RESULT AND DISCUSSIONS**

Table2: Max PD values with different applied voltages

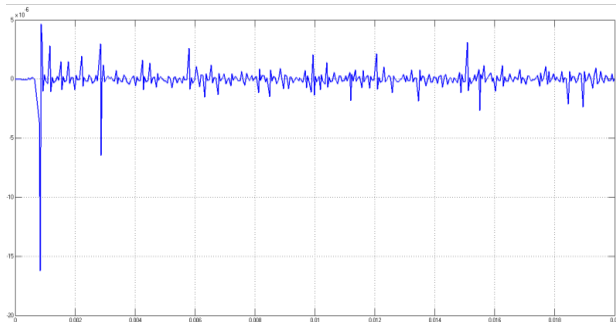


Fig 4: observed partial discharge pulse of cylindrical void at 10kV

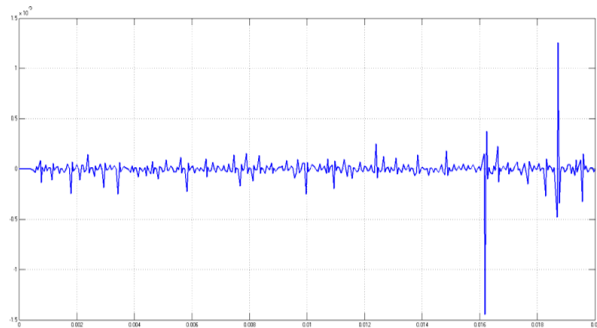


Fig 5: observed partial discharge pulse of cubical void at 10kV

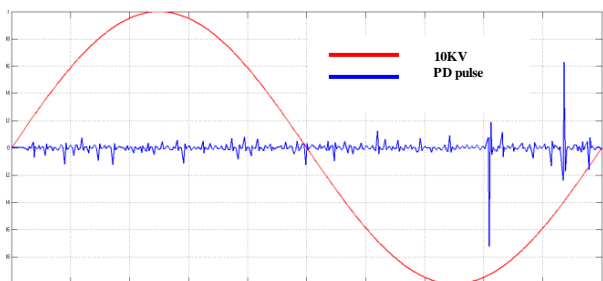


Fig 6: merged input and output PD pulse of cubical void at 10kV

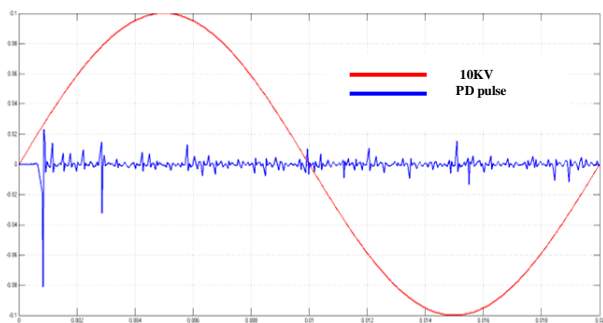


Fig 7: merged input and output PD pulse of cylindrical void at 10kV

It is observed that the region in which the PD activity is higher differs in cylindrical and cubical void from the figure 6 and 7.

Applied Voltage (kV)	Maximum PD amplitude in cylindrical void	Maximum PD amplitude in cubical void
5	2.63	4.008
10	4.67	12.55
15	3.088	3.632
20	3.12	3.16
25	5	3.492
30	4.79	13.46

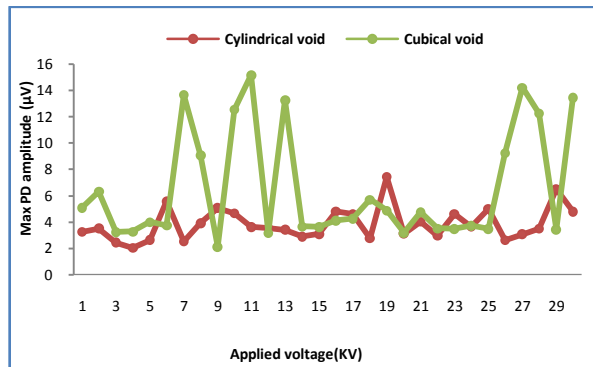


Fig 8: PD Amplitudes of cylindrical and cubical void with different applied voltages

It is observed that amplitude of PD is maximum in case of cubical void for the specified dimensions when compared to that of cylindrical void.

The partial discharge pulses are analyzed by dividing single sinusoidal applied cycle of 50 Hz into eight equal parts. Each part has 45° phase angle interval. The numbers of PD pulses for each interval are plotted for different applied voltages. Figures 9 and 10 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 numbers of PD pulses are not constant. [5]

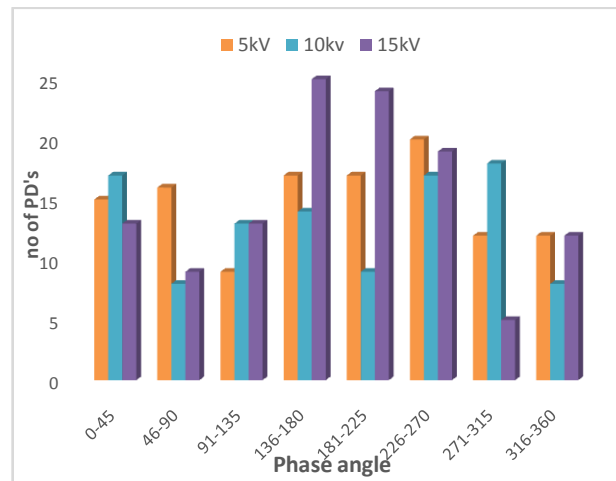


Figure 9: Partial discharge pulses at different phase angle with different applied voltages in cylindrical void.

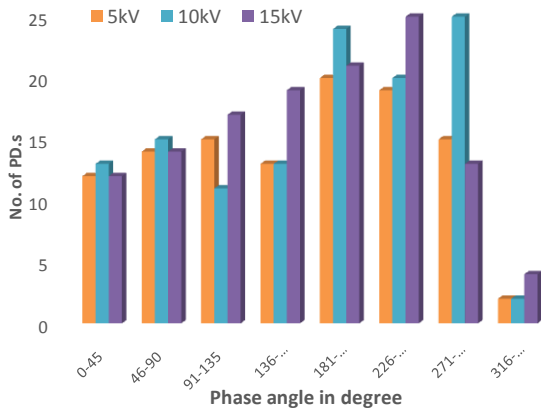


Fig 10: Partial discharge pulses at different phase angle with different applied voltages in cubical void.

It is observed that the PD activity is higher for applied voltage of 15kV when compared to the PD activity for applied voltages 5kV and 10kV. Also there is decrease in the number of PDs in case of applied voltage being 15kV after phase angle exceeds 315° as indicated from figure 9 and 10.

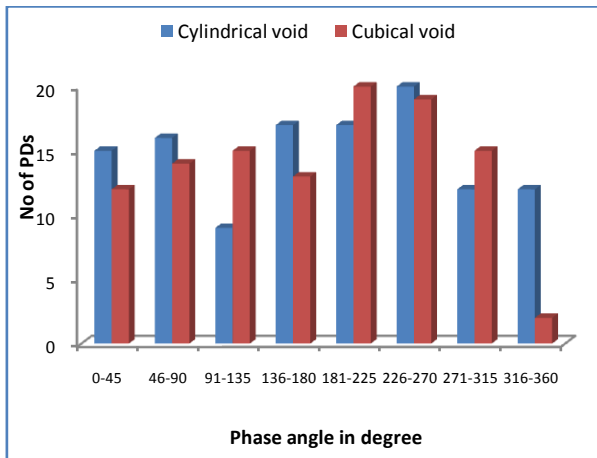


Fig 11: Partial discharges pulses at different phase angle of cylindrical and cubical void at 5kV of applied voltage.

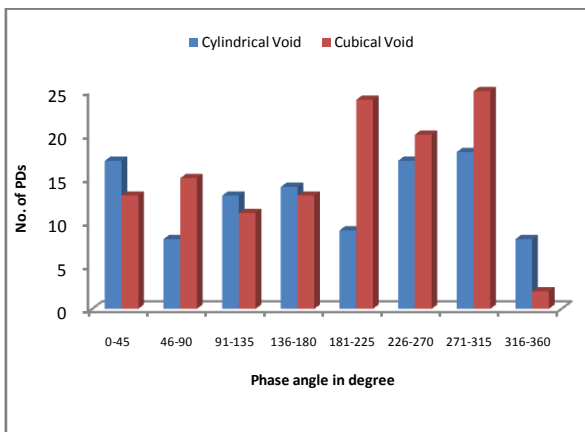


Fig 12: Partial discharges pulses at different phase angle of Cylindrical and cubical void at 10kV of applied voltage.

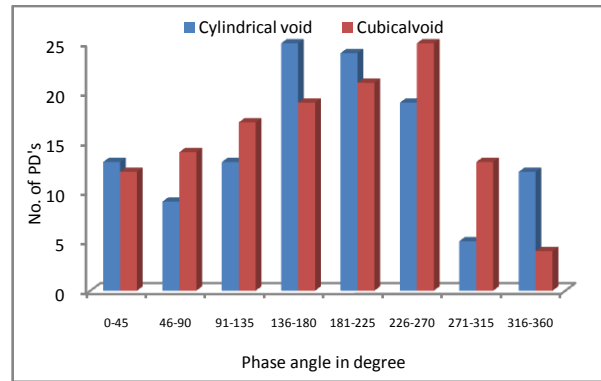


Fig 13: Partial discharges pulses at different phase angle of Cylindrical and cubical void at 15kV of applied voltage

It is observed that between the phase angle from 180° to 315° the number of PDs is greater in cubical void compared to cylindrical void. Whereas between the phase angle 315° to 360° the number of PDs is greater in cylindrical void compared to cubical void.

Table 3: Number of PD's at different applied voltages at different phase angles at 10kV of applied voltage

Sl. No.	Phase Angle in Degree	Cylindrical Void	Cubical void
1	0-45	17	13
2	46-90	8	15
3	91-135	13	11
4	136-180	14	13
5	181-225	9	24
6	226-270	17	20
7	271-315	18	25
8	316-360	8	2

Voltage across the void  $V_a$  is measured and applied to a subsystem in MATLAB Simulink created as per the formula below.

Voltage across the cylindrical void  $V_c$  is given by

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

The apparent charge transferred is calculated by

$$Q = C_b \times V_c \quad [3]$$

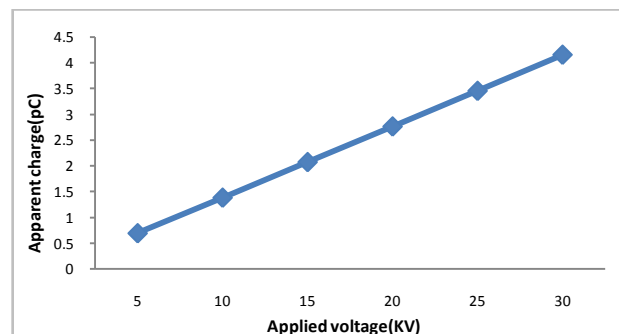


Fig 14: Apparent charge transfer in cylindrical void at different applied voltages

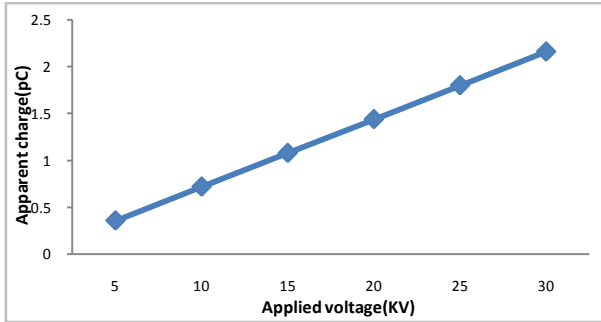


Fig 15: Apparent charge transfer in cylindrical void at different applied voltages

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 [6].

Table 4: Apparent charge transfer at different applied voltages

Applied Voltage (kV)	Apparent Charge in Cylindrical Void	Apparent Charge in Cubical Void
5	$6.91 \times 10^{-13}$	$3.6 \times 10^{-13}$
10	$1.38 \times 10^{-12}$	$7.21 \times 10^{-13}$
15	$2.07 \times 10^{-12}$	$1.08 \times 10^{-12}$
20	$2.76 \times 10^{-12}$	$1.44 \times 10^{-12}$
25	$3.45 \times 10^{-12}$	$1.8 \times 10^{-12}$
30	$4.15 \times 10^{-12}$	$2.16 \times 10^{-12}$

Fast Fourier Transformation (FFT) is used to analyze the frequency content of the obtained PD pulse. The frequency plot of the observed PD pulse with applied voltage of 5 kV is shown in figure 16 and 17. Since PD phenomenon is random in nature so the frequency content of PD pulse is also fluctuating or random. It is also observed that the maximum amplitude of the frequency of the same PD pulse is appearing approximately around 4.8 kHz and 7.5 kHz in case of cubical void which is shown in Fig.16.

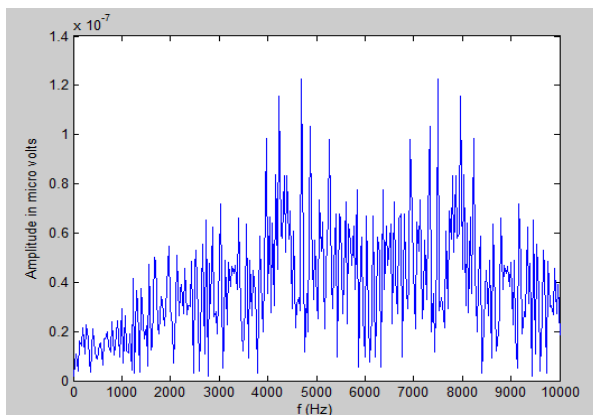


Fig 16: Frequency plot of observed PD pulse at 5 kV Applied Voltage in case of cubical void

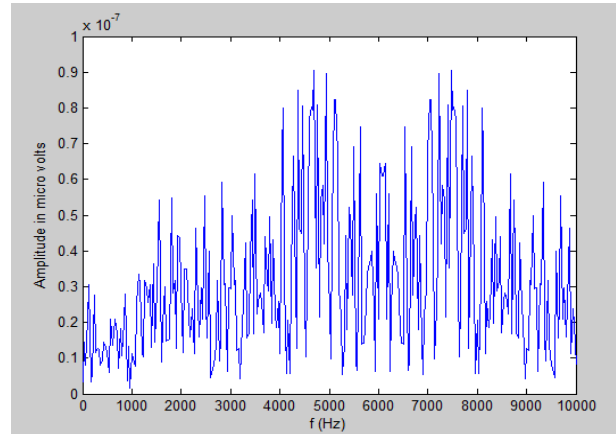


Fig 17: Frequency plot of observed PD pulse at 5 kV Applied Voltage in case of cylindrical void

The dominant frequency of PD appeared because of the time duration of the PD pulses appears for such instance are much shorter compare to the other PD pulse instance present in the observed PD signal [3]. It is also observed that the maximum amplitude of the frequency of the same PD pulse is appearing approximately around 4.5 kHz and 7.5 kHz in case of cylindrical void which is shown in figure 17.

#### 4. CONCLUSION

Detection and measurement of partial discharge is necessary to ensure reliable operation of equipment. In this work, an electrical circuit model of an epoxy resin with a cylindrical and cubical void 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, apparent charge transfer for different applied voltages and frequency content of the observed PD pulse is studied. The results obtained with cylindrical and cubical void as an impurity is compared and analysed. It is observed that the amplitude of PD is maximum in case of cubical void when compared to cylindrical void when the dimensions of void is considered as specified. It is found that with increase in applied voltage across the void charge also increases linearly. The frequency content of PD pulse is also random. Based on the SIMULINK model partial discharge characteristics are plotted.

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### BIOGRAPHIES



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