Analysis of Partial Discharge using Phase-Resolved (n-q) Statistical Techniques

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ABSTRACT

Partial discharge (PD) patterns are an important tool for the diagnosis of high voltage (HV) insulation systems. Human experts can discover possible insulation defects in various representations of the PD data. One of the most widely used representations is phase-resolved PD (PRPD) patterns. In order to ensure reliable operation of HV equipment, it is vital to relate the observable statistical characteristics of PDs to the properties of the defect and ultimately to determine the type of the defect. In this work, we have obtained and analyzed phase-resolved discharge patterns using parameters such as mean, standard deviation, variance, skewness and kurtosis.

Keywords - *Partial Discharge, Phase-resolved, Statistical parameters*

1. INTRODUCTION

PD is a localized electrical discharge that partially bridges the insulation between conductors and which may or may not occur adjacent to a conductor. [1] In general, PDs are concerned with dielectric materials used, and partially bridging the electrodes between which the voltage is applied. The insulation may consist of solid, liquid, or gaseous materials, or any combination of them. PD is the main reason for the electrical ageing and insulation breakdown of high voltage electrical apparatus. Different sources of PD give different effect on insulation performance. Therefore, PD classification is important in order to evaluate the harmfulness of the discharge. [2]

PD classification aims at the recognition of discharges of unknown origin. For many years, the process was performed by investigating the pattern of the discharge using the well known ellipse on an oscilloscope screen, which was observed crudely by eye. Nowadays, there has been extensive published research to identify PD sources by using intelligent technique like artificial neural networks, fuzzy logic and acoustic emission. [2]

The recent upsurge of research on PD phenomena has been driven in part by development of new fast digital and computer-based techniques that can process and analyze signals derived from PD measurements. There seems to be an expectation that, with sufficiently sophisticated digital processing techniques, it should be possible not only to gain new insight into the physical and chemical basis of PD phenomena, but also to define PD 'patterns' that can be used for identifying the characteristics of the insulation 'defects' at which the observed PD occur. [3] One of the undoubted advantages of a computer-aided measuring system is the ability to process a large amount of information and to transform this information into an understandable output. [4]

There are many types of patterns that can be used for PD source identification. If these differences can be presented in terms of statistical parameters, identification of the defect type from the observed PD pattern may be possible. As each defect has its own particular degradation mechanism, it is important to know the correlation between discharge patterns and the kind of defect. Therefore, progress in the recognition of internal discharge and their correlation with the kind of defect is becoming increasingly important in the quality control in insulating systems. [4] Researches have been carried out in recognition of partial discharge sources using statistical techniques and neural network. In our study, we have tested various internal and external discharges like void, surface and corona using statistical parameters such as mean, standard deviation, variance, skewness and kurtosis in phase resolved pattern (n-q) and classified the partial discharge source for unknown partial discharge data.

2. STATISTICAL PARAMETERS

The important parameters to characterize PDs are phase angle φ, PD charge magnitude q and PD number of pulses n. PD distribution patterns are composed of these three parameters. Statistical parameters are obtained for phase resolved pattern (n-q).

2.1. Processing of data (*φ, q and n*)

Statistical analysis is applied for the computation of several statistical operators. The definitions of most of these statistical operators are described below. The profile of all these discrete distribution functions can be put in a general function, i.e., $y_i=f(x_i)$. The statistical operators can be computed as follows:

$$\text{Mean Value: } (\mu) = \frac{\sum_{i=1}^{N}(x_i)\, f(x_i)}{\sum_{i=1}^{N} f(x_i)} \qquad \ldots\ldots\ldots(1)$$

$$\text{Variance: } (\sigma^2) = \frac{\sum_{i=1}^{N}(x_i-\mu)^2\, f(x_i)}{\sum_{i=1}^{N} f(x_i)} \qquad \ldots\ldots\ldots(2)$$

$$\text{Skewness } (S_k) = \frac{\sum_{i=1}^{N}(x_i-\mu)^3 f(x_i)}{\sigma^3 \sum_{i=1}^{N} f(x_i)} \qquad \ldots\ldots\ldots(3)$$

$$\text{Kurtosis: } (K_u) = \frac{\sum_{i=1}^{N}(x_i-\mu)^4 f(x_i)}{\sigma^4 \sum_{i=1}^{N} f(x_i)} - 3 \qquad \ldots\ldots\ldots(4)$$

$$\text{Standard Deviation} = \sqrt{Variance} \qquad \ldots\ldots\ldots(5)$$

where,

x = number of pulses n,

f(x) = PD charge magnitude q,

μ = average mean value of PD charge magnitude q,

σ = variance of PD charge magnitude q

Skewness and Kurtosis are evaluated with respect to a reference normal distribution. Skewness is a measure of asymmetry or degree of tilt of the data with respect to normal distribution. If the distribution is symmetric, Sk=0; if it is asymmetric to the left, Sk>0; and if it is asymmetric to the right, Sk<0. Kurtosis is an indicator of sharpness of distribution. If the distribution has the same sharpness as a normal distribution, then Ku=0. If it is sharper than the normal then Ku>0 else it is flatter i.e. Ku<0. [5][6]

3. RESULTS AND DISCUSSIONS

Analysis involves determining unknown PD patterns by comparing those with known PD patterns such as void, surface and corona. The comparison is done with respect to their statistical parameters. [7]

3.1. Phase resolved patterns (n-q)

The phase resolved patterns n-q are obtained for three known PD patterns: void, surface and corona (as discussed in 3.1.1) and three unknown PD patterns: data1, data2 and data3 (as discussed in 3.1.2). For all the following plots, x-axis is number of cycles (n) and y-axis is magnitude of charge (q).

3.1.1. 2D distribution of n-q for known PD patterns

Fig. 1(a), Fig. 1(b), Fig. 1(c), Fig. 1(d) and Fig. 1(e) are the n-q plot of mean, standard deviation, variance, skewness and kurtosis for void discharge respectively.

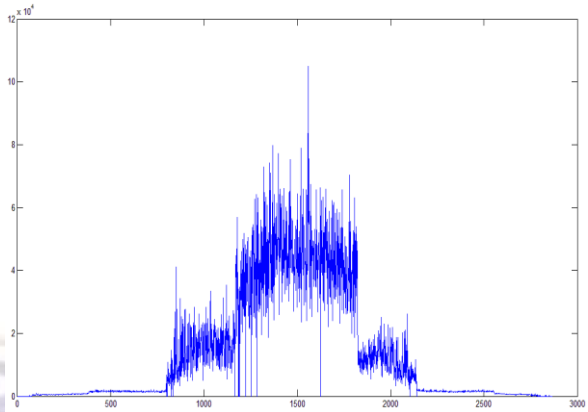

Fig. 1(a) Mean plot (n-q) of void discharge

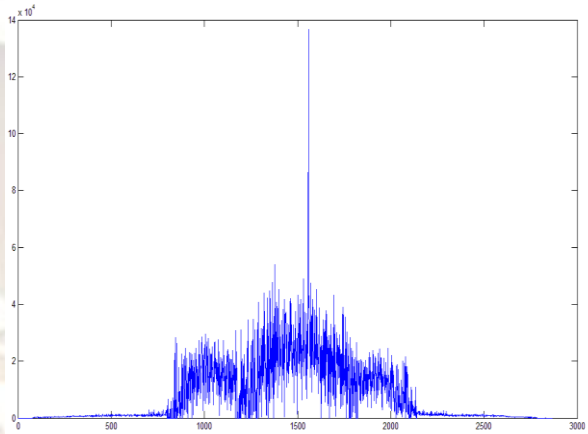

Fig. 1(b) Standard deviation plot (n-q) of void discharge

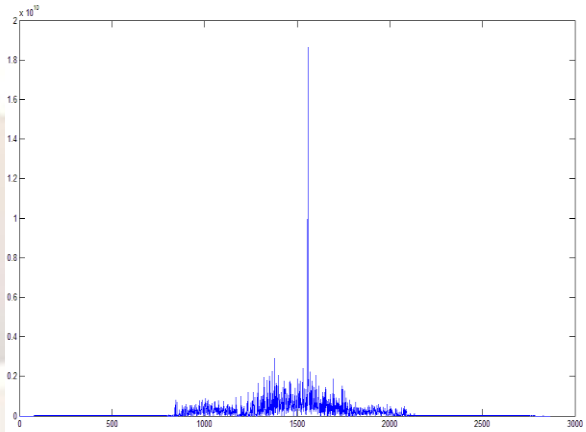

Fig. 1(c) Variance plot (n-q) of void discharge

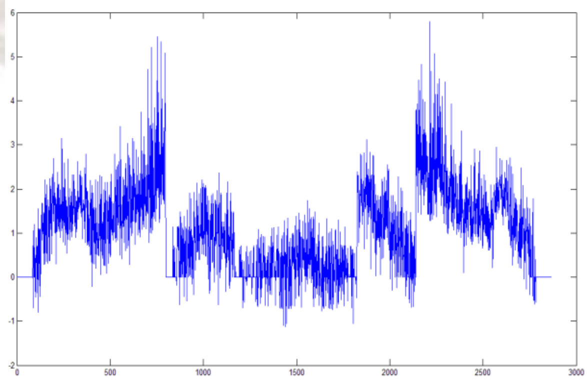

Fig. 1(d) Skewness plot (n-q) of void discharge

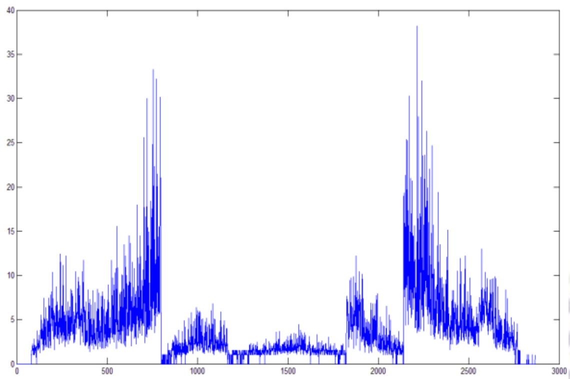

Fig. 1(e) Kurtosis plot (n-q) of void discharge

Referring to Fig. 1(a), Fig. 1(b) and Fig. 1(c) of void discharge, it can be seen there is a peak occurring somewhere after 1500 cycle, which is a void discharge and in Fig. 1(d) and Fig. 1(e) of skewness and kurtosis, the value decreases at that cycle where peak occurs.

Fig. 2(a), Fig. 2(b), Fig. 2(c), Fig. 2(d) and Fig. 2(e) are the n-q plot of mean, standard deviation, variance, skewness and kurtosis for surface discharge respectively.

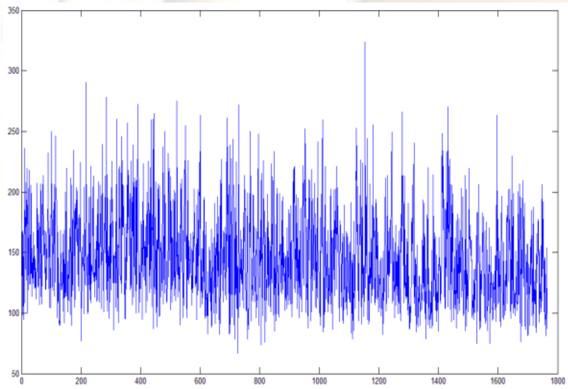

Fig. 2(a) Mean plot (n-q) of surface discharge

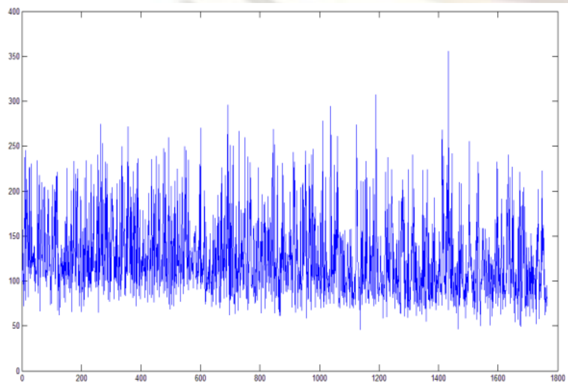

Fig. 2(b) Standard deviation plot (n-q) of surface discharge

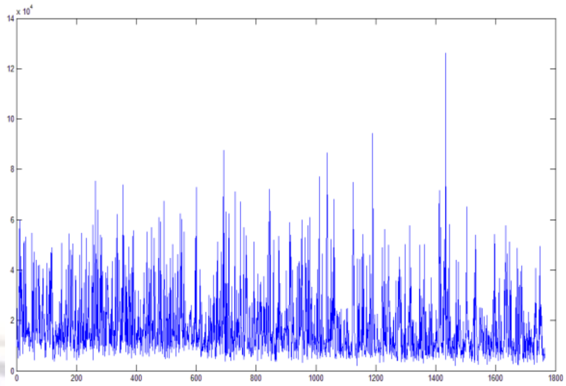

Fig. 2(c) Variance plot (n-q) of surface discharge

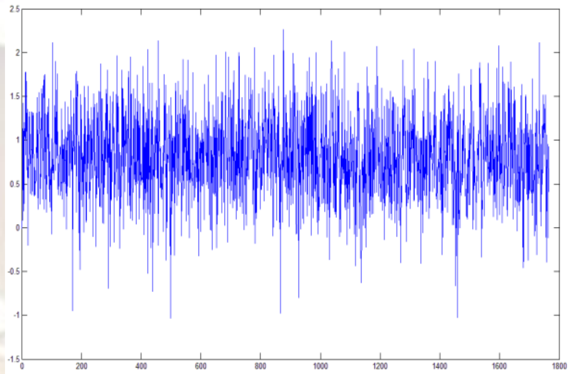

Fig. 2(d) Skewness plot (n-q) of surface discharge

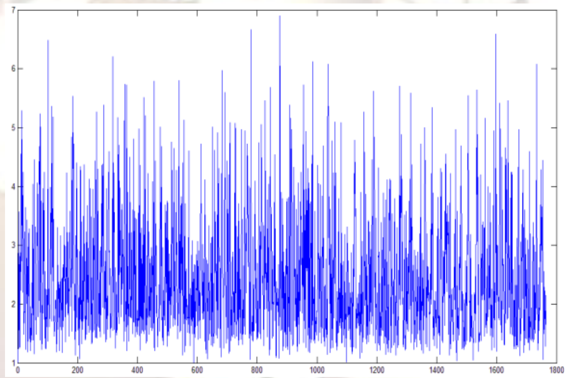

Fig. 2(e) Kurtosis plot (n-q) of surface discharge

In surface discharge, charges are distributed uniformly over all cycles for mean, standard deviation, variance, skewness and kurtosis as shown in Fig. 2(a), Fig. 2(b), Fig. 2(c), Fig. 2(d) and Fig. 2(e).

Fig. 3(a), Fig. 3(b), Fig. 3(c), Fig. 3(d) and Fig. 3(e) are the n-q plot of mean, standard deviation, variance, skewness and kurtosis for corona discharge respectively.

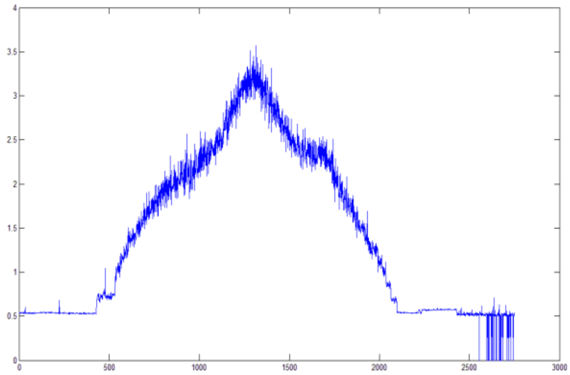
Fig. 3(a) Mean plot (n-q) of corona discharge

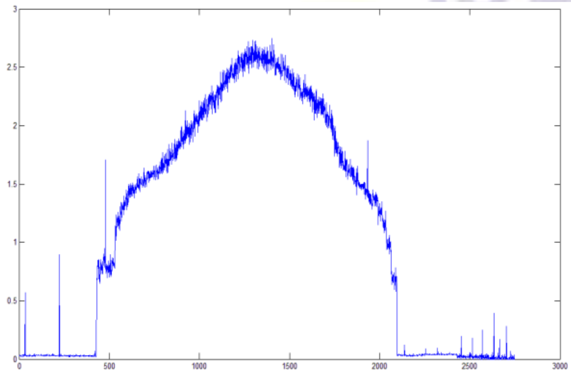
Fig. 3(b) Standard deviation (n-q) of corona discharge

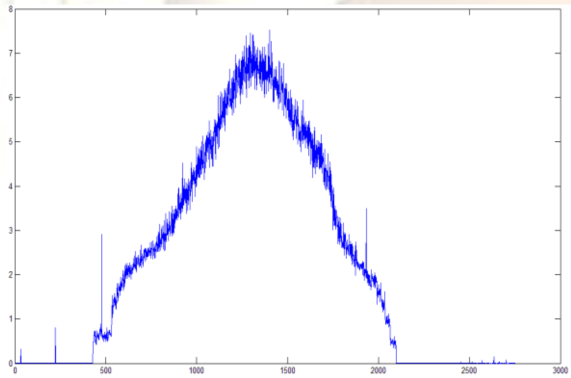
Fig. 3(c) Variance plot (n-q) of corona discharge

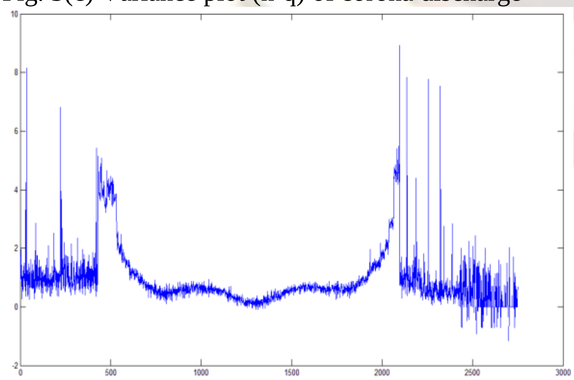
Fig. 3(d) Skewness plot (n-q) of corona discharge

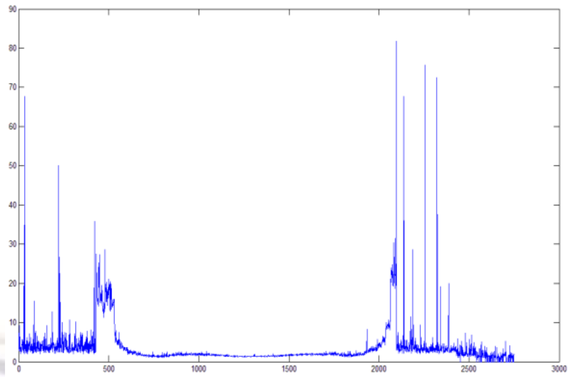
Fig. 3(e) Kurtosis plot (n-q) of corona discharge

Referring to Fig. 3(a), Fig. 3(b) and Fig. 3(c) of corona discharge, it can be seen the charges starts occurring after 500 cycle increasing somewhere up to 1200 cycle and then decreasing after 2000 cycle, and in Fig. 3(d) and Fig. 3(e) of skewness and kurtosis, the value decreases from 500 cycle till 2000 cycle.

3.1.2. 2D distribution of (n-q) for unknown PD patterns

Fig. 4(a), Fig. 4(b), Fig. 4(c), Fig. 4(d) and Fig. 4(e) are the n-q plot of mean, standard deviation, variance, skewness and kurtosis for data1 respectively.

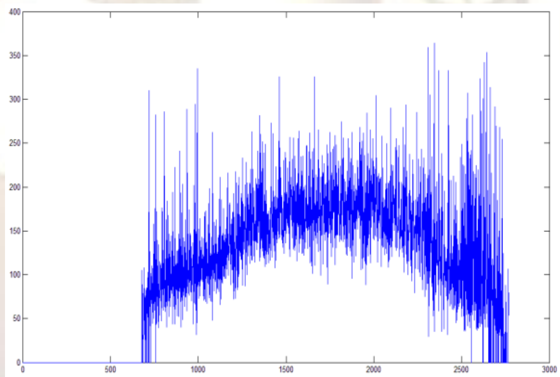
Fig. 4(a) Mean plot (n-q) of data1

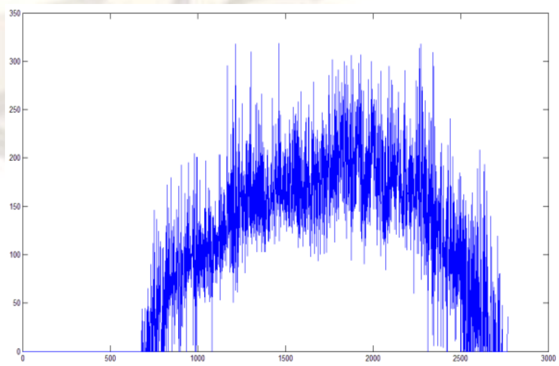
Fig. 4(b) Standard deviation plot (n-q) of data1

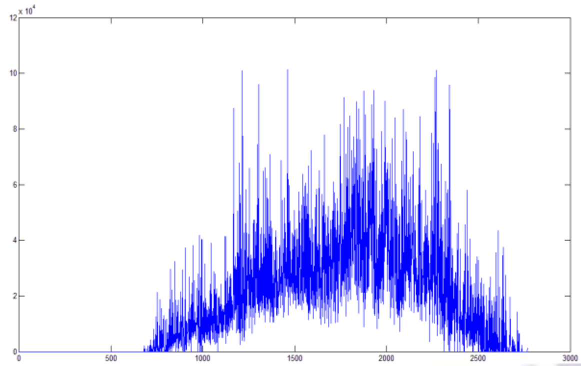

Fig. 4(c) Variance plot (n-q) of data1

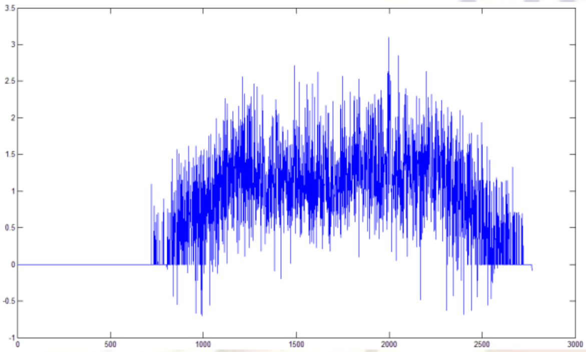

Fig. 4(d) Skewness plot (n-q) of data1

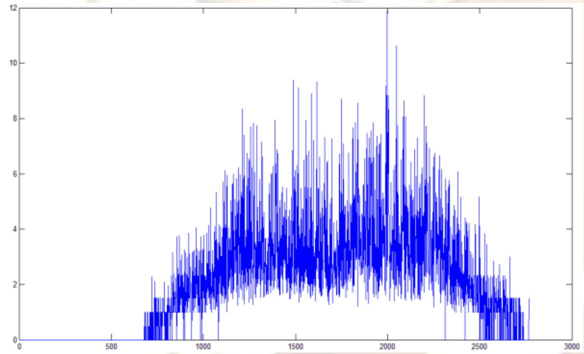

Fig. 4(e) Kurtosis plot (n-q) of data1

In Fig. 4(a), Fig. 4(b), Fig. 4(c), Fig. 4(d) and Fig. 4(e), the charges are uniformly distributed similar to surface discharge. Hence, it can be concluded that data1 is having surface discharge.

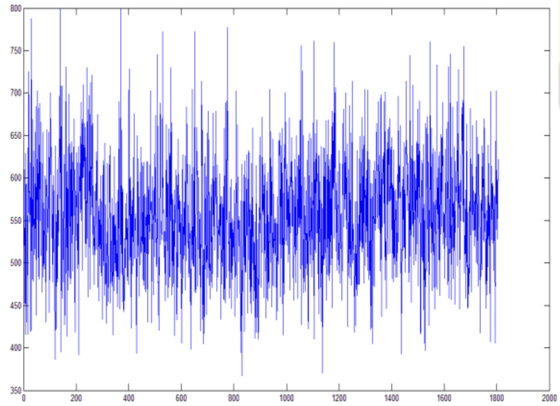

Fig. 5(a) Mean plot (n-q) of data2

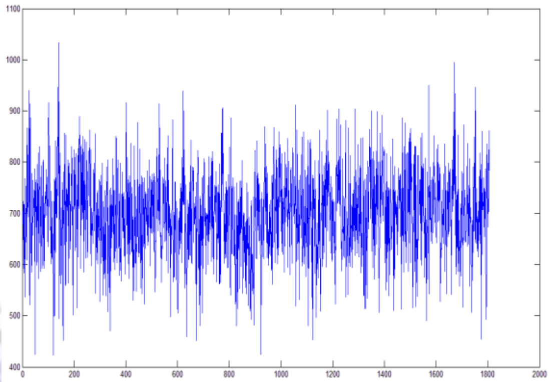

Fig. 5(b) Standard deviation plot (n-q) of data2

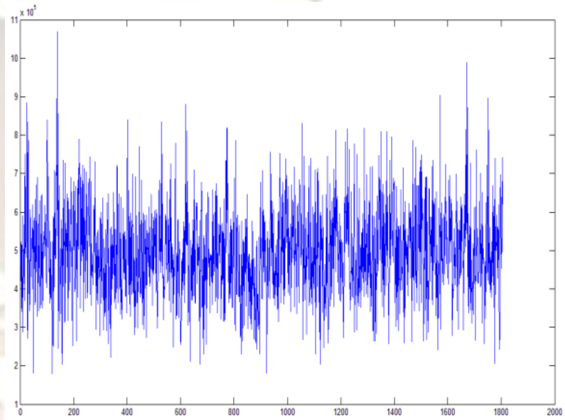

Fig. 5(c) Variance plot (n-q) of data2

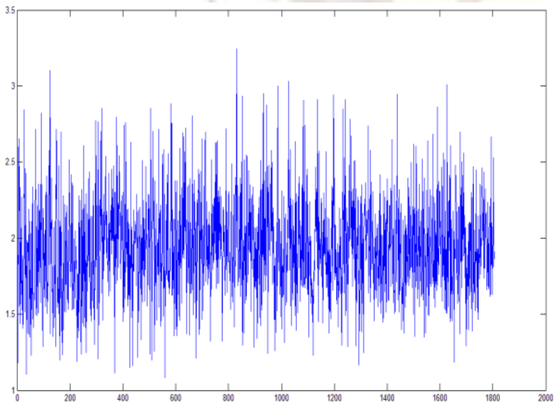

Fig. 5(d) Skewness plot (n-q) of data2

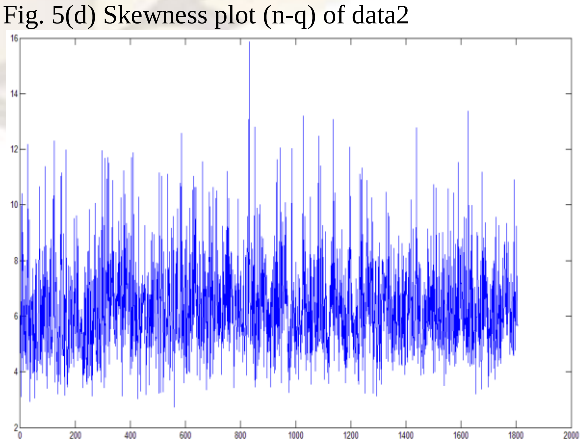

Fig. 5(e) Kurtosis plot (n-q) of data2

Fig. 5(a), Fig. 5(b), Fig. 5(c), Fig. 5(d) and Fig. 5(e) are the n-q plot of mean, standard deviation, variance, skewness and kurtosis for data2 respectively. In these figures we can observe that the charges are uniformly distributed similar to surface discharge. Hence, it can be concluded that data2 is having surface discharge.

Fig. 6(a), Fig. 6(b), Fig. 6(c), Fig. 6(d) and Fig. 6(e) are the n-q plot of mean, standard deviation, variance, skewness and kurtosis for data3 respectively.

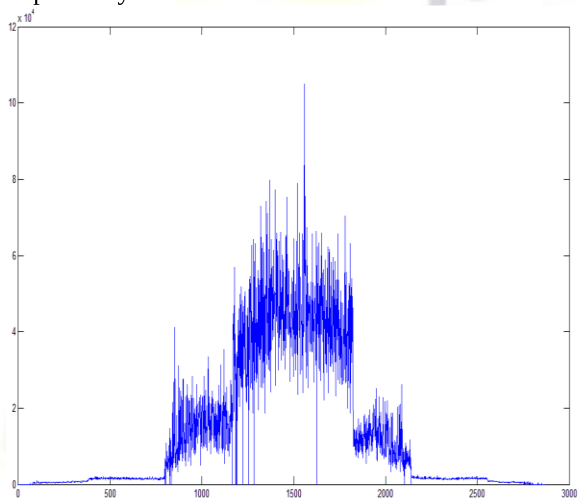

Fig. 6(a) Mean plot (n-q) of data3

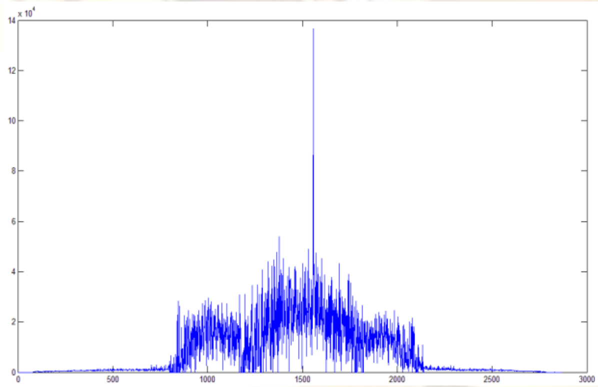

Fig. 6(b) Standard deviation plot (n-q) of data3

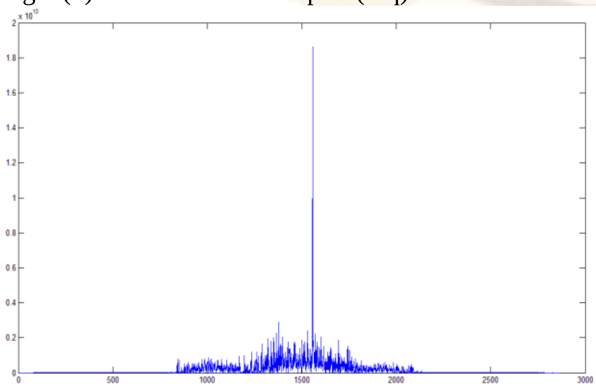

Fig. 6(c) Variance plot (n-q) of data3

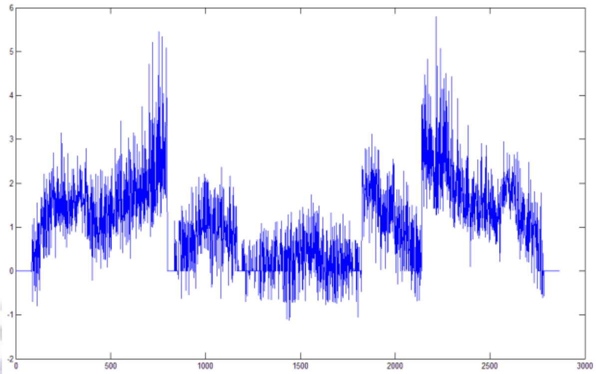

Fig. 6(d) Skewness plot (n-q) of data3

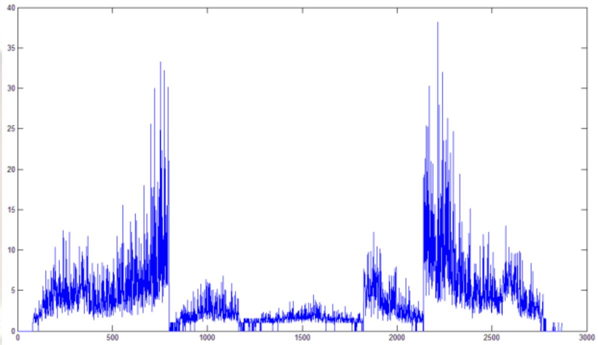

Fig. 6(e) Kurtosis plot (n-q) of data3

In Fig. 6(a), Fig. 6(b) and Fig. 6(c), there is a occurrence of peak after 1500 cycle and in Fig. 6(d) and Fig. 6(e), the skewness and kurtosis value decreases at that peak which is similar to void discharge. Hence, it can be concluded that data3 is void discharge.

3.2. Statistical parameters

After analysis we obtained the results which are summarized in table 1 and table 2.

Table 1. Parameters of known PD patterns

Parameters	void	surface	corona
Mean	13320.32	145.706	1.426
Standard deviation	7553.716	126.009	1.139
Variance	$1.64*10^{8}$	17921.01	2.279
Skewness	$3.66*10^{-17}$	0.809	0.26
Kurtosis	0.04878	2.442	0.966

Table 2. Parameters of unknown PD Patterns

Parameters	data1	data2	data3
Mean	105.119	553.93	13320.32
Standard deviation	97.966	698.3	7553.716
Variance	16714.23	$4.94*10^{5}$	$1.64* 10^{8}$
Skewness	0.692	1.939	$-3.7*10^{-17}$
Kurtosis	2.004	6.31	0.04878

Fig. 7 is the statistical characteristics of mean, standard deviation, variance, skewness and kurtosis of void discharge against data3. Fig. 8(a), Fig. 8(b) are the statistical characteristics of mean, standard deviation, variance, skewness and kurtosis of surface discharge against data1 and data2 respectively.

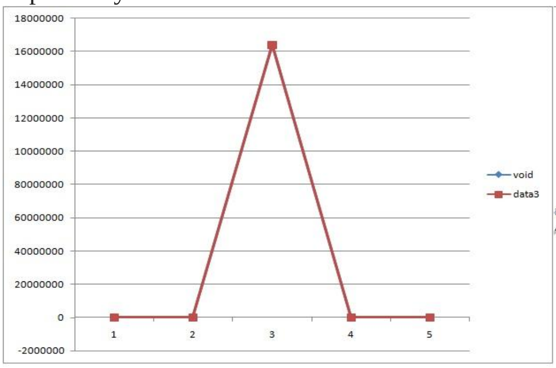

Fig. 7 Statistical Characteristics of data3 against void discharge

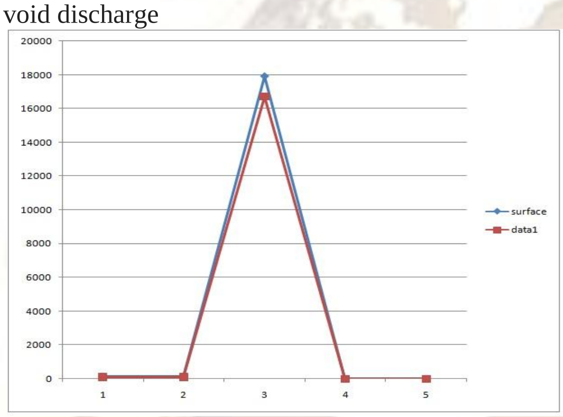

Fig. 8(a) Statistical characteristics of data1 against surface discharge

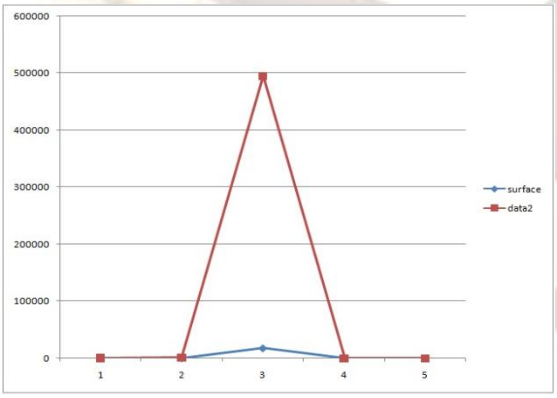

Fig. 8(b) Statistical characteristics of data2 against surface discharge

4. OBSERVATIONS AND CONCLUSION

The following observations are made from the results:

- Plotting statistical parameters of void discharge against data3 in Fig. 8 shows data3 characteristics overlaps void characteristics, it can be concluded that data3 is void discharge.
- Similarly, for surface discharge, data1 and data2 characteristics (Fig. 8(a) and Fig. 8(b)) approximately fits surface discharge characteristics, it can be concluded that data1 and data2 is surface discharge.

The analysis done from statistical parameters are data1 is surface discharge, data2 is surface discharge and data3 is void discharge**.** The analysis using statistical parameters can be done for various types of PD discharges.

From statistical parameters, the PD source cannot be concluded accurately so it needs to be applied to others classification methods such as neural network, Fuzzy logic etc. as a pre-processing parameters for getting accurate PD source.

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