IJIREEICE

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering

ISO 3297:2007 Certified

Vol. 5, Issue 1, January 2017

Identification and Detection of Partial Discharge and Electrical Breakdown within a Cavity by using Wavelet Transform under AC Condition

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Abstract: In high voltage system, the measurement of partial discharge (PD) is used in the assessment of an insulation system. Through modelling the PD 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 and tested by using MATLAB environment. The model has been used to study the effect of various applied voltages on the cavity. The measurements were performed for different amplitudes of the applied voltage. The measured results show that PD is strongly influenced by various conditions such as applied voltages, frequencies and the type of the cavity. The cycle to cycle behavior of PD events, discharge phase and magnitude distributions, numbers of PDs per cycle, total charge magnitude per cycle for each set have been obtained and analyzed. The test results from the PD model have been studied and analyzed. It is found that certain model parameters are dependent on the applied voltage, frequencies and cavity conditions. Parameters that clearly affect PD activity can be readily identified.

Keywords: Partial Discharge, Corona Discharge, Surface Discharge, Treeing & Tracing, Void, Cavity, Wavelet Transform, Signal Energy, Breakdown.

I. INTRODUCTION

PARTIAL DISCHARGE WITHIN A CAVITY IN A SOLID DIELECTRIC

Partial discharge (PD) is a discharge event that does not bridge the electrodes within an electrical insulation system under high field-stress. When PD 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, PD only bridges the cavity and does not bridge the whole insulation between electrodes. PD 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, PD 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 PD within a cavity in a dielectric material which is stressed under a high electric field.

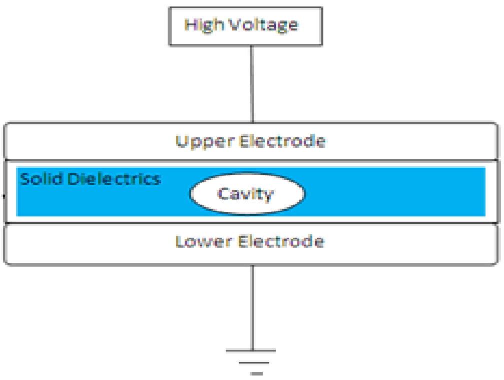

Figure1: Basic diagram of PD within a cavity in a dielectric material

The effect of PD within a cavity in high voltage insulation can be very serious because it can ultimately lead to complete failure of the whole system. Repetition of PD 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 PD in a cavity is the formation of numerous,

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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 tree 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.

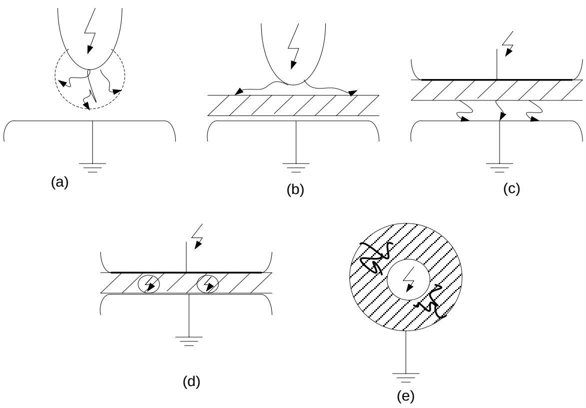

Figure2: Various discharges a) Corona discharge b) Surface discharge d) Partial discharge

FACTORS AFFECTING PARTIAL DISCHARGE (PD)

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

1. Applied voltage

When the applied voltage is increased, the electric field is enhanced and the electron generation rate is increased. As a result more PDs will occur. High voltage ranging from 4 KV to 20 KV is applied to the simulation model to observe PD activity due to the presence of void, which is done using Matlab/Simulink.

2. Different sample materials

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

TABLE-I: Different Sampling Materials

Material	**Dielectric constant Єr**
Air	1
Alumina porcelain	10
Bakelite	3.5-5.0
Cross-Linked Polyethylene (XLPE)	2.4
Epoxy Resin	3.6
Glass	3.7-10
Hard paper (Laminated)	4.5
Marble	8
Mica	2.5-7.0
Oil paper	4
Paper	2-3
Paper Impregnated	5
Polypropylene resin	2
Polyvinyl Chloride (PVC)	3.4
Porcelain	5-7
Press board	4
Rubber	3
Transformer oil (Mineral)	2.2
Vegetable oil	2.5
Vulcanized Rubber	7
Wood (Dry)	2-6

3. Different void size

In the insulation of power equipment, voids are one of the main factors which cause PD and its variation in size has great effect on the characteristics of PD. The lifetime of insulation, very much depended on the size of the void. Smaller size of void takes longer time to harm the insulation. Using Matlab simulated the behavior of PD in insulation system with different void size is studied.

PARTIAL DISCHARGE MODELLINGTHREE CAPACITANCE MODELS

A partial Discharge (PD) model using a three-capacitor circuit model or ‘a-b-c’ model representing an isolated cavity within a dielectric material has been developed. 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 PD 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 not an equipotential 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 figure3 shows the typical three-capacitance equivalent circuit or 'abc' model of a cavity within a dielectric material. $C_{a'}$ and $C_{a''}$ represent the capacitance in the material which is cavity-free, $C_{b'}$ and $C_{b''}$ represent the capacitance in the material in series with the cavity, C_c represents the cavity capacitance.

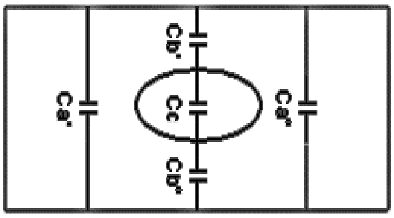

Figure3: Typical three-capacitance equivalent circuit or 'abc' model

The simplified equivalent circuit can be derived from the geometry, as shown in Figure4, where C_a is the equivalent parallel capacitance of $C_{a'}$ and $C_{a''}$, 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} and 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.

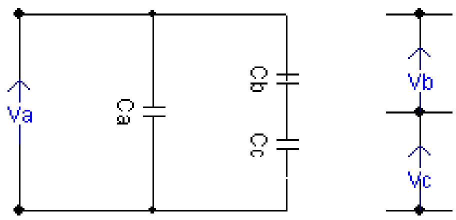

Figure4: The simplified equivalent circuit

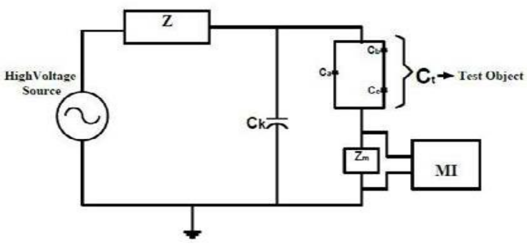

Figure5: The Experimental/Simulation arrangement of the simplified equivalent circuit

The three capacitance equivalent circuit diagram representing PD in a cavity. The PD 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

PD CHARGE MAGNITUDE
In this model, since the discharge process is modelled. The charge magnitude can be calculated numerically. The real and apparent charge magnitudes, $q_{pd}$are calculated by time integration of current, I(t) owing through the cavity and through the ground electrode during the- PD time interval,

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

The current I, through the ground electrode is calculated by integration of current Density, J over the ground electrode surface area, where J depends on the electric field distribution. Since the electric field distribution on the ground electrode is not uniform due to the presence of the cavity, the field distribution in the whole cavity and the material is calculated using the MATLABmethod to determine the PD apparent charge magnitude. Therefore, the advantage of the use of MATLABover classical lumped parameter modelling is that it facilitates dynamic calculation of both real and apparent charges.

BREAKDOWN DUE TO INTERNAL DISCHARGES
Solid insulating materials contain voids or cavities within the medium or at the boundaries between the dielectric and the electrodes. These cavities are generally filled with a medium of lower dielectric strength, and the dielectric constant of the medium in the voids is lower than that of the insulation. The electric field strength in the voids is higher than that across the dielectric. Therefore, even under normal working voltages the field in the voids may exceed their breakdown value, and breakdown may occur.
Let us consider a dielectric between two conductors as shown in Figure 4, where, C_c: capacitance of the void or cavity. C_b: capacitance of the dielectric which is a series with the void and C_a: capacitance of the rest of the dielectric.

The voltage across the void, V_C is given by,

$$Vc = \frac{V * d1}{d1 + \left(\frac{€0}{€1}\right) d2}$$

Where, d1 and d2 are the thickness of the void and the dielectric respectively, having permittivity €0 and€r.
Usually d1 << d2, and we assume the cavity is filled with a gas, then;

$$V1 = V * €r \left(\frac{d1}{d2}\right)$$

Where €r =the relative permittivity of dielectric.
When a voltage V_a is applied, V_a reaches the breakdown strength of the medium in the cavity V_c and breakdown occurs. 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 applied voltage. The voltage and the discharge current waveforms are shown in Figure. These internal discharges (also called partial discharges, PD) have the same effect as treeing on the insulation.

II. WAVELET TRANSFORM

A. ERROR SIGNAL GENERATION

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

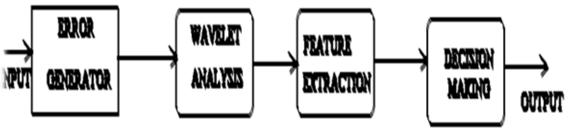

Figure 6: Proposed Disturbance Detection Scheme

B. WAVELET TRANSFORM ANALYSIS

The wavelet analysis block transforms the error signal into different time-frequency scales. The wavelet transform provides information about the frequency content of a signal similar to the Fourier Transform (FT). However, contrary to the FT, wavelet transform is able to focus on short time Intervals for high-frequency components and long intervals for low-frequency components, thus making it a well suited tool for analyzing high-frequency transients in the presence of low-frequency components. The Wavelet transform is inherently more appropriate for non-stationary and non-periodic wideband signals.

The wavelet transform of a continuous signal is:

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

Where
Ψ is the wavelet basis function (mother wavelet),
a is the time scaling factor and
b is the time shifting factor.

The values of wavelet coefficients F (a, b) represent the projection of f(t) along$\Psi(\frac{t-b}{a})$. Assume the center and width of function Ψ (t) is zero and Δ_t in time domain, and zero and Δ_w in the frequency domain. Then, the function $\Psi(\frac{t-a}{b})$ is centered at band has width of $a\Delta_t$ in time domain and (1/a) Δ_w in the frequency domain. To avoid generating redundant information, the base functions 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, ε, $\mathbb{Z}$, and $\mathbb{Z}$ is the set of integers. Setting $a_0$and b_0 to 2 and 1 respectively results in an orthonormal basis of L^2 (IR) which is called dyadic- orthonormal wavelet transform. With this ortho-normal basis, an algorithm of decomposing a signal into different time-frequency scales can be used which is called Multiresolution Signal Decomposition (MSD).

B1. WAVELET IMPLEMENTATION

The filter bank configuration of Fig.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 filters and scaling/wavelet functions (Φ (t) /Ψ (t)) can be written as

$$\phi(t)=\sqrt{2}\sum_n h[n]\phi(2t-n)$$

$$\Psi(t)=\sqrt{2}\sum_n g[n]\phi(2t-n)$$

In general output c_m and scale $s_m$are expressed as:
$c_m[n] = c_{m-1}[n] *h[n/2^{m-1}]$
$s_m[n] = c_{m-1}[n] *g[n/2^{m-1}]$
Where:
$c_0[n] \triangleq e[n]$
$h\left(\frac{n}{2}\right)=\begin{cases} h[k] & ,n=2k \\ 0 & else \end{cases}$

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.

B2. PROPERTIES OF MOTHER WAVELET

Wavelets are families of functions generated from one single function, called as an analyzing wavelet or mother wavelet.

The mother wavelet must have the following properties:
a) It must be oscillatory
b) It must quickly decay to zero
c) It must have a zero average
d) It must be band- pass
e) It must be integrated to zero

B3. ADVANTAGE OF WAVELET TRANSFORM OVER FOURIER TRANSFORM

- Wavelet provide 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.
- 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 of interest in power engineering.

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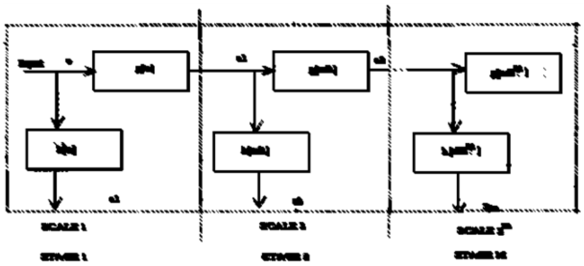

Figure 7:- Realization of wavelet transforms using a filter bank.

C. FEATURE EXTRACTION

The purpose of the feature extraction block is to identify Specific signatures of the disturbances in the system. For example, a short circuit and a capacitor-switching incident result in disturbed voltages with different features. The wavelet transform breaks down the error signal into different time-frequency scales. Each scale represents the error signal in the corresponding band. The energy content of the scale signals relative to the error signal changes depending upon the type of disturbance. Therefore, the relative amplitudes of the scale signals with respect to the error signal are selected as the discriminating features.

D. DECISION MAKING

A function of the decision making block is to discriminate type of disturbances (L-G fault and Capacitor switching) as precisely as possible.

The characteristic of each disturbance, example a faulty, Capacitor switching, depends on several factors, for example (1) type of event, e.g. single-phase-to-ground or phase-to-phase fault,(2) location of the event, (3) time instant of event and (4) network configuration.

In the decision making block, a probability function is defined for the features and the decisions is made using the maximum linked (ML) criteria. This method is used here to discriminate various types of disturbances in a power system.

III. EXPERIMENTAL SET- UP ARRANGEMENT

Figure8: Arrangement of Experimental setup

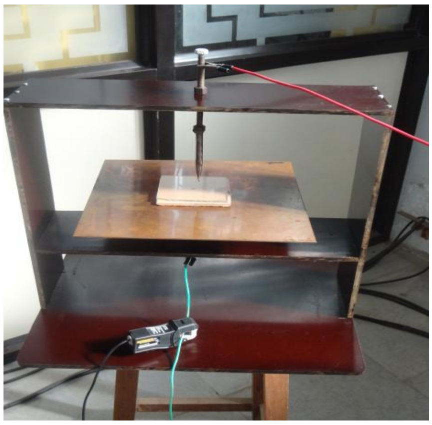

Figure 9: Sample under testing

RESULTS & DICUSSION

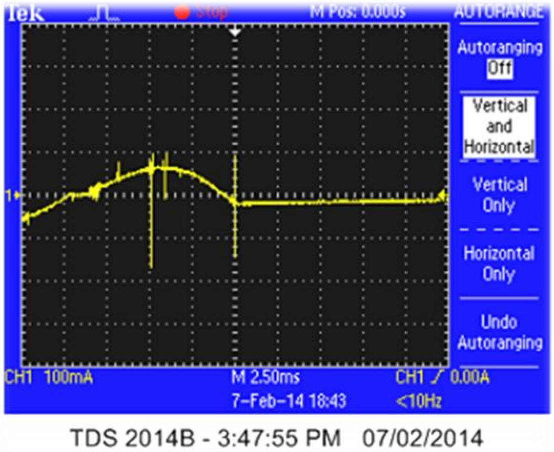

Figure10: Signal received from laboratory sample testing

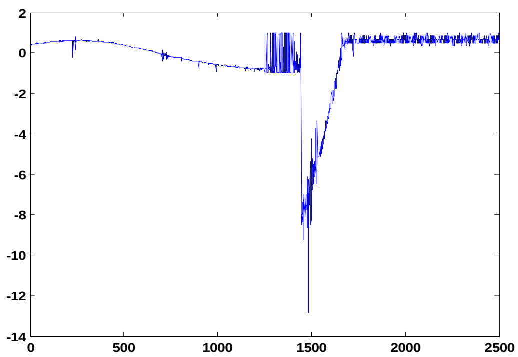

Figure 11: Original partial discharge Signal

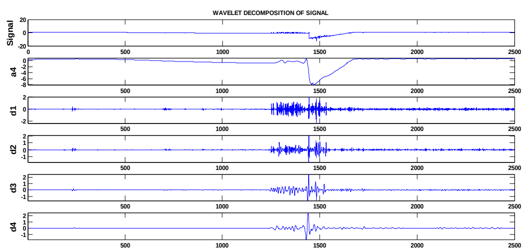

Figure 12: Db4, Decomposition level-4

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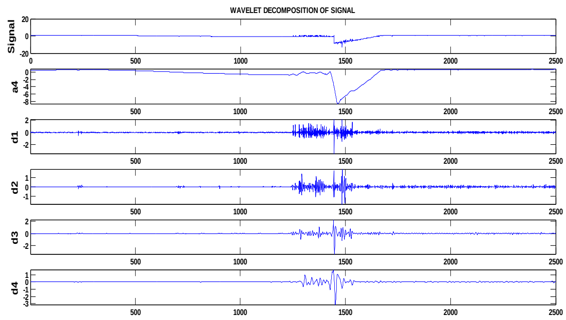

Figure 13: Using sym4

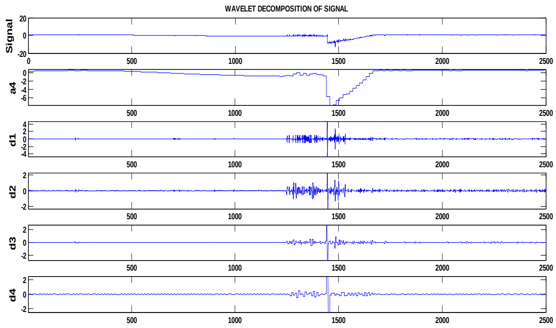

Figure 14: Using Haar

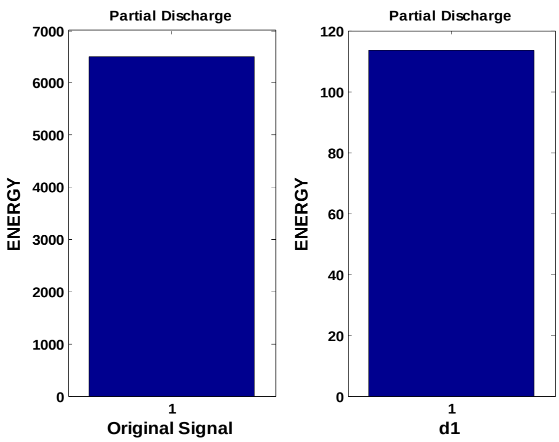

Figure 15: Signal Energy using db4

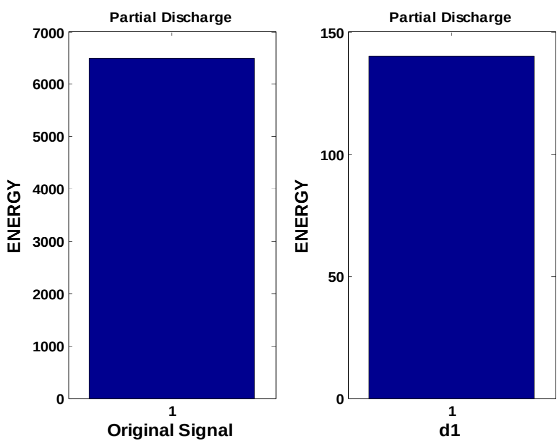

Figure 16: Signal Energy using Sym4

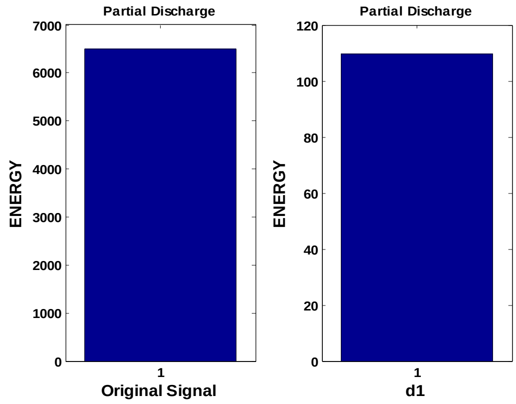

Figure 17: Signal Energy using Haar

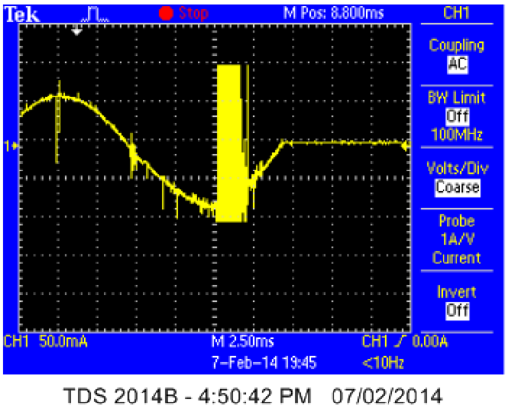

Figure 18: Signal Captured using DSO

The simulation results are formulated for the partial discharge characteristics detection for both solid and liquid 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 earlier in both the configuration in the solid insulator than the liquid insulating oil. Similarly from the simulation results 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 are more in the solid material than the liquid insulating material due to the presence of the air void and others impurities.

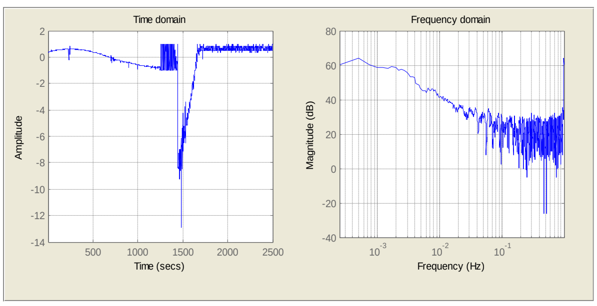

Figure 19: Frequency and time domain of captured signal

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ISO 3297:2007 Certified
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Thus, on the basis of partial discharge characteristics oil is a good insulating material than the solid material and can be used in the high voltage equipment's for a specific application that is for low partial discharge requirements.

IV. CONCLUSION

Partial discharge is the main problem in high voltage power equipment system. Therefore, detection and measurement of partial discharge are necessary to keep the equipments in healthy condition during their operation. In this work simulation study had been carried out for partial discharge measurement and detection using the MATLAB. From the simulation studies, it is observed that in each case the partial discharge detects earlier at the low values of applied high voltages and insulation breakdown occurs at the lower range of 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. MATLABbased model has been developed from the equivalent electrical model of an insulators to observe the characteristics of partial discharge activity inside the solid and liquid insulator at different applied voltage which arranges from 0-20 KV at a constant power frequency (f=50 Hz). It is found that with the increase in applied voltage to the void 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 pulse can be processed with the help Wavelet Transform for time, frequency analysis for better study of PD measurement and detection

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