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Measurement Of Partial Discharge (PD) In High Voltage Power Equipment

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ABSTRACT

In high voltage (HV) power equipment the quality of insulator plays vital role in power systems. For insulation purpose various type of materials are used in different states like solid, liquid and gaseous form. Due to the application of high voltages, aging factor and cumulative effect of electrical, chemical and mechanical stresses, the quality of these materials degrades with the passage of time. These insulators are not in pure form and having some impurities, due to which small air bubbles are created inside the insulator which are called voids. Due to these voids the strength of insulators weakens and become the cause of Partial Discharge (PDs). Due to the presence of PDs originated at voids in insulators, the quality of such insulation degrades which results in the insulation failure in HV power equipment. In this work the PD activity of an equivalent electric model circuit having void inside solid insulator has studied. A small (air bubble) cylindrical void inside the solid insulator is placed under uniform electric field using parallel plane arrangement. In this study the maximum amplitude of PDs, the frequency of PDs, The duration of PDs and the number of PDs generated in a cycle is measured. In addition, relationship between void parameter and induced charge for cylindrical void is discussed.

Keywords (Partial Discharge, PDs, Insulator failure, PDs detection, PDs measurement)

1.Introduction

In high voltage (HV) power systems the insulation is one of the most important parameter to determine the performance of power services [1-8]. In industries most of the HV equipments e.g. transformers, switch gears, HV carrying and cables rotating machines (motors and generator) are used, for the smooth operation of power systems the reliability of these equipments is very necessary. Partial discharge mostly occurs in the insulation of these equipments. The insulators of these equipments is designed, monitored, cared and safely handled under the supervision of expert power engineer [6]. For insulation purpose various types of materials are used in different states like solid, liquid and gases form. Due to the application of high voltages, aging factor and cumulative effect of electrical, chemical and mechanical stresses, the quality of these materials degrades with the passage of time [1-8]. These insulators are not in pure form and having some impurities, due to which small air bubble are created inside the insulator which is called void. Due to these voids, the strength of insulators weaken and become the cause of partial discharge (PDs). Partial Discharges is the phenomena, in which an electric spark is generated inside the insulation medium of equipment placing under the HV electrode. PDs occur wherever the applied electric field strength exceeds the breakdown electric field strength of insulation material used in insulator. Due to the presence of PDs originated at voids in insulators, the quality of such insulation degrades which results in the insulation failure in HV power equipment's. Keeping the above reasons in view, PDs detection and measurement are required to predict the failure of insulation and to ensure a reliable operation of High voltage power equipment's.

Throughout the decades different techniques have been developed for detection, measurement and behavior study of PDs inside the insulation model. Many authors are presented their work about the detection and measurement of PDs as well as study the characteristics of PDs [1-8]. In this work a model is suggested which is based on induced charge. The transients associated with partial discharges in voids can be described in terms of the charges induced on the terminal electrodes of the system [4]. This work discussed the relationship between the induced charge and the properties which are usually measured. The method is illustrated by applying it to a cylindrical void located in a sample of epoxy resin, which is used as dielectric material in most of the equipments. In this work, the relation between amplitude and the number of PDs with the applied high voltages.

2. Electrical Equivalent Circuit for PDs measurement.

The equivalent circuit diagram for the detection of partial discharge is shown in Fig. 1.it consists of high voltage source (Vs), Low Pass Filter (Z),measuring capacitor (Cm), Coupling Capacitor (Cc), Solid insulation model (Ct), measuring instrument (MI) and high pass filter PD detector circuit parallel combination of resistor, capacitor and inductor [1-3]. In this model, the test object is shown in the form of small capacitances in which C3 represent the void capacitance, C2 represent the remaining series (upper and lower) capacitance of the solid insulator and C1 represent the remaining discharge free capacitance of the material.

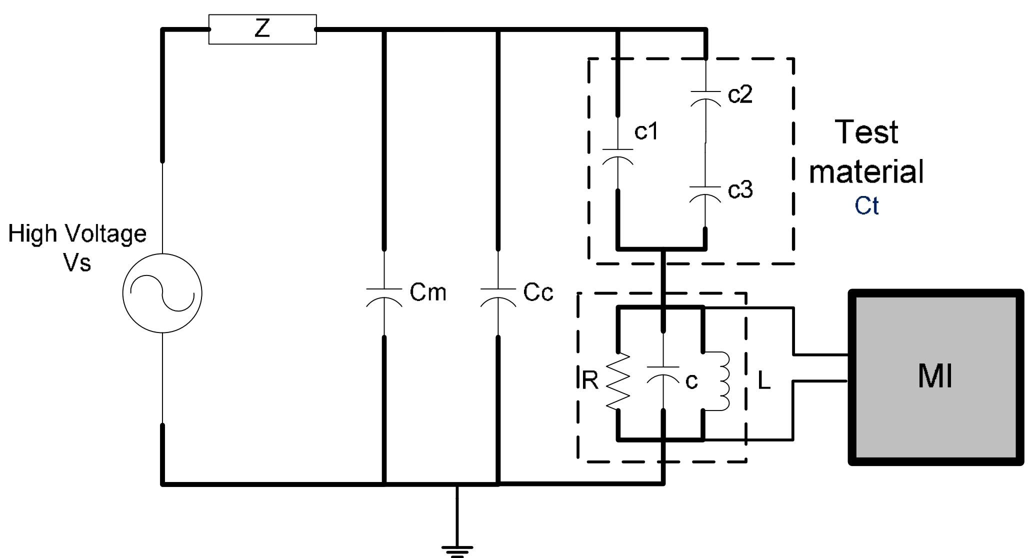


Figure 1. Electrical equivalent circuit model.

Such circuit is energized with the high voltage AC source. The applied voltage source energized the void within the test object, the charge 'q' stored in the void creates an opposite potential to the instantaneous applied voltage. A partial discharge occurs if the difference between the instantaneous voltage V3 and stored potential reaches the break down field of void. The voltage across the capacitors C1, C2 and C3 are V1, V2 and V3 respectively. The calculated voltage across the void C3 is

$$V3 = V1 * \frac{C2}{C1+C2} \qquad (1)$$

The voltage across the capacitance C1, C2 and C3 are V1, V2 and V3 respectively. The apparent charge measured across the C3 during the Partial Discharge activity inside the solid insulator material is given by the empirical formula:

$$q = V1 * C2 \qquad (2)$$

By using the above apparent charge the design model is fail to gives the accurate results as it does not include all the relevant void parameter. To overcome this problem Pederson has suggested a model which is based on the induced charge [4].

$$q = S * \mathcal{E}o * \mathcal{E}r * V * (Ei - El) * \Delta Z \qquad (3)$$

Whereas S is void geometric factor, Ɛ0 is permittivity of free space, Ɛr is relative permittivity of dielectric, V is volume of cylindrical void and is given by $\pi r^2 h$, r is radius of void, h is height of void, E_i is inception voltage for streamer inception, $E_l$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 by Equation. (4)

$$\frac{Ei}{Ep} = \left[1 + \frac{H}{2rp}\right] \qquad (4)$$

Where H is constant characteristics of void, p is pressure of air inside void and r is radius of cylindrical void El/p is taken 24.2 v/pa. m. The important constant parameter value are given in the Table 1.

Table 1

Sr. No	Parameter name	Symbol	Value	Unit
1	Permittivity of free space	$\mathcal{E}_0$	8.852 X 10^{-12}	F/m
2	Relative permittivity of dielectric (for epoxide resin)	$\mathcal{E}_r$	3.5	
3	Constant characteristics of gas	H	8.6	$Pa^{0.5} m^{0.5}$
4	Pressure	p	10^5	N/m2
5	Gap spacing between electrodes	d	0.02	m

3. Design description for partial discharge activity for simulation in MATLAB

Partial discharge is limited to localized region of insulation Material in high voltage (HV) power equipments. The partial discharge phenomena usually occurs within the void, cracks, in air cavity inside the liquid insulation or usually at the boundaries of different type of insulation material, poor conductor profile, contamination and floating metal element in high voltage devices. To evaluate the basic quantities of the PD pulse, the equivalent capacitor circuit of insulating material is taken under test for this work. In test system C3 represent the void capacitance, C2 represent the remaining series (upper and lower) capacitance of the solid insulator and C1 represent the remaining discharge free capacitance of the material. Normally the values of C1 is very large then C2 and C2 is very large then C3.A cube of epoxy resin (having size 0.03 meter in length, 0.03 meter in width and 0.005 meter in height) is considered as the sample for test. A cylindrical void of height 0.004 meter and radius 0.002 meter is taken. The capacitance for the above sample is calculated C1 = 4.836 x 10^{-12} f, C2 = 3.889 x 10^{-13}f and C3 = 2.75 x 10^{-14}f.

4. Generation of partial discharge pulse

To elaborate the PD pulse generation inside the insulating material placed in between the two parallel plate electrodes is considered shown in Figure 3. By applying the high voltage across the test object, the potential appears across the void depends on the entire arrangement. The capacitance across the void C3 is calculated as $C3 = \mathcal{E}o * \frac{A}{h}$, the voltage across C3 is $V3 = q * C2$, the capacitance of healthy part of insulator is C2 calculated by the equation $C2 = \mathcal{E}o * \mathcal{E}r * \frac{\frac{A1}{d-h}}{2}$, where A1 is area of the surface of void, d is the distance between electrodes and h is height of the cylindrical void. The voltage across C2 is V2=V1-V3. The electric field is denoted by (E). The electric field intensity is measured by $E = \frac{V1-V2}{d}$. As applied voltage is sinusoidal so if the rate charge accumulation within the void is faster than the increase rate of applied voltage, the field intensity within the cavity falls quickly due to accumulation of charge, so the amount of field required to maintain the discharge is lesser then that for PD inception. Due to the fast accumulation of charges across the cavity, the field intensity goes below PD breakdown value and the generation of PDs stops.

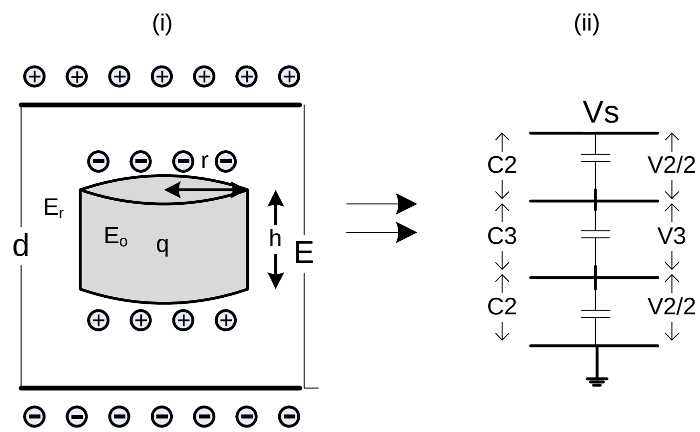


Figure 2. (i) Void representation (ii) Equivalent capacitance circuit

Consider that the q is the charge stored at the surface of void, the surrounding of cavity is assumed to be perfect insulator that charge q will remain store in void, which creates a potential across the cavity so the electric field is measured as

$$El = \frac{v2-\left(\frac{q}{C3}\right)}{h} \qquad (5)$$

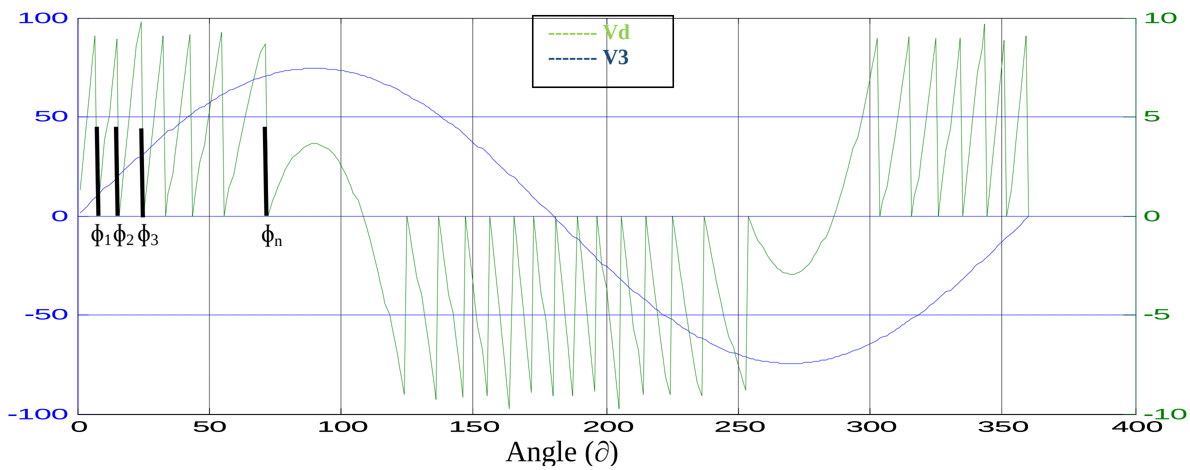


Figure 3 Applied voltage and potential across the void

The partial discharge takes place whenever the field produced across the void is greater than PD $_{\text{break down}}$ Electric field which means the applied field must follow the below relation.

$$E_{void}=E_l > PD_{break\ down} \quad (6)$$

The Figure 3 shows the applied voltage (V3) and actual apparent voltage (Vd) across the void. The field intensity across the cavity after phase ϕ1 is greater than the breakdown potential required for occurring of PDs, therefore at angle ϕ1 a PD pulse is generated. Now the void is charged by q1 which means that the amount of potential required to discharge the void must be greater than the previous value as calculated by the equation(6).

$$v3 = vin - \sum_{0}^{n}.\left(\frac{qn}{C2}\right) \qquad (7)$$

5. Result and discussion

To study the PD activity of insulation material simulation of MATLAB model is considered in this work. To study the PD activity inside the insulating materiel an increasing voltage is applied from 0 to 10 kV to the void model design in MATLAB. It is noted that a very few PDs are found by the application of 0-4kV to cylindrical void model. The field intensity of cavity does not exceed by the breakdown strength of air inside void below the application of 5kV applied voltage. The PDs inception voltage is found at 4.7 kV of applied high voltage. By increasing the applied voltage beyond 5kV the number of PDs increases. The generation of PDs is observing by applying the voltage up to 10kV. The number of PDs is counted by applying a cutoff value of 50 percent of the maximum amplitude of PDs observed from the corresponding applied voltage. It is observed that the amplitude of PDs is changes by varying the applied voltage, also it is observed that a very small amplitude signal is produced by the application of just above 4kV from which it is considered that the inception voltage and breakdown voltage is found ahead of the applied high voltage 10kV. The amplitude of PD is measured by the equation (8).

$$Vpd = \frac{q}{Ca+C*\left(1+\frac{C1}{Cc}\right)} * e^{-\frac{t}{2Rm}} * \cos(wt) \qquad (8)$$

Whereas the q is the apparent charge inside the void, Cc is the coupling capacitance,

$$m = C + C1 * \frac{Cc}{C1+Ck} \quad \text{and} \quad w = \sqrt{\left(\frac{1}{lm} + 1/4R^2m^2\right)}.$$

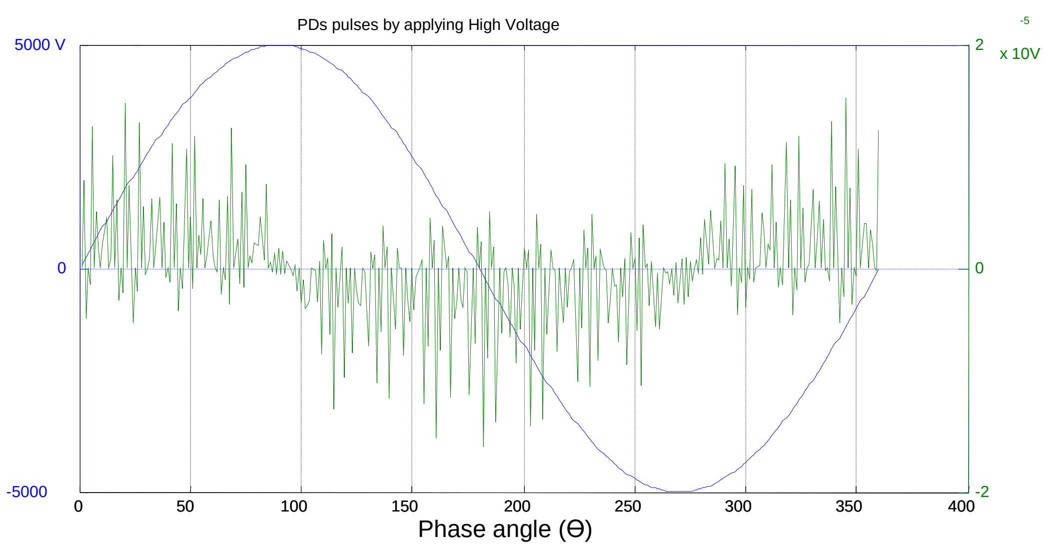


Figure 4

By applying the 5kV on the solid insulator test material total 89 PDs are observed. The observed PDs as shown in the Figure 4 are half in the first half cycle and half in the second half cycle. In the first half cycle positive PD pulse produce when applied voltage is increasing up to 90 degree and become negative while the applied voltage going down. It is also observed that the PD amplitude is greater in the start because of the more time taken to reach the break down field intensity due to the accumulation of charge (q) which is calculated by equation (3) as compared to the peak of applied voltage signal. Also it is observed that the minimum No of PDs is seen at the stable value of applied voltage.

In order to study the design test model a complete cycle of applied voltage from 0-10kV is taken under consideration whose result for 5kV is shown in Figure 4 and Figure 5.

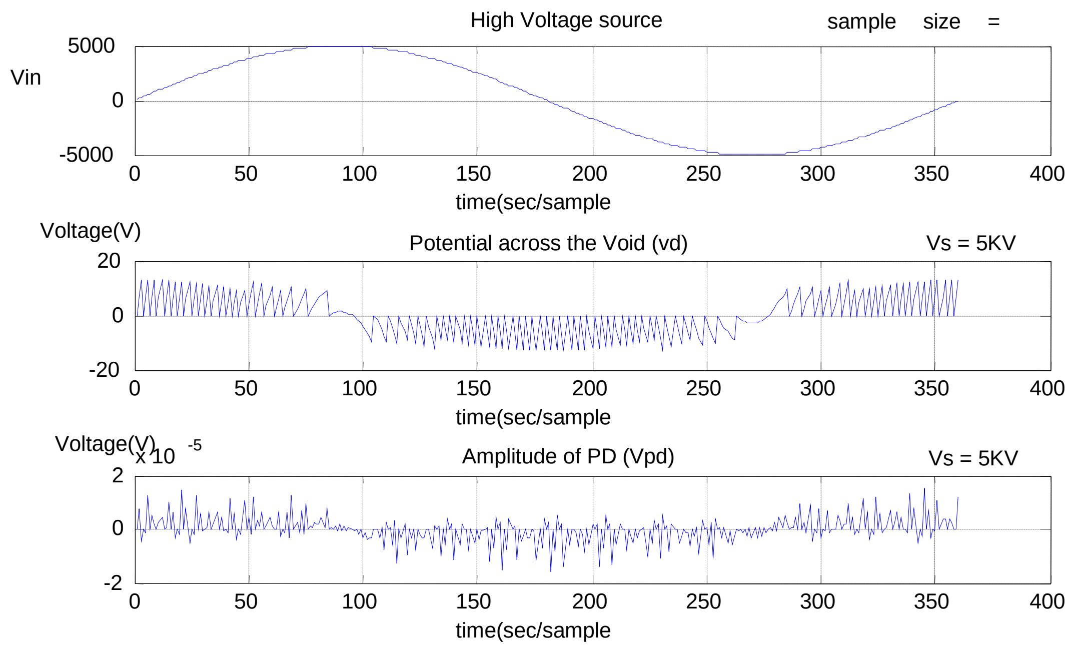


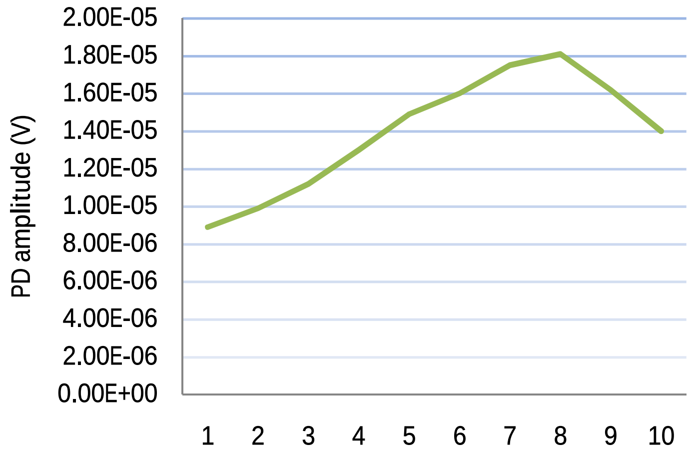
Figure 5

The results are shown in table 2 after analyze the simulation of design equivalent model in MATLAB. It shows that the no of PDs and amplitude of PDs is varying with changing the applied voltage, it is noted that the no of PDs and Amplitude of PDs varying by changing the size of void parameter, which results that by measuring the PDs amplitude and quantity we easily detect the quality degradation with passage of time.

Table 2

Applied Voltage Vs (kV)	No of PDs/Cycle	Amplitude of PDs Generated/ Cycle
1	10	8.90E-06
2	17	9.90E-06
3	29	1.12E-05
4	38	1.30E-05
5	89	1.49E-05
6	117	1.60E-05
7	147	1.75E-05
8	175	1.81E-05
9	204	1.62E-05
10	234	1.40E-05

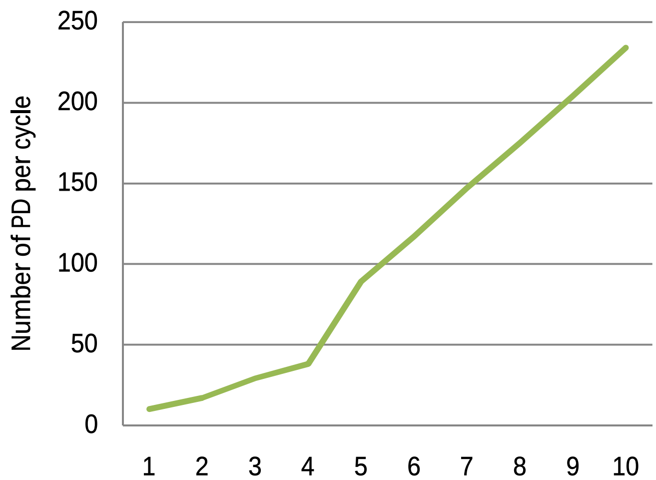
The behavior of the number of PDs and its amplitude collected in Table 2, the result of above simulation is shown in graphic form in Figure 6 and Figure 7. It is observed that the amplitude of the PDs is first increased by increasing the applied high voltage up to 8kV and then decreases by further increase in the applied high voltage.



Applied voltage (kV) 1

Figure 6

In this study it is observed from Figure 6 that amplitude of PD is changing with the variation of applied voltage. The amplitude of PD Initially rises with the application of high voltage from 1kV to 7kV and then decay from 8kV onward up to 10kV. It shows that the amplitude of PD is a function of applied voltage.



Applied voltage (kV)

Figure 7

In this study the number of PDs is observed by varying the applied voltage from 0-10kV. The number of PDs increases by increasing the value of applied voltage, as shown in the Figure 7. A very small change is observed by applying voltage up to 4kV, while above 4kV the number of PDs observed increasing very quickly as earlier than.

6. Conclusion

Partial discharge indicate the failuare of insulation in High voltage power system, PD is required to properly monitored to reduce the incipient failuare in HV power system. In this study we include the entire geomatry of the void inside the solid insulation materiel. In this study a MATLAB based model is discussed in detail by applying various technique to observe beheaviour of the solid insulator equivalent model, by which PD presence is detected which express the health of insulting material in high voltage power system. In this study it is concluded that the number of PDs increase with the increasing voltage across the solid insulating material. In this study an efforts has been made to explore the maximum PD amplitude, frequency and number of generated PDs. This study will help the power engineers to analyze quality of insulation material to ensure the reliable operation of power equipment. This work is a comprehensive for further study in various HV power devices such as transformers, Switch gears and circuit breakers.

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