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# HIGH FIELD ELECTRICAL CONDUCTION AND BREAKDOWN IN SOLID DIELECTRICS: A WAVELET TRANSFORM APPROACH

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**Abstract-** In the high voltage system, the measurement of partial discharge and electrical breakdown is used in the assessment of an insulation system. Through modeling the partial discharge process, a better understanding of the phenomenon may be evaluated. In this paper, a model for a cavity within a dielectric material has been developed using MATLAB environment [2]. The model has been used to study the effect of various magnitudes applied voltages and frequencies on the cavity. The measurements were performed for different amplitudes of the applied voltage. The measured results show that partial discharge is strongly influenced by various conditions such as applied voltages, frequencies and the type of the cavity [12]. Every cycle partial discharge events, discharge phase and magnitude distributions, total charge magnitude per cycle, numbers of partial discharges per cycle for each set have been obtained and analyzed. The simulation results from the partial discharge model have been studied identified and analyzed. It is found that parameters are dependent on the applied voltage, frequencies and cavity conditions. Parameters that clearly affect partial discharge activity can be readily identified [1].

**Keywords:** Partial Discharge, Void, Cavity, Wavelet Transform.

## I. INTRODUCTION

### A. Partial Discharges within a Cavity in a Solid Dielectric

Partial discharge is an event that does not bridge the electrodes within an electrical insulation system under high stress field. As and when partial discharge happens, discharge starts from one end of the cavity surface, bridging through the gas-filled cavity and reaches the other end of the cavity surface. Thus, partial discharge only bridges the cavity and does not bridge the whole insulation between electrodes. Partial discharge normally happens in the presence of a defect within insulation under a high electric field. Examples of defects that may exist in polymeric insulation are voids, cracks, cavities or Partial discharge in a solid dielectric material, usually occurs in gas-filled cavities within the material.

Since the permittivity of the gas is less than the permittivity of the surrounding material, the electric field in the cavity is higher than the material. When the electric field in the cavity is sufficiently high and the breakdown strength of the gas in the cavity is exceeded, partial discharge can occur during the PD event, the gas changes property from a non-conducting to a conducting medium, resulting in the electric field within the cavity dropping from a higher to a lower value in a very short period of time. Figure 1 shows a basic diagram of partial discharge within a cavity in a dielectric material which is stressed under a high electric field.

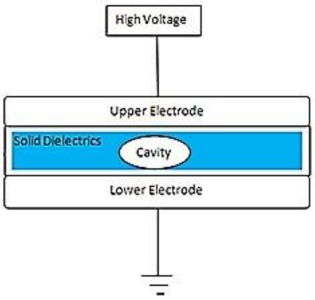

Figure 1. Basic diagram of partial discharge within a cavity in a dielectric material

The effect of partial discharge within a cavity in high voltage insulation can be very serious because it can ultimately lead to complete breakdown of the whole dielectric system. Repetition of partial discharge causes progressive chemical deterioration of the material. The chemical transformation of the cavity surface may increase the conductivity of the cavity surface. It may also cause the pressure in the cavity to change due to creation of gaseous by-products, depending on the type of the gas content in the cavity and the material surrounding the cavity. It is theoretically proposed that the cumulative effect of partial discharge in a cavity is the formation of numerous, branching partially conducting discharge channels in the material, called electrical treeing.

Electrical treeing is a significant degradation mechanism that can lead to insulation breakdown and consequently leading to breakdown of the insulation system when the three channels form a conducting path between the electrodes.

There are several types of discharge other than partial discharge, including surface discharge and corona discharge. Surface discharge is a discharge event that occurs on an insulating surface where the tangential field across the surface is high. This discharge can bridge the potential difference between the high voltage source and the ground electrode through cracks or contaminated paths on the insulation surface. Examples of surface discharge in the field or on the insulation surface of a high voltage cable or at the end-windings of stator windings of large generators. Corona discharge is discharged in gas due to a locally enhanced field from a sharp point of an electrode which ionizes the surrounding gas molecules. Figure 2 shows the various types of the discharges in a dielectric medium.

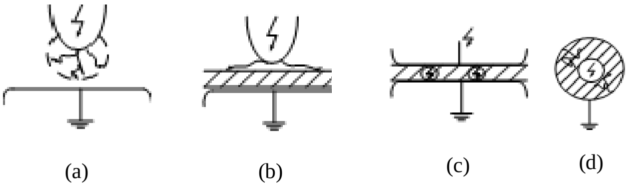

Figure 2. Various Discharges - (a) Corona Discharge, (b) Surface Discharge, (c) Partial Discharge, (d) Treeing and Tacking

### B. Factors Affecting Partial Discharge

Partial discharge activity in a solid dielectric material depends upon applying voltage, dielectric constant of the material and the size of the void. These are considered as the important factors affecting Partial Discharge in solid dielectrics.

### B.1. Applied Voltage

When the applied high voltage is increased, the electric field is enhanced and the liberation electron rate is increased. As a result more Partial Discharges will occur. High voltage ranging from 4 KV to 20 KV is applied to the simulation model to observe the various activities due to the presence of void, which is done with the help of a laboratory experiment setup.

### B.2. Different Sample Materials

Depending upon different materials used in the insulation model the apparent charge varies. Parameters in Table 1 are simulated using MATLAB to observe the variation of Partial Discharge with different materials used in the sample model. Each material has different dielectric constants.

### B.3. Void Size

In the insulation of power equipment, voids are one of the important factors which cause the partial discharge and its variation in size has great impact on the characteristics of partial discharge. Smaller size of void takes a long time to affect the strength of insulation. The dielectric strength of insulation depends on the size and shape of the cavity or void. Using MATLAB software simulates the behavior of partial discharge in insulation system with different void size is studied.

Table 1. Different samples of the material

| Material | Dielectric Constant $\varepsilon_r$ |
|---|---|
| Air | 1 |
| Polypropylene resin | 2 |
| Cross-Linked Polyethylene (XLPE) | 2.4 |
| Fluroethylene (ECTFE) | 2.5 |
| Paper | 3 |
| Polyvinyl Chloride (PVC) | 3.4 |
| Epoxy Resin | 3.6 |
| Porcelain | 5.2 |
| Mica | 6 |
| Vulcanized Rubber | 7 |
| Alumina porcelain | 10 |

### C. Partial Discharge Modeling - Three Capacitance Models

A partial Discharge model using a three-capacitor circuit model or it is also known as 'a-b-c' model representing an isolated cavity within a dielectric material has been developed [11]. Discharge is represented by an instantaneous change in the charging of a capacitance in the test object. A similar model has been used to study Partial Discharge behavior. The statistical behavior of this three-capacitance circuit is very complex, even though the circuit is Simple and deterministic. However, this model is not realistic in describing cavity properties because in a real cavity, there is surface charge accumulation on the cavity surface after a discharge occurs and the cavity surface is an unequal potential distributed surface. There is an improved 'a-b-c' model which has considered charging accumulation on the cavity surface after a discharge. The discharge is simulated as a time and voltage dependent resistance, which represents the discharge event as a change in the cavity from being insulating to conducting.

The Figure 3 shows the typical three-capacitance equivalent circuit or *'a-b-c'* model of a void within insulating material. In the model $C_a'$ and $C_a''$ which represents the capacitance in the material which is cavity-free, similarly $C_b'$ and $C_b''$ shows the capacitance in the material fall in series with the void and $C_c$ represents the actual capacitance of the void.

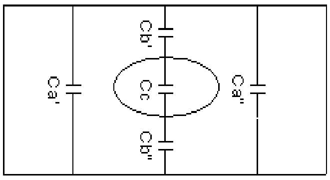

Figure 3. Typical three-capacitance equivalent circuit or *'a-b-c'* model

The simplified equivalent circuit can be derived from the geometry, as shown in Figure 4, where $C_a$ is the overall equivalent capacitance of $C_a'$ and $C_a''$, similarly $C_b$ is the equivalent series capacitance of $C_b'$ and $C_b''$ and $V_c$ is the voltage across the cavity. Discharge is assumed to occur when the voltage across the cavity capacitance

$V_c$ is higher than the inception voltage, $V_{inc.}$ stops when it is less than the extinction voltage, $V_{ext.}$ when a discharge occurs, $C_c$ is short circuited, causing a fast transient current to flow in the circuit due to the voltage difference between the voltage source and across $C_b$. A fast transient voltage signal is created due to sudden voltage drop due to the impedance of the external circuit. Although this model is simple, it can represent the transient related to a discharge.

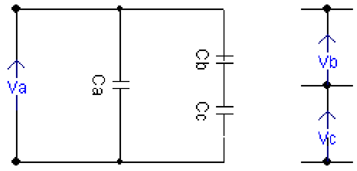

Figure 4. The experimental arrangement of the simplified equivalent circuit

Three capacitance equivalent circuit diagram representing Partial Discharge in a cavity. The Partial Discharge current pulse and apparent charge magnitude as a function of time, which results from a voltage across the cavity and the current flowing through the cavity due to the partial discharge.

### D. PD Charge Magnitude

In this *'a-b-c'* model, the charge magnitude can be calculated numerically. The real and apparent charge magnitudes, $q_{pd}$ can be calculated by time integration of current, $I(t)$ owing through the void and ground electrode during the Partial Discharge time interval, where

$$q_{pd} = \int_{t}^{t+dt} I(t)dt \qquad (1)$$

The current $I(t)$, through the ground electrode is calculated by integrating the current Density, $J$ over the surface area of the ground electrode, where $J$ depends on the electric field distribution. Because of the electric field distribution on the ground electrode is non-uniform due to the presence of the void, the field distribution in the entire cavity and the material is calculated using the MATLAB environment to determine the partial discharge apparent charge magnitude. Therefore, the advantage of the use of MATLAB over classical lumped parameter modeling is that it helps for dynamic calculation of both real and apparent charges.

### E. Breakdown due to Internal Discharges

The solid dielectrics contain voids or cavities within the media or at the boundaries within the dielectric and the electrodes. These cavities are usually filled up with a medium of lower dielectric strength, and the dielectric constant of the insulating material in the voids is lower than that of the insulation. The electric field strength in the voids is more than that across the dielectric material. Therefore, even under normal working voltages the field in the voids may go beyond their breakdown value and the complete breakdown may take place.

Let us consider a dielectric between two electrodes as shown in Figure 4, where, $C_c$ is capacitance of the void or cavity, $C_b$ capacitance of the dielectric which is a series with the void and $C_a$ is capacitance of the rest of the dielectric.

The voltage across the void, $V_C$ is given by

$$V_C = \frac{V.d_1}{d_1 + \left(\frac{\varepsilon_0}{\varepsilon_1}\right)d_2} \qquad (2)$$

where, $d_1$ and $d_2$ are the thickness of the void and the dielectric respectively, having permittivity $\varepsilon_0$ and $\varepsilon_1$. Usually $d_1 << d_2$, and we assume the cavity is filled with a gas, then

$$V_1 = V.\varepsilon_r \left(\frac{d_1}{d_2}\right) \qquad (3)$$

where $\varepsilon_r$ is the relative permittivity of the dielectric.

When a voltage $V_a$ is applied, it reaches the breakdown strength of the medium in the cavity $V_c$ and breakdown take place, where, $V_c$ is called the discharge inception voltage. When the applied voltage is AC, breakdown occurs on both the half cycles and the number of discharges will depend on the magnitude of the applied voltage. These internal discharges have the same effect as treeing and tracking on the insulation.

## II. WAVELET TRANSFORM

### A. Error Signal Generation

The error signal generation block extracts the superimposed distortions on the measured voltages. It is obtained by subtracting the fundamental component of the input signal (Figure 5).

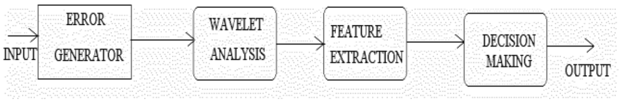

Figure 5. Proposed disturbance detection scheme

### B. Wavelet Transform Analysis

Wavelet analysis transforms the error signal into a different time and frequency scales. Similar to the Fourier Transform the wavelet transform provides information about the frequency content of a signal. Both the Fourier Transform and Wavelet Transform is able to focus on short time Intervals for high-frequency components and long intervals for low-frequency components, hence making it a compatible tool for analyzing high-frequency transients in the incidence of low-frequency components. The Wavelet transform is basically more suitable for non-stationary and non-periodic wideband signals.

The wavelet transform of a continuous signal is:

$$F(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} f(t).\Psi(\frac{t-a}{b})dt \qquad (4)$$

where, $\Psi$ is the wavelet basis function (mother wavelet), $a$ is the time scaling factor and $b$ is the time shifting factor. The wavelet coefficients $F(a,b)$ represents the projection of $f(t)$. Assume the center and width of function $\Psi(t)$ is zero and $\Delta t$ in time domain, and zero and $\Delta w$ in the frequency domain. Then, the function is centered at $b$, and has width of $a.\Delta t$ in time domain and $(1/a).\Delta w$ in the frequency domain. To avoid generating terminated information, the foundation tasks are generated discretely by selecting $a=a_0^m$ and $b=nb_0\ a_0^m$ where, $a_0$ and $b_0$ are fixed constants with $a_0>1$ and $b_0>0$, $m, n, \varepsilon, Z$, and $Z$ is the set of integers. Setting $a_0$ and $b_0$ to 2 and 1, respectively results in an ortho-normal origin of $L^2(IR)$ which is called dyadic ortho-normal wavelet transform. With this ortho-normal basis, an algorithm of decomposing a signal into various time-frequency scales can be used which is called Multi-resolution Signal Decomposition (MSD).

### C. Wavelet Implementation

The filter bank configuration of Figure 2 is used to implement the wavelet transform based on the MSD technique. At the first stage, the error signal is decomposed into $c_1$ and $s_1$ which represent smoothed and detailed versions of the main signal respectively. In the next step, the smoothed signal is decomposed into $c_2$ and $s_2$. The process of decomposing can be continued as many stages as required by the application. The relationship between the filters and scaling / wavelet functions $(\Phi(t)/\Psi(t))$ can be written as

$$\Phi(t)=\sqrt{2}\sum_{n}h[n].\phi(2t-n) \tag{5}$$

$$\Psi(t)=\sqrt{2}\sum_{n}g[n].\phi(2t-n) \tag{6}$$

In general output $c_m$ and scale $s_m$ are expressed as

$$c_m[n]\ =\ c_{m-1}[n]*h\left[n/2^{m-1}\right] \tag{7}$$

$$s_m[n]\ =\ c_{m-1}[n]*g\left[n/2^{m-1}\right] \tag{8}$$

where

$$c_0[n]=e[n] \tag{9}$$

$$h[\frac{n}{2}]=\begin{cases} h[\mathrm{k}] & n=2k \\ 0 & \text{else} \end{cases} \tag{10}$$

and $*$ is the convolution sign after transforming the error signal into different scales ($2^j$), the next step is to define features of the signal.

### D. Properties of Mother Wavelet

Wavelets are families of functions generated from one single function, called as an analyzing wavelet. The mother wavelet must have some properties. Such as, it must be oscillatory, it must quickly decay to zero, it must have a zero average, it must be band-pass, and it must be integrated to zero

### E. Advantage of Wavelet Transform over Fourier Transform

Wavelet proves greater resolution in time for high frequency components of a signal and greater resolution in frequency for low frequency components of a signal. Wavelet performs better with non-periodic signals that signals that contains short duration impulse components as is typical in power systems transients. Wavelet has a window that automatically adjusts to give appropriate resolutions. It is different from fast Fourier Transform, the wavelet transform is approach is more efficient in monitoring various disturbances as time varies. Wavelet uses a short window at high frequencies and long window at low frequencies. The iterative wavelet method for system converges rapidly for cases in power system engineering.

## III. RESULTS AND DISCUSSIONS

The simulation results are formulated for the partial discharge characteristics detection for solid insulating materials from the experimental setup using the partial discharge detector & it is observed that when external high voltage applied through the separate source & amplitude of the partial discharges are higher & detected earlier in the solid insulator. The breakdown occurs in the configuration in the solid insulator. Similarly from the simulation result, it is also observed that the amplitude of the partial discharges is more in the solid insulator and occurs at the low range of the applied high voltages. Thus, it is suggested that the partial discharges occur in the solid material due to the presence of the air void and others impurities. Thus, on the basis of partial discharge characteristics, solid is a good insulating and can be used in the high voltage equipment for a specific application that is for low partial discharge requirements. The experimental setup in the laboratory is as shown in Figures 6 and 7.

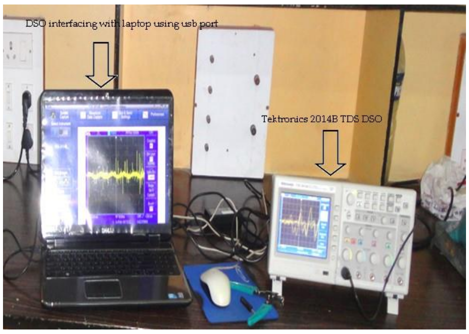

Figure 6. Experimental setup condition with PC interface

Figure 7. Experimental setup condition with high voltage source

The original partial discharge signals are as shown in Figure 8. By applying the Db4 Wavelet at decomposition level 4 the following results are found as shown in Figure 9. By applying the Sym4 and Haar Wavelet at decomposition level-4 the following results are found as shown in Figures 10 and 11. The Energy levels of original signals using Db4 at decomposition level-1 are as shown in Figure 12. The Histograph of the original signal is as shown in Figure 13. The time domain and frequency domain graph of the original partial discharge signal is as shown in Figure 14.

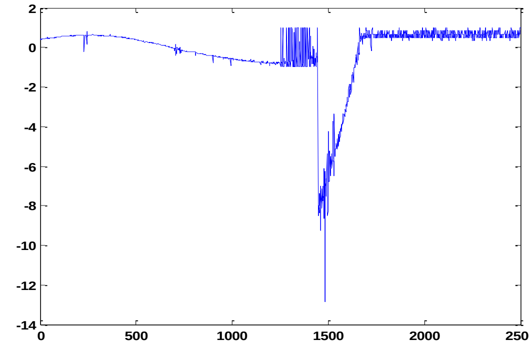

Figure 8. Partial discharge Signal builds with MATLAB

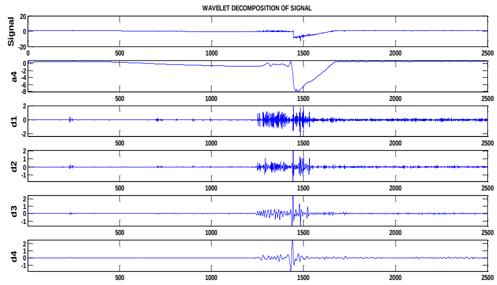

Figure 9. Db4, decomposition level-4

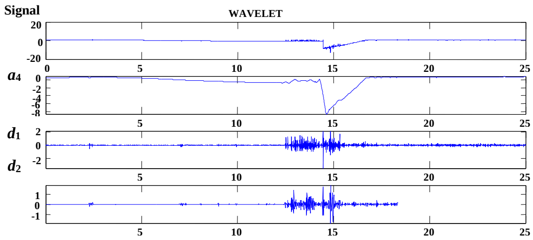

Figure 10. Decomposition of the signal using Sym4 at level-4

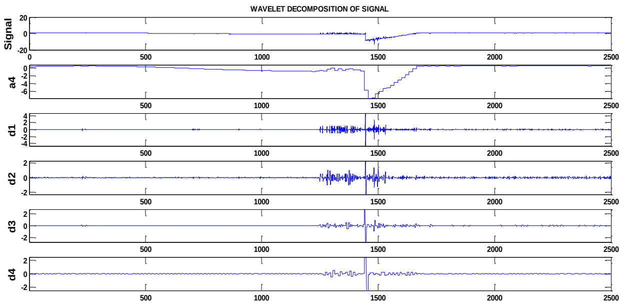

Figure 11. Decomposition of the signal using Haar

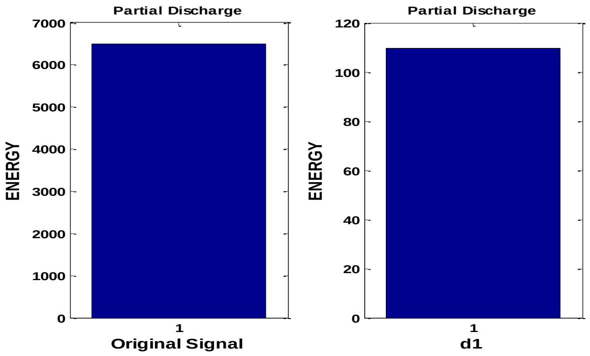

Figure 12. Signal energy using Db4

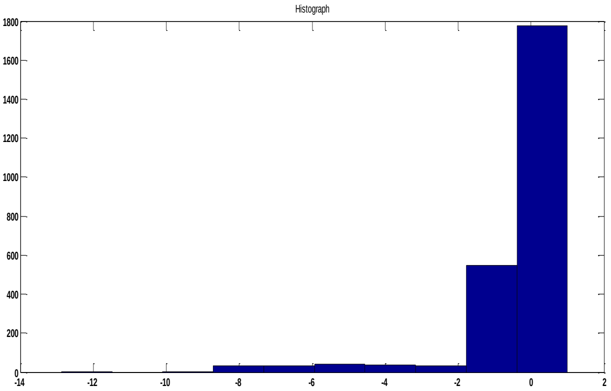

Figure 13. Histograph of the captured signal

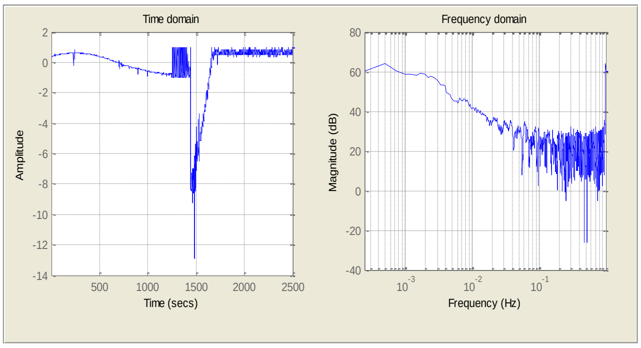

Figure 14. The time domain and frequency domain graph

## IV. CONCLUSION

Partial discharge is the main difficulty in high voltage power equipment system. Therefore, detection and measurement of partial discharge are necessary to keep the equipment in healthy condition during their operation in a power system. In this work simulation and experimental study had been carried out for partial discharge measurement and detection using the MATLAB. From the studies, it is observed that in each case the partial discharge detects earlier at the low values of applied high voltages and breakdown of dielectric material occurs in the lower range of applied high voltage in case of solid insulating material than the oil. So it is concluded that the amplitude of partial discharges is more on the solid insulating materials when the applied voltage is increased because of the presence of air voids and other impurities.

The MATLAB based model has been developed from the equivalent electrical model of an insulators to find the characteristics of partial discharge activity inside the solid and liquid dielectrics at different applied voltage which arranges from 0-30 KV at a constant power frequency ($f$ = 50 Hz). It is found that with the increase in applied voltage to the cavity present inside the insulation, partial discharge increases in solid dielectric material.

This work can also be extended in the future for different high voltage power equipment model for detecting the partial discharge activity. Further the collected partial discharge signal can be processed with the help Wavelet Transform for time, frequency analysis for better study of partial discharge measurement and detection and to analyze the breakdown phenomena in solid dielectrics.

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## BIOGRAPHIES

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