Analysis of Partial Discharge Activity in Pressboards Using MATLAB SIMULINK

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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 have some impurities, due to which small air bubbles are created inside the insulator which are called voids in case of solid and liquid insulators. Due to these voids the strength of insulators weakens and become the cause of Partial Discharge (PDs) [1]. 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 the pressboard material has been studied using MATLAB Simulink software.

Keywords-Partial Discharge, Void, MATLAB, Permittivity, C_a, C_b, C_c

I. INTRODUCTION

Partial discharge is a phenomenon in high voltage insulation system. This phenomenon is a discharge in a void or cavity in an insulation layer. The discharge does not break the full mass of the dielectric layer. The dielectric strength and breakdown voltage of the dielectric layer are affected and lowered by subsequent partial discharge activities. These long-term PD activities will be monitored and the result will be used for diagnostic purposes and for maintenance [2]. Partial discharges are defined in IEC60270 as localized electrical discharges that only partially bridge the insulation between conductors and which can or cannot occur adjacent to a conductor. Partial discharges are in general a consequence of local electrical stress concentration in the insulation or on the surface of the insulation. Generally, such discharges appear as pulses having duration of much less than 1 μs. Hence most effective way to assess the insulation condition of high voltage equipment is monitoring of Partial Discharge activity. In this work, the PD activity of an equivalent electric model circuit having void inside the pressboard material has been studied using MATLAB Simulink software. Also the maximum amplitude of PD, PD pulses at different applied voltages, number of PD’s with respect to phase angle and apparent charge transfer for different applied voltages are studied.

II. PARTIAL DISCHARGE

A. Classification of partial discharge:
Partial discharge phenomenon is divided into two types:

i. External Partial Discharge: External Partial discharge is the process which takes place outside of the power equipment. Such type of discharges occurs in overhead lines, on armature etc [3].

ii. Internal Partial Discharge: This is the PD which occurs inside a system. It arises in cavities or voids which lie inside the volume of the dielectric or at the edges of conducting inclusions in a solid or liquid insulating media [3].

B. Type of Typical Partial Discharge:

i. Corona Discharge: PD around a conductor in free space is called corona discharge. Corona discharge takes place due to non-uniform field on sharp edges of the conductor subjected to high voltage. The insulation provided is air or gas or liquid.

ii. Surface Discharge: Surface discharge takes place on interfaces of dielectric material such as gas/solid interface as gets over stressed times the stress on the solid material.

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iii. Cavity Discharge: The cavities are generally formed in solid or liquid insulating materials. The cavity is generally filled with gas or air. When the gas in the cavity is over stressed such discharges are taking place.

iv. Treeing Channels: High intensity fields are produced in an insulating material at its sharp edges and it deteriorates the insulating material. That is responsible for production of continuous partial discharge, called as treeing channel.

Cavity discharge  Treeing channel

**Figure 2: Cavity discharge and Treeing channel**

**III. EXPERIMENTAL SETUP FOR PD MEASUREMENT**

The schematic diagram for detection of partial discharge inside the insulation is shown in Fig.3. 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 the capacitor. The cylindrical void model (test object) of the insulating material is represented as ‘abc’ diagrams. 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 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 pressboard insulator. Such circuit is energized with 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

\[
V_c = \frac{V_a 	imes C_b}{C_a + C_b}
\]

where, \(V_a\), \(V_b\) and \(V_c\)are the voltage across the corresponding capacitance \(C_a\), \(C_b\) and \(C_c\) respectively [4]. The apparent charge \(q\) across the test object is measurable during the PD activity inside the insulation which is calculated by the empirical Equation: 

\[
q = C_b \times V_c
\]

**Sample Preparation:**
Pressboard insulator with void inside is considered having dimensions of 100mm X 100mm with thickness of 10mm. The void is having dimensions of 10mmX10mm with thickness of 1mm. As the electrical circuit model consists of three capacitors the values of these capacitors are calculated by the following equations:
Where \( \varepsilon_0 \) = absolute permittivity
\( \varepsilon_r \) = relative permittivity

\[
\begin{align*}
C_a &= \frac{\varepsilon_0 \times \varepsilon_r \times A}{d} \\
C_b &= \frac{\varepsilon_0 \times \varepsilon_r \times A}{d - t} \\
C_c &= \frac{\varepsilon_0 \times A}{t}
\end{align*}
\]

IV. SIMULINK MODEL FOR PD MEASUREMENT

The calculated values of capacitances are essential to obtain the partial discharge characteristics. Fig 4 shows the Simulink model for detecting the partial discharge characteristics. The capacitances \( C_a \), \( C_b \) and \( C_c \) constitutes the test object (pressboard). \( C_m \) refers to the measuring capacitor and \( C_k \) refers to the coupling capacitor. The model drawn is simulated using MATLAB. When high voltage is applied across the test object, voltage across the dielectric \( V_a \) is increased thereby voltage across the cavity \( V_c \) also increases. When \( V_c \) reaches breakdown voltage, discharge will occur in void. The voltage across the test object at which discharge begin to occur is called the Inception voltage [6].

Table 1: Parameters used for Simulation

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Parameter</th>
<th>Symbol</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>HV measuring capacitor</td>
<td>( C_m )</td>
<td>1000pF</td>
</tr>
<tr>
<td>2</td>
<td>Coupling capacitor</td>
<td>( C_k )</td>
<td>1000( \mu )F</td>
</tr>
<tr>
<td>3</td>
<td>Permittivity</td>
<td>( \varepsilon_0 )</td>
<td>8.854x10^{-12} F/m</td>
</tr>
<tr>
<td>4</td>
<td>Relative permittivity</td>
<td>( \varepsilon_r )</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>Resistance</td>
<td>R</td>
<td>50( \Omega )</td>
</tr>
<tr>
<td>6</td>
<td>Inductance</td>
<td>L</td>
<td>0.6mH</td>
</tr>
<tr>
<td>7</td>
<td>Capacitance</td>
<td>C</td>
<td>0.45( \mu )F</td>
</tr>
</tbody>
</table>

V. RESULTS

The PD pulses produced in the void are measured and captured. Figures 5, 6 and 7 shows the Partial Discharge characteristics for the applied voltage of 5kV, 10kV and 15kV respectively.

When 5kV is applied across the test object, it is observed that the maximum amplitude of PD pulse correspond to 1.2mV is between the time period 0.016 to 0.018 second.
When 10kV is applied across the test object, it is observed that the maximum amplitude of PD pulse correspond to 600µV occur at 0.014 second.

When 15kV is applied across the test object, it is observed that the maximum amplitude of PD pulse correspond to 750µV is between the time period 0.002 to 0.004 second.

The applied voltage is increased in steps of 2kV upto 18kV to observe the maximum amplitude of PD pulses across the test object. The corresponding data shown in table 2 and graph has been plotted as shown in fig 8. From the graph it is observed that the maximum amplitude of 1100µV is obtained at 14kV of applied voltage.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Applied voltage in kV</th>
<th>Max. PD amplitude in µV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>160</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>510</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>600</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
<td>350</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>600</td>
</tr>
<tr>
<td>6</td>
<td>12</td>
<td>290</td>
</tr>
<tr>
<td>7</td>
<td>14</td>
<td>1100</td>
</tr>
<tr>
<td>8</td>
<td>16</td>
<td>260</td>
</tr>
<tr>
<td>9</td>
<td>18</td>
<td>310</td>
</tr>
</tbody>
</table>

The partial discharge pulses are analyzed by dividing single applied sinusoidal cycle of 50Hz into 10 equal parts. Each part has 36° phase angle interval. Thenumber of PD pulses for each interval is plotted for different applied voltages. Figures (9, 10, 11 and 12) shows graph for number of PD pulses with respect to phase angle for different applied voltages. The partial discharge phenomenon is random in nature hence the number of PD pulses is not constant for every
cycle.

![Figure 9: PD pulses at different phase angle with applied voltages of 5kV](image1)

![Figure 10: PD pulses at different phase angle with applied voltages of 10kV](image2)

![Figure 11: PD pulses at different phase angle with applied voltages of 15kV](image3)

![Figure 12: PD pulses at different phase angle with applied voltages of 20kV](image4)

The calculated apparent charge is shown in table 3 and graph is plotted with respect to the applied input voltages. From Fig. 13, it is observed that as the applied voltage increases, the apparent charge transferred increases linearly.
Table 3: Apparent charge transfer at different applied voltages

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Applied Voltage (kV)</th>
<th>Apparent Charge (nC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>2.58</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>4.97</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>7.87</td>
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<td>4</td>
<td>8</td>
<td>10.76</td>
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<td>5</td>
<td>10</td>
<td>12.63</td>
</tr>
<tr>
<td>6</td>
<td>12</td>
<td>16.15</td>
</tr>
<tr>
<td>7</td>
<td>14</td>
<td>18.63</td>
</tr>
<tr>
<td>8</td>
<td>16</td>
<td>21.12</td>
</tr>
<tr>
<td>9</td>
<td>18</td>
<td>25.26</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>27.74</td>
</tr>
</tbody>
</table>

Figure 13: Charge transfer with respect to applied input voltage

VI. CONCLUSIONS

In this work void in pressboard insulation is considered and MATLAB Simulink based model has been adopted to observe the partial discharge activity. It is found that with increase in applied voltage across the void, partial discharge increases. This study is employed to find out the maximum partial discharge, Charge transfer with respect to applied voltage, number of PD pulses with respect to phase angle, number of PD pulses for different applied voltage. From the plot of phase angle versus applied voltage, it is concluded that the partial discharge phenomenon is random in nature. Based on the SIMULINK model developed, partial discharge characteristics are plotted.

REFERENCES


