International Journal of Electrical and Electronics Research ISSN 2348-6988 (online)
Vol. 3, Issue 1, pp: (149-155), Month: January - March 2015, Available at: www.researchpublish.com

Simulation Model of Partial Discharge in Power Equipment

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Abstract: **In high voltage electrical power system, variety of solid, liquid and gaseous materials are used for insulation purpose to protect the incipient failure inside the power equipment. Among these the solid insulation is widely used for high voltage power equipment in electrical power system. Most of insulating materials are not perfect in all respect and contains always some impurities. The presence of air bubble (void) is one of such impurities in insulating materials and highly undesirable for such type of insulation which causes a local weak zone inside the insulator. Insulation of the power equipment gradually degrades inside the insulator due to collective effect of electrical, chemical and thermal stress. Due to the high voltage stress the weak zone inside the insulator causes the partial discharge (PD) which is known as local electrical breakdown. As a result the insulation properties of such materials are enormously degrades its quality due to the PD. In this work, the simulation of PD activity due to presence of a small cylindrical and cubical void inside the solid insulation material of high voltage power equipment is studied with the MATLAB Simulink platform.**

Keywords: **Electrical Insulation, Cylindrical Void, Partial Discharge, High Voltage Equipment.**

1. INTRODUCTION

Rapid growth in power system has given the opportunity to protect the equipments for reliable operation. Their operating life in most of the power system equipments are made of with different type of high quality insulation to protect against the high voltage stress. A variety of solid, gaseous, liquid materials are used as insulation in high voltage power equipment. Among those the solid insulation like epoxy resin is widely used, not only as a component of complex insulating system such as HV rotating machine, transformers and in many different high voltage power equipment insulation. To access the quality of such insulation is a challenging task to the power engineers while the same power equipment is under operating with high voltage stress for a long period. However, the insulation of power equipments are gradually degrades due to the collective effects of electrical, chemical and mechanical stresses caused by the partial discharges (PDs). Partial discharge is a localized electrical discharge that only partially bridges the insulation between electrodes. It is studied from the several articles that most of insulators are not hundred percent perfect in nature and always contains some impurity. During the manufacturing process the presence of air/gas bubble in the insulating material is one of the causes for making the insulation imperfect. The presence of air/gas bubble during the manufacturing process may in the form of different geometrical shape such as rectangular, spherical, elliptical, cylindrical cubical etc. The presence of air bubble in any shape inside the insulation formed an impurity inside the insulation which weakens the insulation region and responsible for occurrence of PDs in the high voltage power equipment. It is studied that the field intensity while exceeds the breakdown strength of gas in void, then partial discharge takes place. However, once the PD starts inside the high voltage power equipment it is continue for a long time if it is not taken care of them. the pd phenomenon usually commences within the void, cracks, in bubbles within liquid dielectrics or inclusion within the solid insulating medium. in addition, pds also occur at the boundaries between the different insulating materials, contamination, poor conductor profiles and floating metal-work in the hv equipment.

Insulation properties of such materials having impurities degrade its quality. Because of this reason PD detection and measurement is necessary for prediction of insulation life [12-14]. In this work, an electrical circuit model of void presence inside the solid insulation material is used to study the PD activity inside the insulator. A small cylindrical and cubical void is taken into consideration and placed at the middle of the insulator which is kept under the plane-plane electrode arrangement which produced the uniform electric field. The whole simulation has been done in the MATLAB simulink environment. The simulation is the basis for a physically meaningful interpretation of PD data. In this study an efforts have been made to investigate the maximum PD magnitude.

2. ELECTRICAL CIRCUIT FOR PD MEASUREMENT

The schematic diagram for detection of partial discharge inside the solid insulation is shown in Fig. 1[1]. It is consists of high voltage transformer (V_s), filter unit (Z), high voltage measuring capacitor (C_m), coupling capacitor (C_k), void model of solid insulation called as test object (C_t), detector circuit for measurement of partial discharge (Z_m) and the measurement instrument (MI). The detector circuit for measurement of PD is a parallel combination of the resistor, inductor and capacitor. A different possible shape of void model is considered for test object of the insulating material. These are represented as C_a, C_b and C_c value corresponding to the shape of void. In the equivalent circuit the test object is represented in the form of small capacitance and the capacitance C_c corresponds to the void present inside the solid insulation, C_b corresponds to the capacitance of the remaining series insulation with void (C_c) and C_a corresponds to the capacitance of the remaining discharge-free insulation of the rest of the solid insulator.

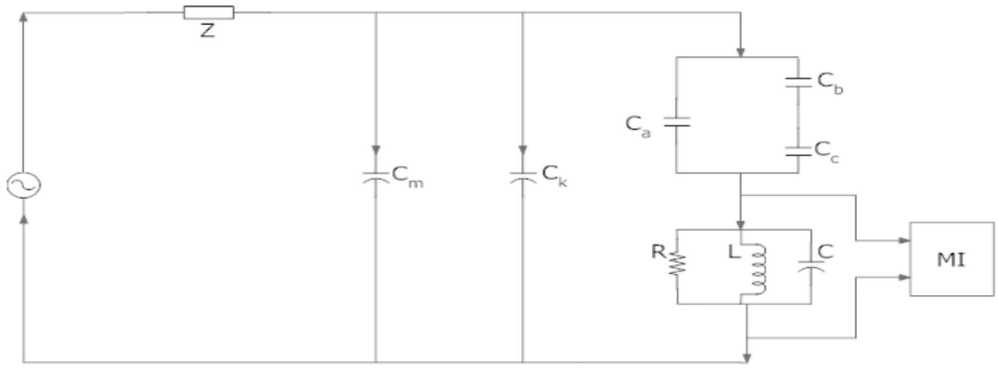

Figure 1: Electrical equivalent circuit model of void (test object) in solid insulation

This electrical equivalent circuit model of void (test object) in solid insulation along with power equipment circuit is energized [2]. AC voltage, a recurrent discharge occurs C_c is charged, reaches the breakdown voltage of the cavity, is charged again and breaks down. The voltage across the cavity C_c is

$$V_c = \frac{V_a V_b}{V_a + V_b} \qquad (1)$$

Where, the V_a, V_b and V_c are the voltage across the corresponding capacitance C_a, C_b and C_c respectively. The apparent charge q across the test object is measurable during the PD activity inside the solid insulation which is calculated by the empirical (2).

$$q = C_b . V_c \qquad (2)$$

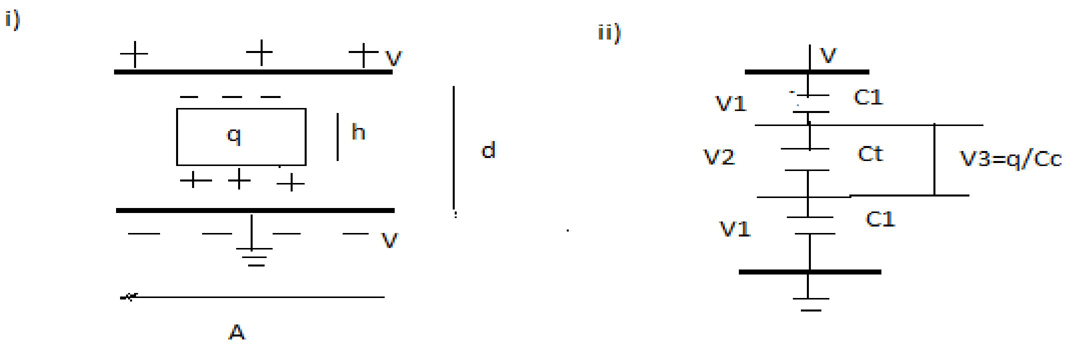

Figure 2: Schematic diagram of (a) void representation in parallel plate (b) equivalent capacitive network

This apparent charge is not given the accurate results as all the relevant void parameter is not included. To overcome the above problem A. Pedersen has suggested a model which is based on induced charge. According to this model, apparent charge for a given small cylindrical void can be expressed in equation (3).

$$q = S.V(E_i - E_1)\varepsilon o.\varepsilon r \,.\, \Delta Z \qquad (3)$$

In which, S is void geometric factor, V is volume of cylindrical void and is given by πr2h, r is radius of void, ε_0 is permittivity of free space, ε_r is relative permittivity of dielectric, E_i is inception voltage for streamer inception, El is limiting field for ionization and ΔZ is reciprocal of space between two electrodes is (1/d). The value of (E_i-E_l) can be calculated as(4).

$$\frac{\mathrm{Ei}}{\mathrm{p}} = \frac{\mathrm{El}}{\mathrm{p}}.\left[1 + \frac{\mathrm{B}}{\sqrt{2\mathrm{ap}}}\right] \qquad (4)$$

Where, B is constant characteristic of gas in void, ‘a’ is radius of void, p is pressure of gas in void and El /p (for air) is taken 24.2 v/pa. m [1].

Table 1: Parameter used for simulation of partial discharge in solid insulation [1]

Sl. No.	Parameter	Symbol	Default value	Dimension
1	Gap spacing between electrodes	D	0.005	M
2	Relative permittivity of dielectric (for epoxide resin)	E_r	3.5	--
3	Permittivity of free space	ε_0	8.852×10-12	F/m
4	Constant characteristics of gas	B	8.6	Pa0.5 m0.5
5	Pressure	P	105	N/m2

The parameter used for simulation of partial discharge in solid insulation. A simulink model descriptions for detection of partial discharge partial discharges are electrical discharges confined to a localized region of the insulating medium in high voltage (hv) power equipment. the electrical pd detection method are based on the appearance of the pd current or voltage pulse across the test object for fundamental investigation, which may be either a simple dielectric test object or large hv power apparatus. to evaluate the fundamental quantities of pd pulse, a simple equivalent capacitor circuit of solid insulator having cylindrical void is taken into consideration for this work. in the equivalent circuit the capacitance cc corresponds to the cylindrical void present inside the solid insulation, C_b corresponds to the capacitance of the remaining series insulation with void (C_c) and ca corresponds to the capacitance of the remaining discharge-free insulation of the rest of the solid insulator. generally, (C_a>>C_b>>C_c). according to the size of void in insulation sample (epoxy resin), a cylindrical void of height of 4 mm and a radius of 2 mm is used in a cube sample (30mm ×30mm ×5mm) in this model. and An epoxy resin insulator with dimensions 15mm, 20mm and 25mm is considered. In that insulator a cubical void is present. The void is having dimensions 3mm, 4mm and 5mm the void is located in the centre of the insulation sample .the applied voltage to the sample is 5 kv and frequency of 50 Hz. measurement of pd inside the solid insulation is taken as and the capacitance value of sample is calculated as for cylindrical void ca= 4.83×10-12 f, cb= 3.89×10-13 f, cc= 2.78×10-14 f. An epoxy resin insulator with dimensions 15mm, 20mm and 25mm is considered. In that insulator a cubical void is present. The void is having dimensions 3mm, 4mm and 5mm And the capacitance value of sample is calculated as for cubical void C_a=2.079×$10^{-13}$$C_b$ =5.420×$10^{-13}$$C_c$=30.6×$10^{-13}$in this study the value of the void model and the other high voltage equipment respectively[1-6].

Table 1: Specification of Different Components [1]

S. No.	Components	Value/ratings
1.	HV transformer	0.23/50 kV,50 kVA
2.	measuring capacitor	200/1500pF
3.	HV coupling capacitor	1000μF
4.	Detector circuit resistance	50Ω
5.	Detector circuit inductance	0.63mH
6.	Detector circuit capacitance	0.47μF

Specification of different components and their values used for simulation partial discharge is a highly localized partial breakdown within a small region of the insulation system where the local electric field exceeds the electrical strength of the insulating material. Generally, the presence of void inside the insulation creates a weak zone which further suffers a high voltage stress during the operating of their life[11]. In case of sinusoidal applied voltage the instantaneous voltage between the plate electrodes varies with time. If the rate of accumulation of charge within the void is higher than the rate of rise of applied voltage, which is true in the most of the cases, the field intensity within the void decreases quickly due to charge accumulation. Again, it is well known that the field intensity that is required to maintain a discharge is lower than that required to initiate the discharge. Hence, the field intensity below which PD stops is lower than that for PD inception. Due to fast accumulation of charge across the void when the field intensity within the void goes below this PD extinction value, the PD stops within the void[7-10].

3. RESULTS AND DISCUSSIONS

The partial discharge find out due to the presence of cubical and cylindrical void inside a solid epoxy resin insulator. The voltage of 1kv, 2kv, 3kv……up to 15 kV is applied in between the electrodes. The partial discharge characteristics cannot be measured directly in high voltage power equipment system. Hence it is necessary to see the partial discharge inside a solid insulation is found out using MATLAB Simulink model.

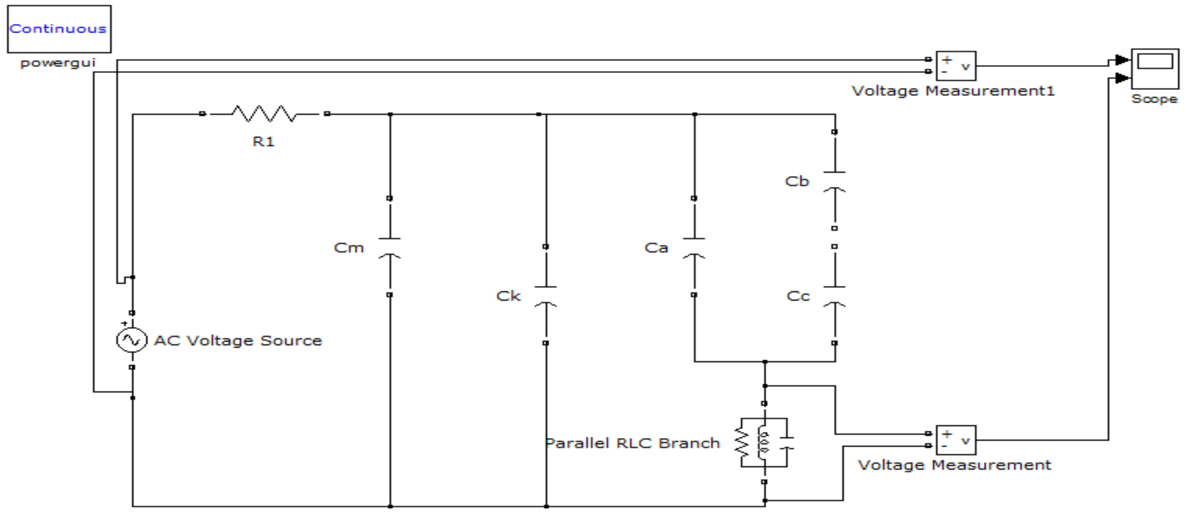

Figure 3: MATLAB Simulink model.

An increasing voltage of 1kv in steps up to 15 kV is applied to the solid insulation to observe the partial discharge characteristics. To observe the partial discharge characteristics it is necessary to see the maximum partial discharge values at different applied voltages. It helps for the partial discharge detection and measurement in high voltage power equipment system. We cannot see partial discharge characteristics for a long time interval. So the applied voltage is increased to see the maximum partial discharge and thus the partial discharge pulses are seen that are short term breakdown.

To understand the PD activity inside the solid insulation a MATLAB based simulink model has been developed in this work shown in figure (3). Partial discharges are a major source of insulation failure in high voltage power system. which needs to be monitor continuously to avoid the incipient failure in the power system network. In this work it is studied that the PD activity inside the solid insulation is highly depends on the entire geometry of the void presence inside the solid insulation model To observe the partial discharge characteristics it is necessary to see the maximum partial discharge values at different applied voltages. It helps for the partial discharge detection and measurement in high voltage power equipment system. We cannot see partial discharge characteristics for a long time interval. So the applied voltage is increased to see the maximum partial discharge and thus the partial discharge pulses are seen that are short term breakdown.

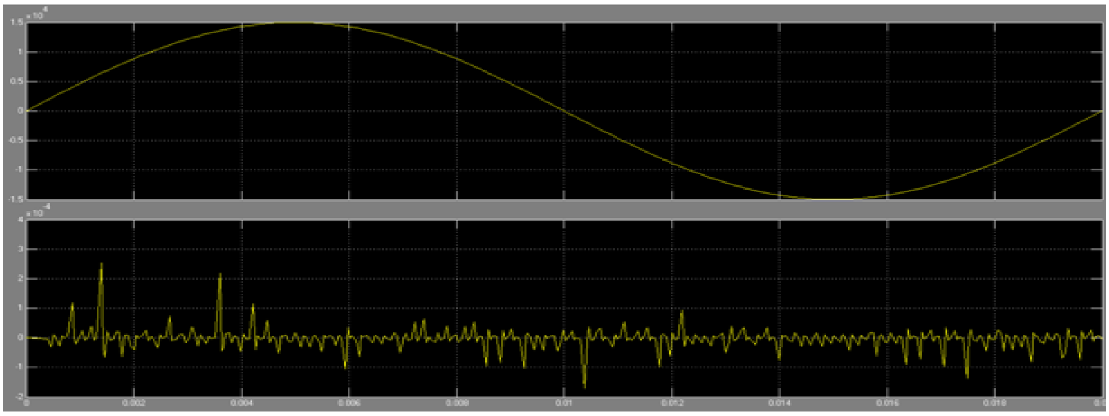

Figure 4: The PD obtained in cubical voids in insulators are tested at 15 kv

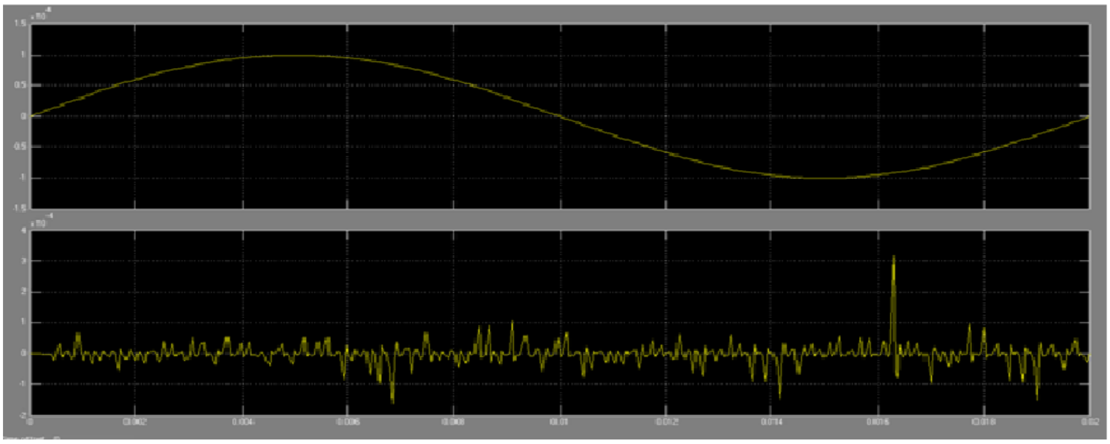

Figure 5: The PD obtained in cylindrical voids in insulators are tested at 15 kv

The PD obtained in both cubical and cylindrical voids in insulators are tested separately for 0 to 0.02 sec at 50 hz supply. In this model the voltage is applied 1kv to 15 kv in steps. The PD obtained with application 15kv is shown in figure-4. The PD voltage is maximum at approximate at 0.001sec as shown in figure-4. However the PD obtained due to cylindrical void is maximum at time 0.016 sec as shown in figure-5. The PD obtained due to the application of voltage start from 1kv to 15 kv with increase in 1kv in each step. The result obtained for maximum PD for both cubical and cylindrical void is shown in table-3. Also the comparative result for both types of void is shown in figure-6.

Table 3: maximum PD for both cubical and cylindrical void is shown in

Voltage in KV	Cubical void in 10-4volt	Cylindrical void in10-4volt
1	1.39	1.6
2	3.19	1.8
3	1.22	4
4	2.41	1.2
5	1.4	4
6	2.6	6
7	2.4	2.8
8	1.9	2.35
9	1.6	2.8
10	1.5	3.2
11	1.2	2.5
12	1.7	2
13	1.5	4.2
14	1.39	4
15	2.55	2.05

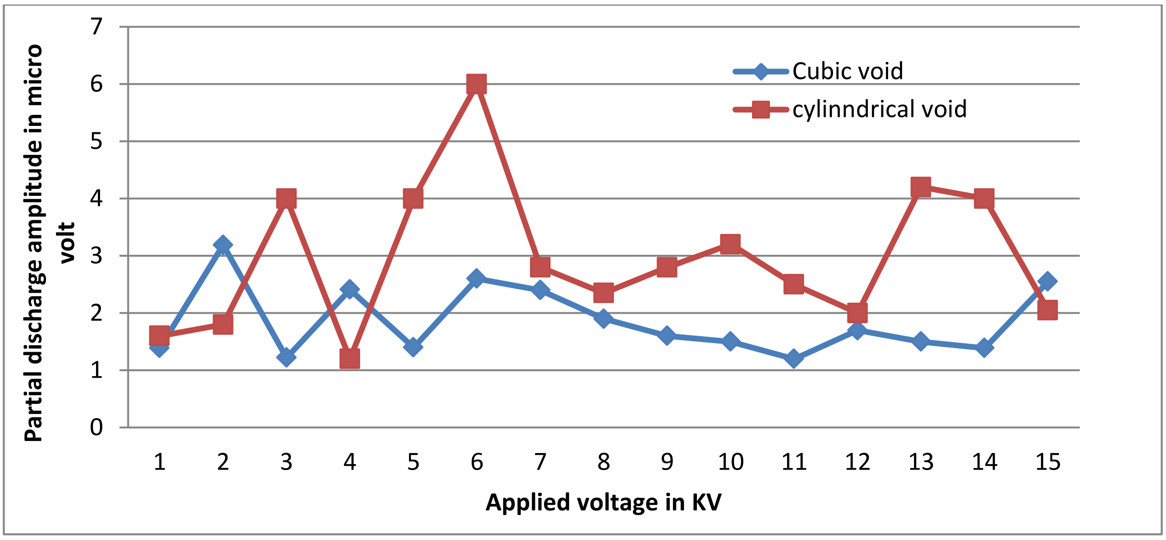

Figure 6: comparative result maximum PD

4. CONCLUSION

To know the PD activity inside the solid insulation MATLAB Simulink based model have used. Partial discharge is the main problem in high voltage power equipment system. Therefore, finding and measurement of partial discharge is necessary to maintain the power equipments in healthy condition during their operation. In this work an epoxy resin is consider as a solid insulation material to monitor the partial discharge activity inside the solid insulation. It is found that with the increase in applied voltage to the void present inside the insulation, partial discharge changes. In this study two different types of shapes of void cubic and cylindrical are taken. Based on the SIMULINK model partial discharge characteristics are plotted. The present work can also be extended for different high voltage power equipment model for detecting the PD activity. Further we could find out the partial discharge activity in different types of insulation

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