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PD Analysis in Cubical Void With Respect to Geometry of the Void

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Abstract: The partial discharge (PD) activity inside insulation is the cause of insulation failure. The understanding of PD characteristics will help in improving the performance of insulator in high voltage power system. The presence of void creates a weak zone in the material used for insulating purpose and responsible for the occurrence of PD activity [1]. The PD activity inside an insulator needs to be monitored continuously. The magnitude of PD discharges is usually small and they can cause progressive deterioration which may leads to ultimate failure, hence it is essential to detect their presence as a non-destructive test [4]. Considerable efforts have been made so as to analyze PD pulse patterns, PD pattern recognition and charge transfer [5]. In this work an electric circuit model of an epoxy resin with void of 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 variation in the parameters of the void such as length, height, breadth and volume of the cubical void as an impurity is analysed.

Keywords: Partial discharge (PD), void, High voltage (HV), C_a, C_b, C_c. ℓ-length, b-breadth and t-thickness of void.

1. INTRODUCTION

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]. PD activity inside the void affects the performance of the insulator used. The geometry of void present inside the insulation affects the PD activity by creating a weak zone. The dielectric stress of the void is considerably less than the dielectric stress of its surrounding.

Due to this reason the electric stress across the void is more than across an equivalent distance of dielectric [2]. In this work, an electrical circuit model of an epoxy resin as an insulator with a void of cubical shape is considered for the analysis of PD activity inside the insulator with the application of high voltage using MATLAB Simulink software, as shown in figure 2. In this study, apparent charge transfer with respect to variation in the dimensions of the void (ℓ, b and h), PD amplitude with respect to variation in the dimensions of the void for both positive and negative half cycle of the applied voltage is studied. Also the rise time, fall time and pulse width of the PD pulses are calculated and frequency content of the observed PD pulse is studied.The results obtained with cubical void as an impurity is analysed so as to determine the effect of geometry of cavity or void on PD activity.

Sample preparation:
As the electrical circuit model consists of three capacitors the values of these capacitors are calculated by following equations [1].

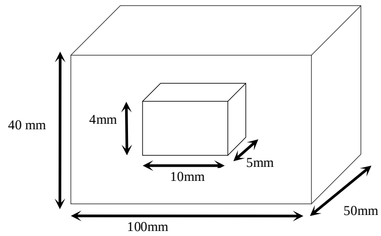

Fig 1: Void model of epoxy resin insulator with cubical void

Formulas for Cubical void:

$$C_a = \frac{\varepsilon_0 \times \epsilon_r \times A}{d}$$

$$C_b = \frac{\varepsilon_0 \times \epsilon_r \times A}{d - t}$$

$$C_c = \frac{\varepsilon_0 \times A}{t}$$

Where ε_0 = absolute permittivity
ε_r = relative permittivity

The values of capacitance is calculated from the equations specified above.

2. EXPERIMENTAL SETUP

The calculated capacitance values are required to get desire partial discharge characteristics. Here an equivalent circuit of solid insulator having a cubical

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shape void is taken to evaluate the partial discharge characteristics. The Simulink model for detecting partial discharge characteristics is shown in figure.

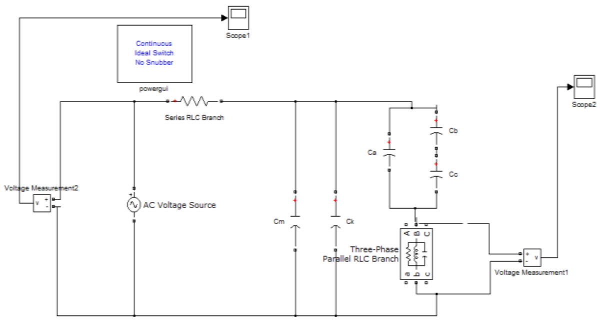

Fig 2: Simulink model

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 C_k refers to the coupling capacitor.

The model drawn in Fig.2 is simulated using MATLAB. When high voltage is applied across the test object, voltage across the dielectric V_a is increased thereby the voltage V_c across the cavity also increases. When V_c reaches inception voltage, discharge in the void occurs. The voltage across the sample at which discharges begin to occur is called **Inception voltage.**

In Fig 2 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 [6].

In this study the values of the HV equipments used 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	Dimen-sion
1	HV measuring capacitor	C_m	1000	pF
2	Coupling capacitor	C_k	1000	μF
3	Permittivity	ε_o	$8.85X10^{-12}$	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

3. RESULT AND DISCUSSIONS

Charge Transfer:

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

Voltage across the cubical void Vc is given by

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

The apparent charge transferred is calculated by

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

The PD activity is not directly measurable therefore apparent charge method is used. According to IEC 60270 apparent charge q of a PD pulse is that charge which if injected in a short time between the terminals of a test object in a specified test circuit, would give the same reading on the measuring instruments as the PD current pulse itself [1].

The apparent charge is usually expressed in pico Coulombs. Figure 3 shows the relation between apparent charge and variation in thickness of the void from 1mm to 10 mm, where the length and breadth of the void is kept constant(ℓ=10mm and b=5mm) at the applied voltage being 30kV.

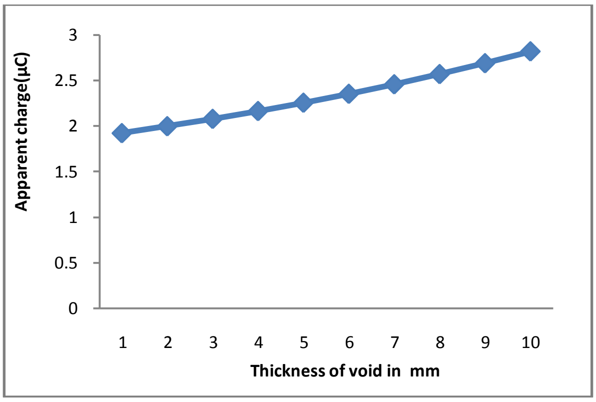

Fig 3: Variation of apparent charge for different thickness of the void, where ℓ and b are constants (ℓ=10mm and b=5mm).

It is observed from figure 3 that as the thickness of void is varied from 1mm to 10mm, the charge transfer has increased from $1.9208*10^{-12}$ to $2.8182*10^{-12}$ C.

Figure 4 shows the relation between apparent charge and variation in length of the void from 1mm to 10 mm where the breadth and thickness of the void are kept constant (b=5mm and t=4mm) at the applied voltage being 30kV. It is observed figure 4 that as the length of void is varied from 1mm to 10mm, the charge transfer has increased from 0.2163 pC to 2.1631 pC.

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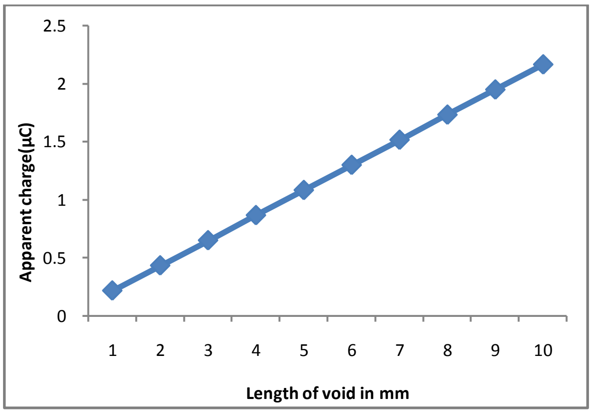

Fig 4: Variation of apparent charge for different length of the void, where b and t are constants (b=5mm and t=4mm).

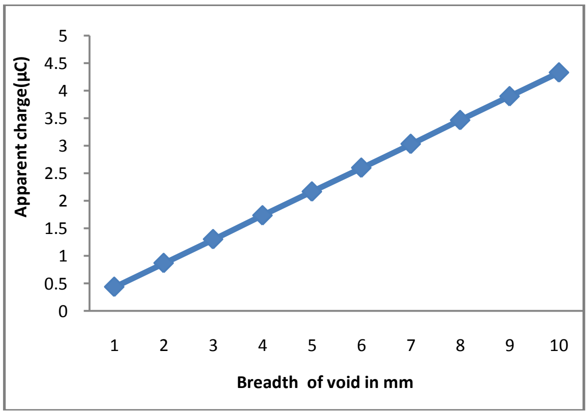

Fig 5: Variation of apparent charge for different breadth of the void, where ℓ and t are constants (ℓ=10mm and t=4mm).

Figure 5 shows the relation between apparent charge and variation in breadth of the void from 1mm to 10 mm where the length and thickness of the void are kept constant (ℓ =10mm and t=4mm) at the applied voltage being 30kV.

It is observed figure 5 that as the breadth of void is varied from 1mm to 10mm, the charge transfer has increased from 0.43262 pC to 4.3262 pC.

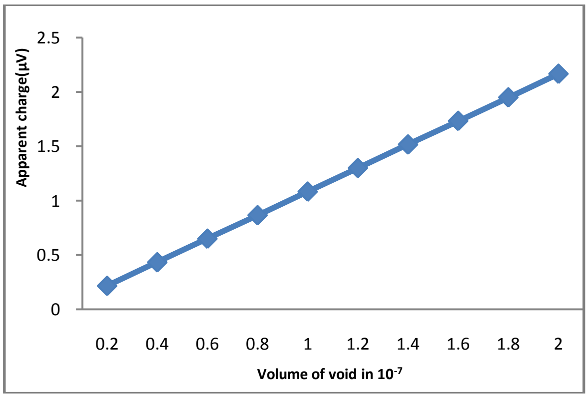

Fig 6: Variation of apparent charge for different volume of the void

Figure shows relation between apparent charge and volume of the void. It is observed that the apparent charge increases as the volume of void increases. It is observed from the above figures that the variations in the dimensions of the void with respect to ℓ, b, t and volume, the apparent charge transfer is linear as shown in figure 3,4,5 and 6.

PD Amplitude:

Figure 7, 8 and 9 represents the variation of maximum PD amplitude in case of positive half cycle and negative half cycle of the applied voltage with respect to variation in ℓ, b and t of the void. It is clear from the figures that the dimension of the void affects the PD amplitude.

It is also observed that the maximum amplitude of PD pulse increases in positive half cycle and decreases in negative half cycle as the dimension of the void varies. The magnitude of internal discharges increases with increasing cavity dimensions [4].

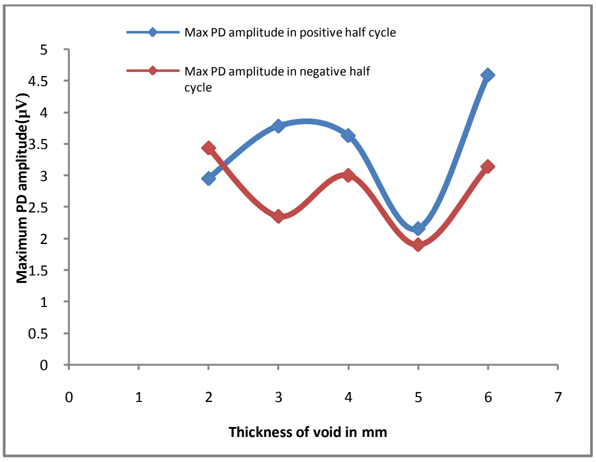

Fig 7: Variation of PD amplitude for different thickness of the void, where ℓ and b are constants (ℓ=10mm and b=5mm).

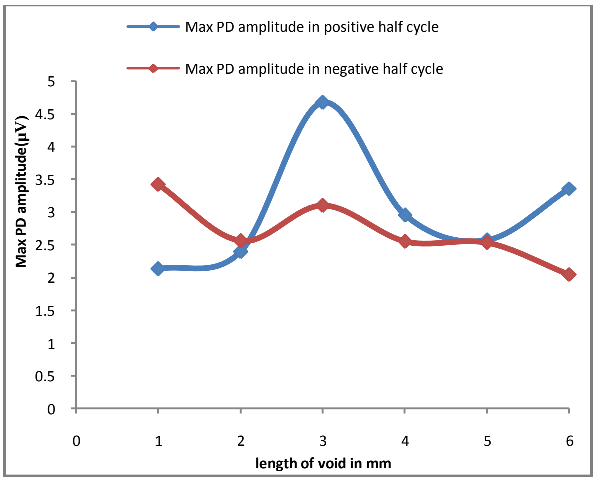

Fig 8: Variation of PD amplitude for different length of the void, where b and t are constants (b=5mm and t=4mm).

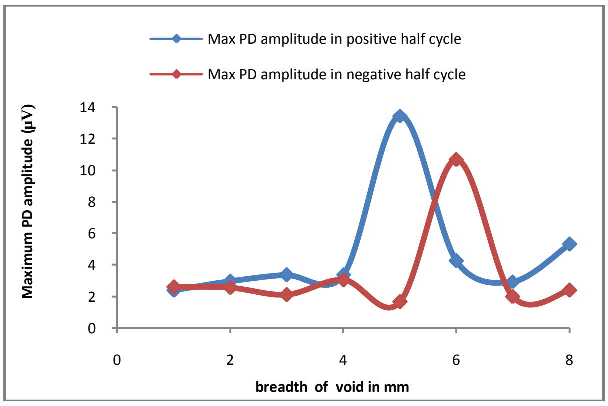

Fig 9: Variation of PD amplitude for different breadth of the void, where ℓ and t are constants (ℓ=10mm and t=4mm).

Rise Time (t_r) & Fall Time (t_f):

The t_r, t_f and pulse width of the output pulses are calculated by considering six PD pulses out of which three pulses are in positive half cycle and three pulses are in negative half cycle as shown in figure 10. Where figure 10 represents the output PD pulses at 5 kV of applied voltage.

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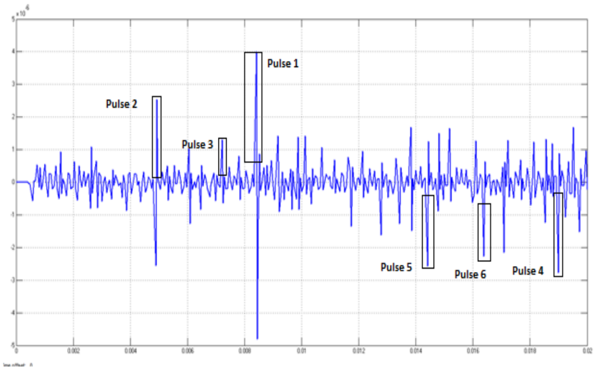

Fig 10: Output PD pulses at 5kV of applied voltage

The calculated rise time, fall time and pulse width of PD pulses considered in positive half cycle are depicted in Table 2. The calculated rise time of the pulse 1 is 70µsec; the duration of rise time is $8.335*10^{-3}$-$8.405*10^{-3}$sec. The calculated fall time is 25 µsec and duration of fall time is $8.405*10^{-3}$-$8.43*10^{-3}$.

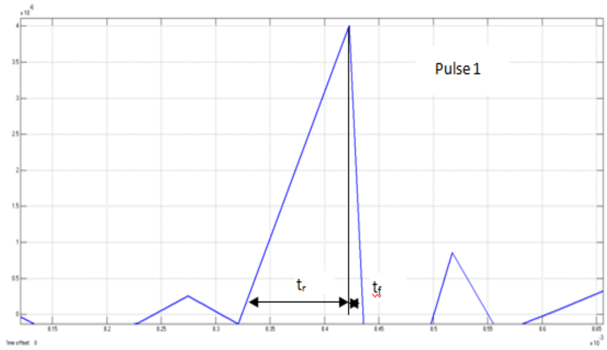

Fig 11: Rise time and fall time of PD pulse 1 in positive half cycle

The pulse width of the pulse 1 is addition of rise time and fall time i.e. 95 microseconds.

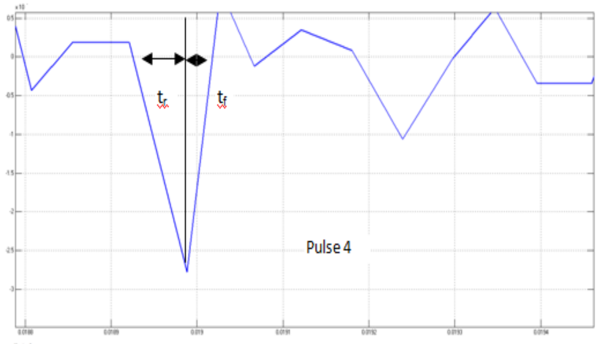

Fig 12: Rise time and fall time of PD pulse 4 in negative half cycle

The calculated rise time, fall time and pulse width of PD pulses considered in negative half cycle are depicted in Table 3. The calculated rise time of the pulse 4 is 60µsec; the duration of rise time is 0.01892-0.01898sec. The calculated fall time is 20µsec and duration of fall time is 0.01898-0.019sec. The pulse width of the pulse 4 is addition of rise time and fall time i.e. 80 microseconds. It is observed from the Table 2,3 that the PD pulses are having rise time, fall time and pulse width in the range of micro-second and the duration of the fall time is usually less than that of the rise time.

Table 2: Rise time and fall time of indentified pulses at 5kV applied voltage in positive half cycle.

Pulse no	Duration of rise time (sec)	Rise time (µsec)	Duration of fall time (sec)	Fall time (µsec)	Total time (µsec)
1	$8.335*10^{-3}$-$8.405*10^{-3}$	70	$8.405*10^{-3}$-$8.43*10^{-3}$	25	95
2	$4.91*10^{-3}$-$4.922*10^{-3}$	12	$4.922*10^{-3}$-$4.952*10^{-3}$	30	42
3	$7.158*10^{-3}$-$7.215*10^{-3}$	57	$7.215*10^{-3}$-$7.24*10^{-3}$	25	82

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Table 3: Rise time and fall time of identified pulses at 5kV applied voltage in negative half cycle.

Pulse no	Duration of rise time (sec)	Rise time (µsec)	Duration of fall time (sec)	Fall time (µsec)	Total time (µsec)
4	0.01892-0.01898	60	0.01898-0.019	20	80
5	0.01435-0.0144	50	0.0144-0.01444	40	90
6	0.01633-0.016375	45	0.016375-0.01642	45	90

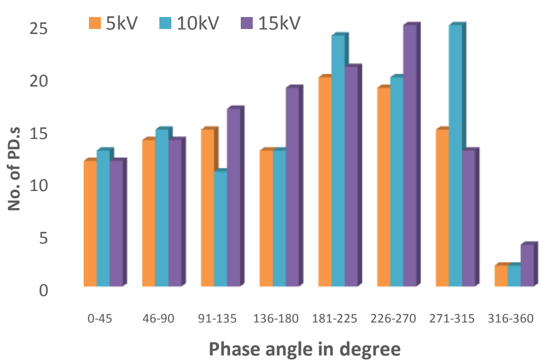

Fig 13: Partial discharge pulses at different phase angle with different applied voltages in cubical void.

The partial discharge pulses are analyzed by dividing single sinusoidal applied cycle of 50 Hz into eight equal parts. Each part has 45^0 phase angle interval. The numbers of PD pulses for each interval are plotted for different applied voltages. Figures 13 shows graph for number of PD pulses v/s different phase angle for different applied voltages (i.e, 5kV, 10kV and 15kV) where the dimension of the void is ℓ=10mm, b=5mm and t=4mm. The partial discharge phenomenon is random in nature so the numbers of PD pulses are random [6].

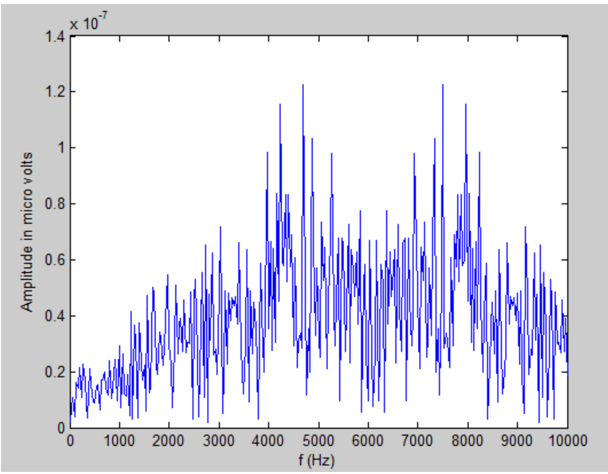

Fig 14: Frequency plot of observed PD pulse at 5 kV applied Voltage.

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 14. PD phenomenon is random in nature. So, the frequency content of PD pulse is also fluctuating or random as the dimension of the void varies. The dimension of the void in this case is ℓ =10mm, b=5mm and h=4mm. 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 which is shown in Fig.14. 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].

4. CONCLUSION

Continuous monitoring of PD activity is essential to ensure the effective performance of the insulator. In this work, the effect of geometry of the void on the PD activity is analyzed. The variation of apparent charge transfer with variation in the dimensions (ℓ, b, t and volume) of the void, PD amplitude with variation in the dimensions of the void is studied. It is observed that the relation of apparent charge vs the variation of void dimension is linear one. The magnitude of internal discharges increases with increasing cavity dimensions. It is observed that the maximum amplitude of PD pulse increases in positive half cycle and decreases in negative half cycle as the dimension of the void varies. Thereby the PD activity depends on the dimensions of the void. Rise time (t_r), fall time (t_f) and pulse width of the PD pulses are calculated. The calculated time period of PD pulses are less than 100µs. The PD pulses are having rise time, fall time and pulse width in the range of micro-second. The frequency content of PD pulse is analyzed. It is fluctuating in nature as PD phenomenon is random in nature.

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