SPECTRUM ANALYSIS OF PARTIAL DISCHARGE SIGNALS

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ABSTRACT

Partial Discharge (PD) is the major cause for insulation degradation. These discharges occur due to presence of voids or cracks or impurities inside the insulation. There are different types of partial discharges occurring in the insulation system depending on the nature and location of source of discharge. Commonly observed discharge types in rotating machines are delamination, void discharge, end winding discharge, surface discharge etc. Different discharge sources produce different Phase Resolved Partial Discharge (PRPD) patterns. Physical processes taking place at different locations with different intensities during occurrence of partial discharges are responsible for such varying behaviour. The PD detector gives the PRPD data. The values of number of PD pulses (N) and Apparent Charge (Q) from this data is used to calculate effective charge. This effective charge is used to obtain the spectrum plots for delamination type of discharge with increasing applied voltage. Simple Digital Signal Processing (DSP) based tools are used to obtain the frequency spectrum from the PD data. It is observed from these results that the even though the amplitude of the effective charge increases for increase in applied voltage, the spectrum of the PD remains same. This paper proposes spectrum analysis as one of the method for PD source identification.

KEYWORDS: *Partial Discharge, High Voltage Insulation System, Rotating Machines, Digital Signal Processing, Frequency Spectrum.*

I. INTRODUCTION

Partial Discharge (PD) is the process of electrical discharges which do not completely bridge the electrodes. Such discharges occur inside the insulation or at the insulation-electrode interface. Based on the source, PDs are classified as internal, external, corona etc type of discharge. The PD is responsible for progressive deterioration of insulation, ultimately leading to electrical breakdown of the high voltage insulation system. The types of discharges commonly seen in generator are slot discharge, delamination, surface discharge, end winding discharge, gap discharge, bar-to-bar etc. PD measurement is an important tool for diagnosis of the health of insulation. Apparent charge is readily available through PD detectors which also captures the number of PD pulses of different magnitudes. The PD pulses are generated in the range of nanoseconds having frequencies varying from KHz to hundreds of MHz.

PD pulses are stochastic in nature. Different methods are adopted by several researchers to analyze the PD. Analysis of these stochastic characteristics of the PD pulses is carried out in terms of pulse-height, pulse-phase, rise time and the spectrum of PD. Broadly, there are three different categories of PD pulse data patterns gathered from the digital PD detectors during the experiments. They are: phase-resolved data, time-resolved data and data having neither phase nor time information [1]. Several statistical operators like skewness, kurtosis etc are used for the classification of the type of defect [2, 3, 4]. Different signal processing techniques can also be used for feature extraction for PD analysis [1, 5]. Among the most fundamental and useful tools in digital signal processing (DSP) is the estimation of the Power Spectral Density (PSD) of a discrete time deterministic and stochastic process. There are different methods of PSD estimation [6]. Estimating spectrum is a fundamental tool used in DSP for analysis of stochastic processes. The frequency spectrum of PD in case of power transformer is used to locate source of PD [7, 8, 9]. Liu Yunpeng *et. al.* [10] proposes a method of pattern recognition based on spectrum of PD gray-scale image using six kinds of typical discharge models. Spectrum of electromagnetic (EM) noise occurring due to PD [11, 12] is also used to analyze PD. PD occurring in Gas Insulated Switchgear (GIS) is detected using the Wavelet transform by finding the spectrum of EM wave emitted from the PD. The frequency dependence of PD is studied in [13, 14, 15] by modelling the PD spectrum for a cavity inside the insulation. Online PD detection can be performed on cables using the spectrum analyzer. The suitability and sensitivity of the method is studied using the frequency spectrum of measured PD [16]. Z. Liu *et. al.* has studied propagation of PD pulses in the power cables using the mathematical model for the PD pulse [17]. The optical method is one of the methods used for PD detection. The optical spectrum of PD gives important information about type of PD since the optical spectrum of different types of discharges is not the same [18]. The physical processes of recombination and ionization during the PD mechanism varies as per the PD location and the applied voltage magnitude. The spectrum analysis can be used as a tool to explore frequency characteristics for different types of PD. The work is carried out on actual PD data obtained from the measurements on rotating machines.

Spectral density estimation gives the spectral density of a random signal from a sequence of time samples. Depending on what is known about the signal, estimation techniques can involve parametric or non-parametric approaches, and may be based on time-domain or frequency-domain analysis. For example, a common parametric technique involves fitting the observations to an autoregressive model. A common non-parametric technique is the periodogram.

The methodology of estimation of spectrum of PD and its application to delamination type of discharge is discussed in section 2. The results thus obtained are discussed in section 3.

II. SPECTRUM ANALYSIS OF PD

The PD of different magnitudes occurs at different time instances which increase / decrease with applied voltage. The PD measuring system consists of the PD detector, coupling capacitor, external calibrator, measuring impedance. PDs are detected using a PD detector in the rotating machines when they are subjected to high applied voltages. The PDs of different magnitudes occurring at different instances are obtained at different phase angles and at different applied voltages. The pattern thus obtained are called as Phase Resolved PD (PRPD) patterns. The PRPD patterns detected by any PD detector, the magnitude of Q Vs. Ø is plotted and number of PD pulses (N) is also indicated for a given number of cycles. Thus data obtained from PD detectors contain plot of N & Q for phase angle between 0^o to 360^o. After analyzing various practical data, it was found that product of N and Q gives better information on PD than using just Q [19]. The product is thus termed as effective charge and is given by

$$Q_{eff} = N \times Q \quad (1)$$

where Q = Apparent Charge. Spectrum of this Q_{eff} is obtained for individual type of discharge in case of generators for increasing applied voltage

Different types of PDs commonly observed in rotating machines are Slot, delamination, end winding, surface, void discharges etc. The spectral analysis in case of delamination is discussed in this section.

Two types of delamination exist. The first one pertains to delamination of the ground-wall insulating tape itself, whereas the other one is related to delamination of the insulation close to the inner conductor strands [2]. Delamination is the deterioration of layers of insulation. Typical characteristic PRPD pattern for delamination is as shown in Figure 1a. Figure 1b shows the corresponding NQ plot. It is clearly seen from Figure 1 that the PD activity in positive & negative half cycle is symmetric. Other than symmetry in two half cycles, the characteristics of delamination discharge also include abrupt increase of PD activity at the starting of each half cycle. Figure 1b shows that the plot of effective charge (Q_{eff}) resembles the PRPD pattern (Figure 1a). It is observed that Q_{eff} gives more appropriate information than just Q and can be used as an analytical parameter. Therefore, the spectrum of effective charge is the parameter used in this analysis.

The spectrum has been obtained by applying Fourier transform of the auto-correlated signal of Q_{eff}. Here, the Q_{eff} values are for all phase angles of sinusoidal applied voltage (i.e. there are 360 values of Q_{eff})._After performing auto-correlation the number of samples gets doubled resulting 720 samples.

Therefore, the sampling frequency is 36 kHz. The frequency values in analog domain can be obtained from the x-axis values of the spectrum plots. The value of frequency of x^{th} sample is equal to $[(f_s.x)/720]$, where f_s is the sampling frequency. Now, the x-axis of the spectrum plot of figure 2 shows that the PD activity occurs till 100^{th} sample approximately. Figure 2 shows spectrum of effective charge for delamination type of discharge. Thus the frequency of PD in this case is of 5 kHz.

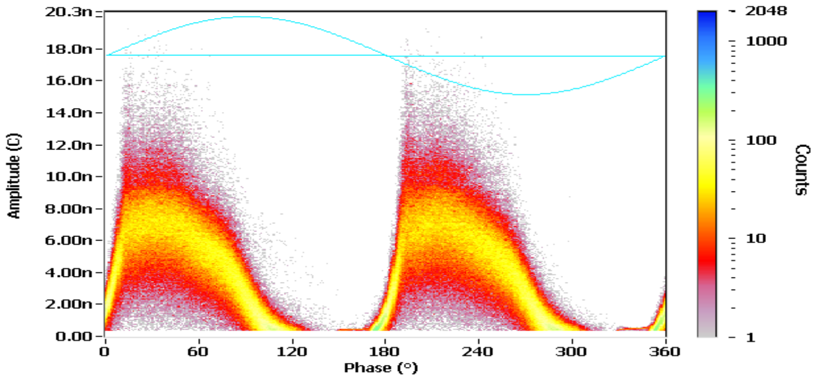

Figure 1a: PRPD Pattern

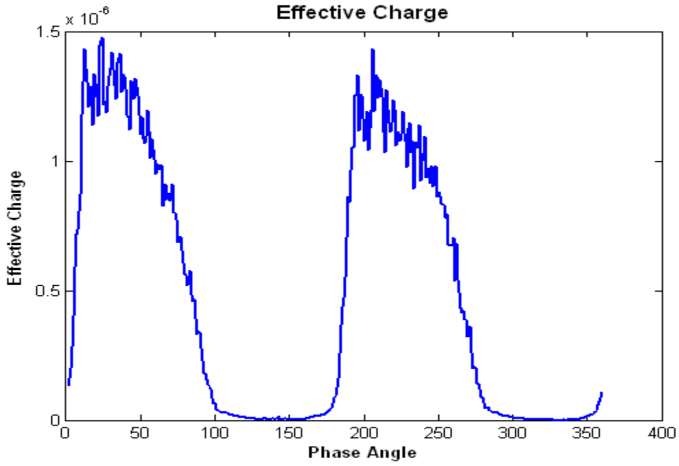

Figure 1b: Envelope of Q_{eff} versus phase angle

Figure 1. Characteristics of Delamination type of PD

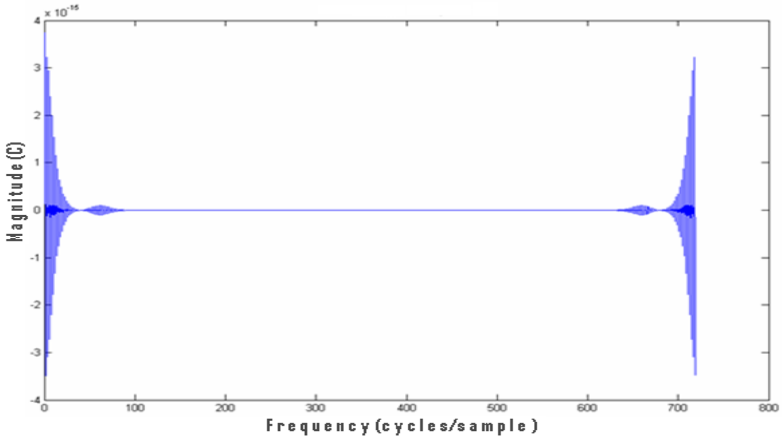

Figure 2. Spectrum of Q_{eff} for delamination type of PD

A program is written in MATLAB (Mathworks Inc.) software to perform the estimation of spectrum from the PD data. The algorithm is as follows:

1) Take the values of N and Q from the PD data as the input. Construct the plot of effective charge $[Q_{eff} = (N \times Q)]$ versus the phase angle as shown in figure 1(b).
2) Perform the Auto-Correlation of this Q_{eff} signal.

3) Take the Fourier Transform of this Auto-correlated Signal. This gives the Power Spectrum. Density (PSD) of the Q_{eff} or the spectrum of Q_{eff} as shown in figure 2.

Now, to observe the PD activity from the spectrum plot more clearly, the following steps are followed.

a) The area under the Q_{eff} curve (say, for example as shown in figure 3a) is calculated for every phase window of 10^o. This gives the representation of the same information in the normalized form.
b) Perform steps 2 and 3 mentioned above and obtain spectrum plot (for example, figure 3b gives normalized spectrum plot using the data from figure 3a).
c) Obtain the spectrum for voltages 3 kV to 6 kV.
d) Observe and study the changes in spectrum of PD for increase in the applied voltage.

The spectrum for delamination with increasing voltage is shown in figure 3 to 6.

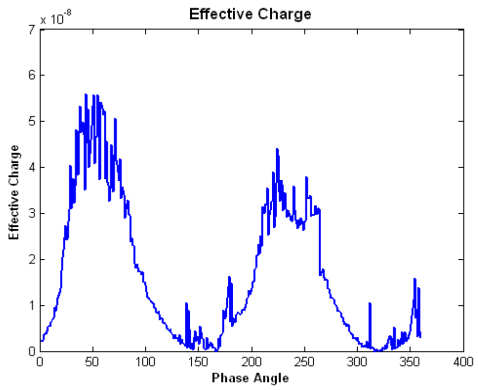

Figure 3a. Envelope of Q_{eff} at 3 kv

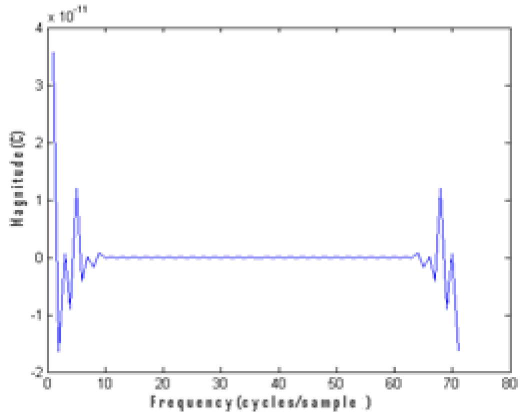

Figure 3b. Spectrum of Q_{eff} at 3 kv

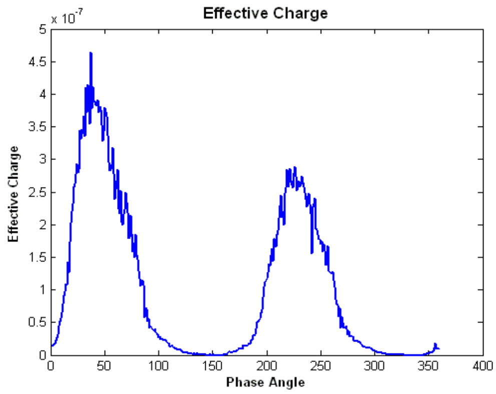

Figure 4a. Envelope of Q_{eff} at 4 kv

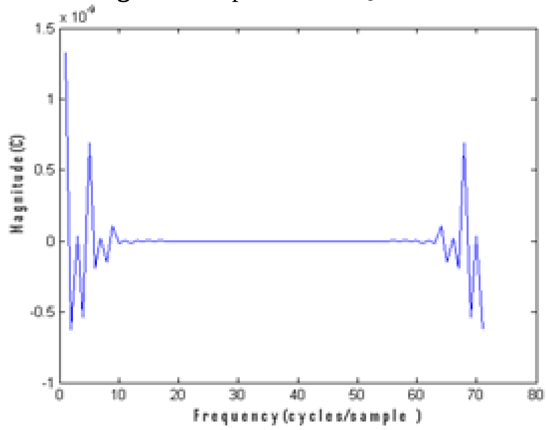

Figure 4b. Spectrum of Q_{eff} at 4 kv

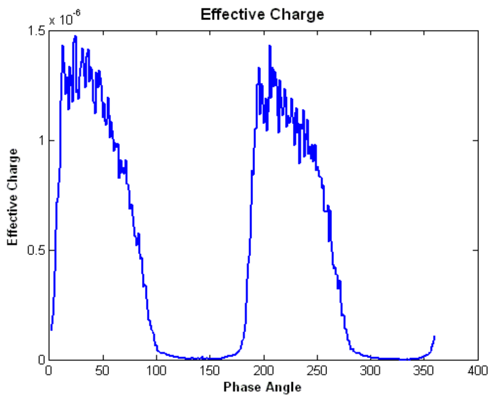

Figure 5a. Envelope of Q_{eff} at 5 kv

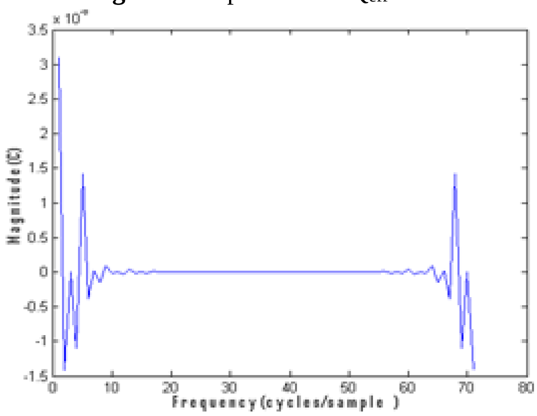

Figure 5b. Spectrum of Q_{eff} at 5 kv

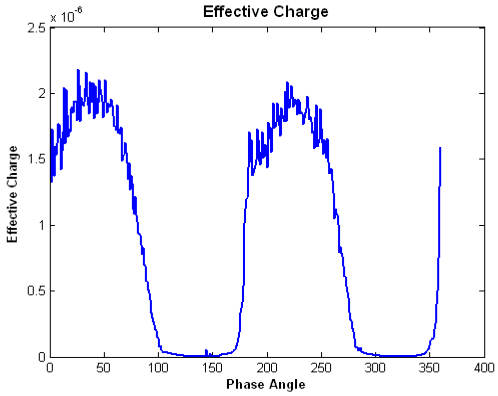

Figure 6a. Envelope of Q_{eff} at 6 kv

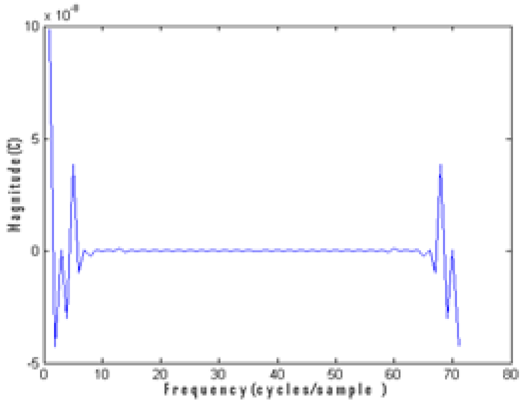

Figure 6b. Spectrum of Q_{eff} at 6 kv

Figure 3-6. Envelope and Spectrum of Effective Charge for delamination discharge for 3 to 6 kV

III. Results and Discussion

The plot of effective charge resembles the PRPD pattern. Figure 3a to 6a shows the plot of effective charge in case of delamination discharge for increasing applied voltage i.e. from 3 to 6 kV respectively. This data is of 11 kV generator coil. The inception voltage observed in this case is of 3kV, so the plots above inception are only considered in figure 3-6 below. It can be seen from figure 3a to 6a that as the voltage increases, the magnitude of PD increases. Also, the plot of Q_{eff} shows the characteristics of delamination when there is substantial PD activity i.e. at higher voltages; as shown in figure 5a and 6a. The characteristics of delamination include symmetry of PD activity in positive and negative half cycles of phase angle of applied voltage [2]. The spectrum details (the crests and troughs) for delamination from figure 2 are not clearly visible. So, the area under the curve of Figure 1b is calculated with window size of 10° and then the spectrum is estimated for these area under the curve values. Therefore the spectrum plots of figure 3b to 6b are the normalized plots, as compared to figure 2, for voltage magnitudes 3 to 6 kV respectively. It can be observed from the magnitude (Y-axis) of the plots of figure 3b to 6b that, the magnitude of spectrum is increasing with increase in applied voltage. The maximum magnitude of effective charges noted are 0.04 nC, 1.5 nC, 3 nC and 100 nC for the applied voltage 3 kV, 4 kV, 5kV and 6kV respectively. The spectrum of PD activity for all voltages is concentrated up to 10^{th} sample approximately i.e. the frequency of PD is 5KHz. It can be concluded that, even though the pattern of effective charge is changing with respect to applied voltage, the spectrum of effective charge does not change. The discharge mechanism is a highly random phenomena and it depends on the parameters like geometry of the voids, material properties etc. The parameters in this case; the internal voids between the lamination layers causing delamination does not change drastically with the applied voltage. This may be the reason that similar spectrum is obtained. Also, the ionization growth taking place at the discharge site may also not be getting altered since the physical conditions at the discharge site are not changing drastically.

These conclusion sticks to one particular type of discharge i.e. delamination in this case. However, it can be said that for some other types of discharge say Slot discharge, surface discharge etc., frequency spectrum may not be same as that of delamination.

IV. Conclusion

Effective charge is estimated using apparent charge (Q) and number of pulses (N). The values of N & Q are extracted from the PD data obtained from the PD detector. The effective charge is used as the analytical parameter. The spectrum of this effective charge is estimated and studied for delamination type of discharge in this paper. It is concluded that the frequency spectrum does not change for same discharge source even though the applied voltage is increasing. Spectrum for various other types of PDs needs to be investigated. If the spectrum obtained from different PD sources are different then PD source identification may be possible from the same.

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