EFFECTS OF VARIABLE APPLIED VOLTAGE AMPLITUDE TOWARDS PARTIAL DISCHARGE IN SOLID INSULATION

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Abstract— **Partial discharge (PD) plays an important role in the aging of solid insulation system. Over the past decade, PD has become an interesting topic for researchers due to its complexity. Even today, a precise documentation of PD is still not achievable because researchers have found new evidence of factors contributing to PD occurrence. In this paper, a generalized approach of investigating the effects of variable applied voltage amplitude towards PD is discussed. PD activity of a single cylindrical void, inside a solid insulator is simulated using SIMULINK. The solid insulator sample used was epoxy resin. Parameters such as voltage discharge of sampling resistance and current discharge of void are studied in order to understand the relationship between the amplitudes of applied voltage and PD. From the results achieved by simulation, it was found that PD pulses increases linearly with the increase of applied voltage. This shows that PD occurrences are dependant of the amplitude of the applied voltage.**

Keywords— **Partial discharge, solid insulator, applied voltage amplitudes, partial discharge pulses**

I. INTRODUCTION

PD is occasionally associated with the degradation of power apparatus insulation system. In term of definition, PD is a localized electrical discharge that happens across a portion of the insulation without fully bridging the electrode [1]. Factors that contribute for the occurrence of PD that have been known include voids, cracks, air bubbles and other types of impurities. According to the authors [2]-[3] these impurities occur during the manufacturing process of the insulation and also from mechanical stress, tend to have lower dielectric strength than the insulation material thus considered as the weakest point in the insulation and can be easily discharge, which causes insulator deterioration and lastly total failure of the insulation system.

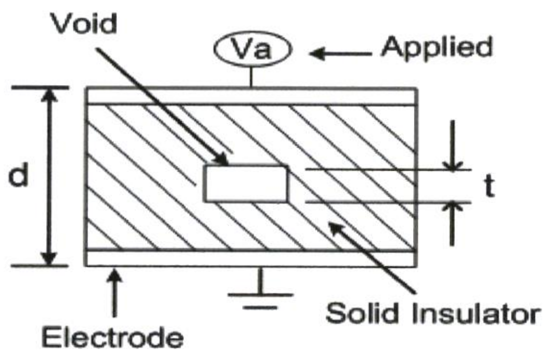


Fig. 1: A physical representation of a void occupying a solid insulation medium

PD computer model or PD simulation and PD measurement test have been proven to be a useful tool in order to understand the fundamental principle of PD and as an assessment of insulation properties [4]. For the past decades, many papers about PD and factors affecting its characteristics within the insulation materials have been published. Researchers have developed computer simulation models and experimental procedures to investigate PD phenomenon and compared the data obtained from both procedures in order to verify their findings. Parameters like type of defect, number of voids in insulation, applied voltage frequency, type of insulation and many more, have been manipulated in order to obtain more information on PD mechanisms. Consequently, due to in-depth studies and immense number of publications on PD, it causes difficulties to elaborate in detail on the chronological of PD mechanism [5].

The aim of this paper is to investigate the effect of different applied voltage amplitude towards PD characteristics in a solid insulator, which is represented by a sample of epoxy resin and looking into PD attributes in a general way, without taking into account much of the specific factor that may also influence PD. The relevancy of this project is to give better theoretical understanding, especially to undergraduates. According to [6], discharge behaviour of PD in the field is very complex and is dependant of many other external factors. In supplement with the problem stated by [5], it is almost fair to say that a general approach is better in order to give basic understanding of PD.

II. PARTIAL DISCHARGE MODELLING

A. Classical Equivalent Circuit Model

In 1932, Gemant and Philippoff have developed a simple equivalent circuit in order to represent PD behaviour in voids, cavities and others which is embodied in the insulator. This type of model is also known as 3-capacitance model or ABC model [4]. The name came from the three capacitors used in the circuit to imitate the electrical discharge process that took place during the occurrence of PD.

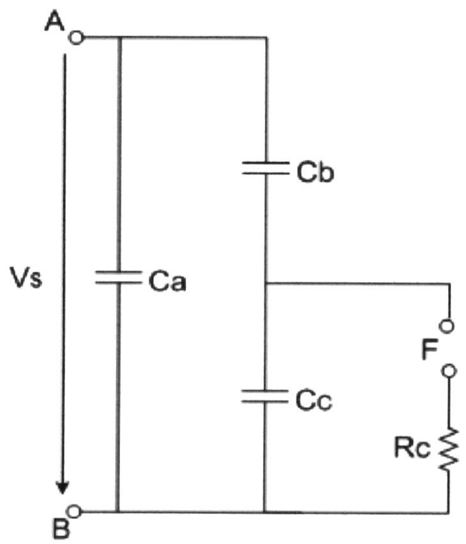


Fig. 2: 3-capacitance or ABC model of PD circuit.

In this circuit, Vs is the applied voltage, Ca resembles the remaining healthy insulation, Cb represent the healthy insulation in series with the void, Cc is the capacitance of the inclusion or void and F is the spark gap representing the electrical discharge process of Ca, Cb and Cc [1]. The resistor Rc meanwhile is the sampling resistor. PD occurs when spark jumps through the spark gap within the void and a small amount of current will conduct.

B. Extended Equivalent Circuit Model

Large number of researchers are against the classical model due to its design that did not took into account of all relevant parameters associated with the void [3]. Hence, an extended equivalent circuit has been used by some researchers in order to investigate PD mechanism. This intention of this extended equivalent circuit is to consider the additional electric field generated by preceding discharges [7]-[8].

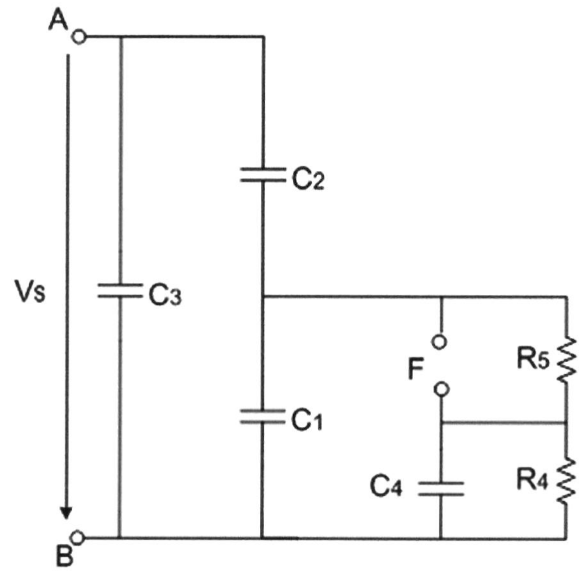


Fig. 2.1: An extended equivalent circuit of PD

In this circuit, Vs is the applied voltage, C_1 represent capacitance of void, C_2 represent capacitance of healthy insulation in series with void, C_3 represent capacitance of remaining healthy insulation, C_4 is the capacitance of local charges accumulation and F represent the spark gap [7]-[9].

III. METHODOLOGY

SIMULINK was used for the purpose of computer simulation based on the extended equivalent circuit model of PD.

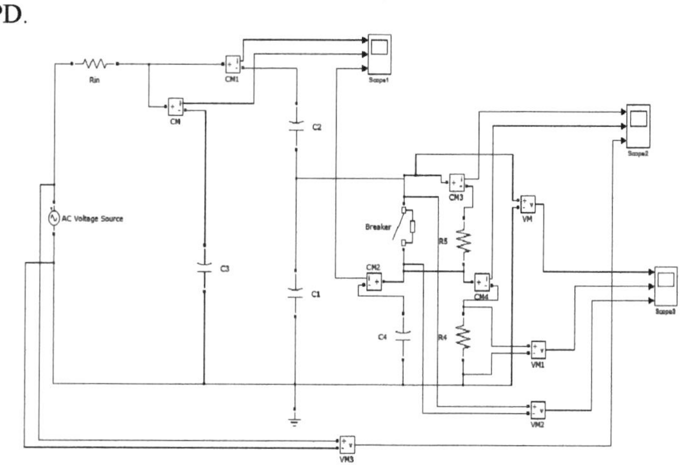


Fig. 3: Circuit used in SIMULINK

In alliance with common sizes of void present in an insulation medium, a cylindrical void with height, h of 3 mm and a radius, r of 6 mm was used in a cubic sample (30 mm × 30 mm × 5 mm) in the simulation [10]-[12]. The void was assumed to be located in the middle of the epoxy resin sample [10]. The AC voltage applied varied from 5 kV to 30 kV with a constant frequency of 50 Hz [12].

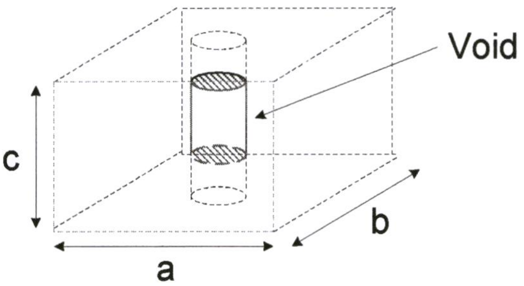


Fig. 3.1: Illustration of the cubic sample with a void occupying in the middle of the sample.

The equivalent capacitance of the circuit can be calculated by using the following equation [12]:

$$C_3 \approx \frac{\varepsilon_0 \times \varepsilon \times (a-2r) \times b}{c} \quad (1)$$

$$C_2 \approx \frac{\varepsilon_0 \times \varepsilon \times \pi \times r^2}{c-h} \quad (2)$$

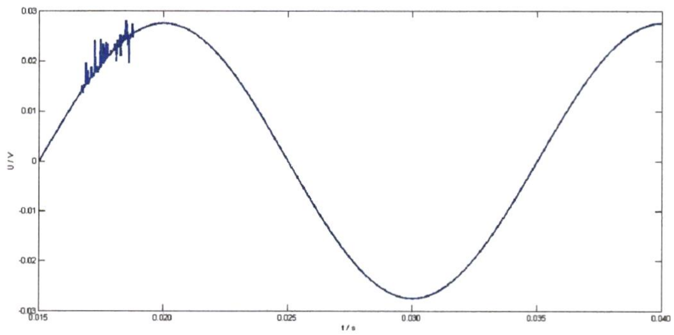
$$C_1 \approx \frac{\varepsilon_0 \times \pi \times r^2}{h} \quad (3)$$

ε_0 represent the electric constant or permittivity of free space and ε is the relative permittivity of epoxy resin, which is taken as 3.5 [10], [12]. 'a' is the length of the cube sample, 'b' is the width of the cube sample and 'c' is the height of the cube sample. Their values are a = 30 mm, b = 30 mm and c = 5 mm. From the formula, the values for each capacitance are $C_1 = 3.34\times10^{-13}$ F, $C_2 = 1.75\times10^{-12}$ F, $C_3 = 3.35\times10^{-12}$ F. Meanwhile, C_4 is taken as a constant of value 1×10^{-13} F. The value of C_4 comes from the assumption that $C_3 >> C_2 >> C_1 >> C_4$ [1], [3].

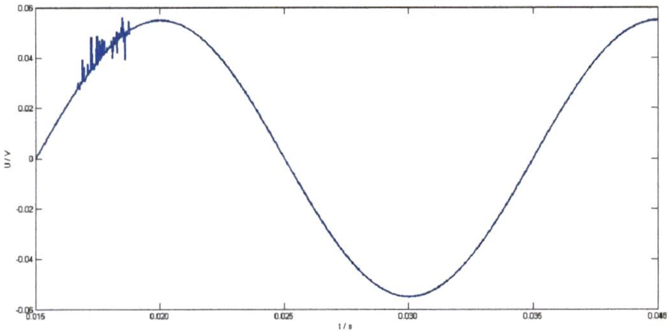
IV. RESULTS AND DISCUSSION

From the simulation, the discharge voltage waveform of sampling resistance and discharge current waveform of void are obtained for all applied voltage and are shown in Figure 4.

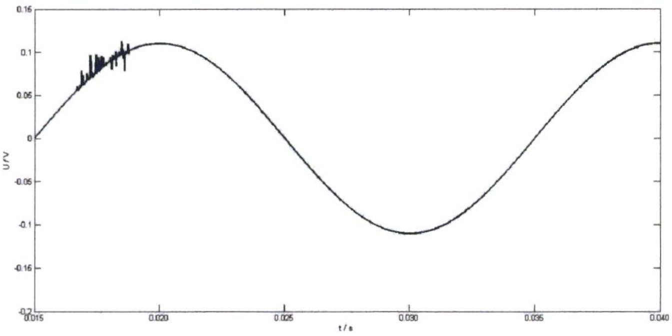
A. Discharge Voltage Waveform.



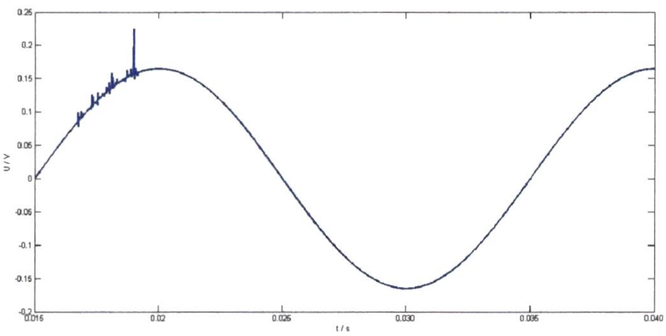
(a) The discharge voltage waveform of sampling resistance at applied voltage of 5 kV.



(b) The discharge voltage waveform of sampling resistance at applied voltage of 10 kV.



(c) The discharge voltage waveform of sampling resistance at applied voltage of 20 kV.

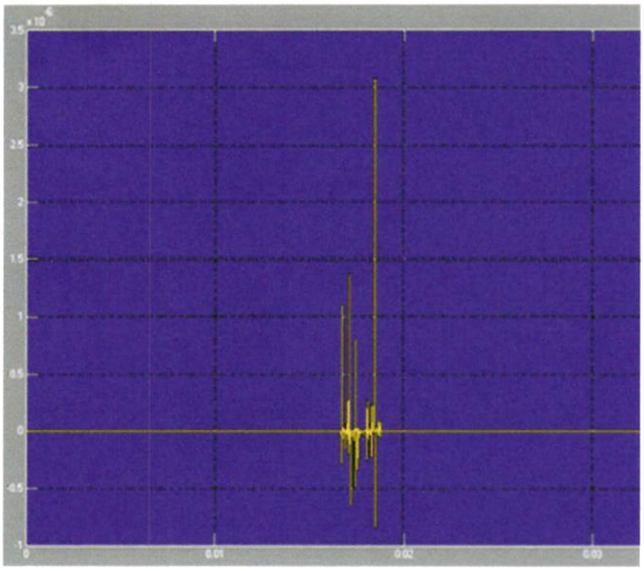


(d) The discharge voltage waveform of sampling resistance at applied voltage of 30 kV.

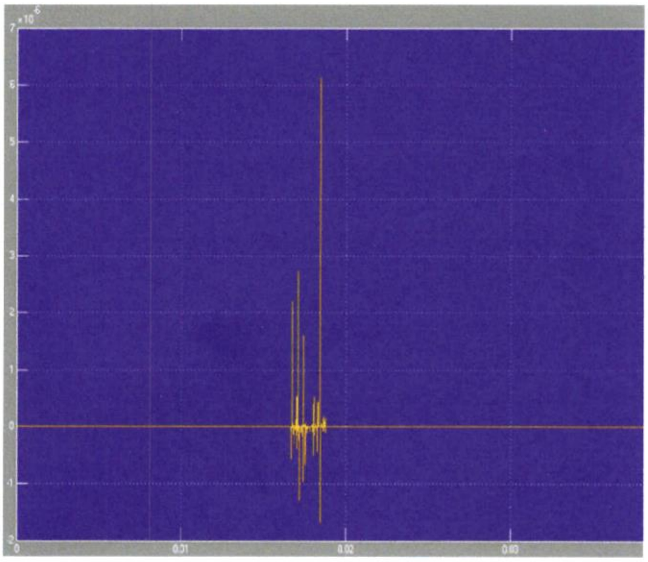
Fig. 4: The discharge voltage waveform of sampling resistance at applied voltage of 5 kV, 10 kV, 20 kV and 30 kV.

From Fig. 4(a) to Fig. 4(d), it can be seen that PD occurs only once and that is during the positive half cycle of the voltage waveform. This is due to the circuit breaker switching. From observation, as the amplitude of applied voltage is increased, the discharge voltage amplitude of sampling resistance increases. The values are observed at the highest amplitude of the pulses occurred in each waveform. It was found that PD has a linear relationship with the applied voltage.

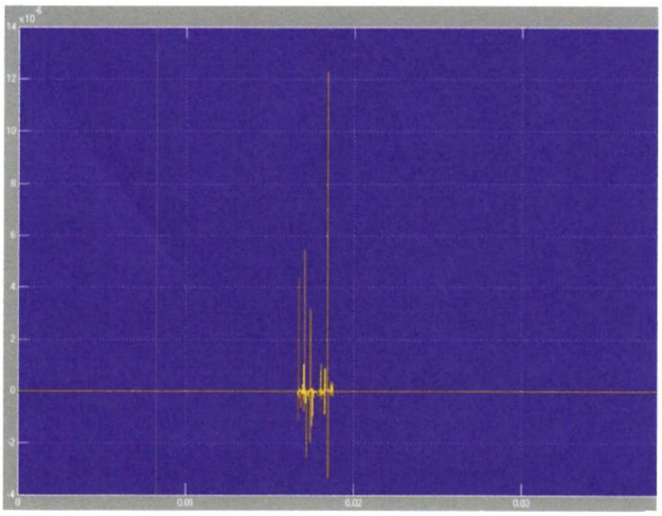
A. Discharge Current Waveform



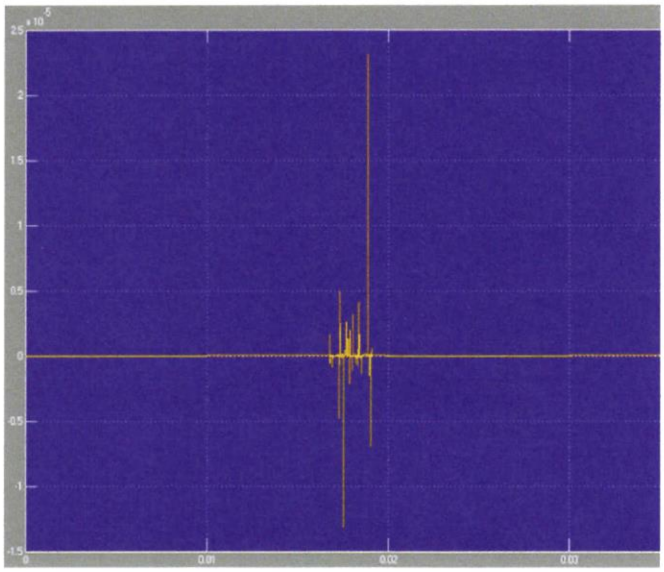
(a) The discharge current waveform at applied voltage of 5 kV.



(b) The current discharge waveform at applied voltage of 10 kV



(c) The current discharge waveform at applied voltage of 20 kV.



(d) The current discharge waveform at applied voltage of 30 kV.

Fig. 4.1: The discharge current waveform at applied voltage of 5 kV, 10 kV, 20 kV and 30 kV.

From the results obtained, the values for discharge current of void are observed and recorded, in order to study the effect of variable applied voltage amplitude towards the discharging of PD current. The values are tabulated in the table below:

TABLE I. RESULTS OF DISCHARGE CURRENT

	Applied Voltage Amplitude (kV) at 50 Hz			
	5	**10**	**20**	**30**
Discharge current (μA)	≈ 3.1	≈ 6.2	≈ 12.2	≈ 24

Table 1: Variable applied voltage amplitudes and discharge current value of void.

The discharge current value increases when the amplitude of the applied voltage was increased. When the applied voltage was set to 10 kV, the discharge current value recorded was 6.1 μA, and as the applied voltage is increased to 20 kV, the discharge current value obtained was 12.2 μA. What can be seen here is that, the value of the discharge current of the void increases almost double when the applied voltage is also increases. The value of the void discharge current is taken at the highest amplitude observed in the waveform. In other words, the value of discharge current of void shows a proportional relationship with the value of applied voltage.

Higher voltage amplitude creates higher stress on the solid insulator and may exceed its dielectric strength. Void inside the solid insulator is known to have lower dielectric strength thus capability to withstand high voltage stress is lower compared to the solid insulation. This gradually weakens the void dielectric strength. As a result, higher amount of current is allowed to conduct through it and on long term basis, might cause insulation breakdown. In a simple manner, PD increased exponentially as applied voltage increases and approaches the breakdown strength.

V. CONCLUSION

From the PD computer simulation circuit built using SIMULINK, it can be concluded that voltage amplitude contributes to the effect of PD in solid insulation. The higher the value of the applied voltage, the higher the value of PD. Higher value of PD may lead to the degradation of the solid insulator. This is due to the high current conductivity across the void which later will affect the insulator properties. When the insulation system failed it can cause equipment or apparatus failure and damage. Manufacturer of insulator must take into account the applied voltage value when designing an insulation product as this can guarantee longer insulation lifespan and users can rely on the reliability of the equipment or system from failure. Even though the result might be different from real model of PD, but theoretically the simulation manage to verify that voltage stress affects the value of PD in a solid insulation material.

VI. RECOMMENDATION

One of the reasons why partial discharge only occurs in a half cycle is because of the breaker switching. To overcome this, a subsystem circuit can be use to replace the breaker, and represent the discharge process of the void. Other than that, experimental work can be done and the result can be compared with computer simulation result to verify the PD characteristics.

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