Analysis Of Partial Discharge Using Phase-Resolved (Φ-Q) And (Φ-N) Statistical Techniques

Namrata Bhosale, Priyanka Kothoke, Amol Deshpande, Dr. Alice N. Cheeran
Department of Electrical Engineering, VJTI

Abstract

Partial discharges (PDs) in high-voltage (HV) insulating systems originate from various local defects, which further results in degradation of insulation and reduction in life span of equipment. In order to ensure reliable and durable 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 skewness and kurtosis.

Keywords: Partial Discharge, Phase-resolved, Statistical parameters.

1. Introduction

A PD is generally thought of as a highly localized or confined electrical discharge within an insulating medium between two conductors, and in some cases PD is the precursor to a complete electrical breakdown or fault. The occurrence of PD can be the cause of electrically-induced aging of insulating materials, for example, by formation of corrosive gaseous byproducts, erosion, sputtering, and 'tree' formation. PD, despite its localized nature, is an enormously complex phenomenon that often exhibits chaotic, non-stationary, or fractal type behaviour[1].

The PD data consist of a time sequence of charge pulses which can be represented in various ways. One possibility is the phase angle φ of the ac voltage at which the pulse of strength q is detected. This gives a phase resolved partial discharge (PRPD) pattern. A statistical description of the data is obtained by averaging over a large number of ac periods. The 2-D distribution (φ-q) represents a pattern containing information about the nature of the defect[2].

One of the important objectives of PD test is to discriminate different type of PD sources. Different types of insulation defects produce different discharge patterns. PD measurement often provides a means for detecting defects that could lead to the breakdown of the dielectric. Advancements in computer measurement techniques have made it convenient and faster to process a large amount of information and to transform this information into an understandable output[3]. In this work we process a data to calculate various statistical parameters from different discharge pulses detected during the measurement period.

Different types of patterns can be used for identification of source of PD. These different patterns can be presented in terms of statistical parameters and may make it possible to identify the defect type. 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 gaining importance in the quality control of insulating systems[4]. Various 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 skewness and kurtosis in phase resolved pattern (φ-q) and (φ-n) 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 number of PD pulses '*n*'. PD distribution patterns are composed of these three parameters. Statistical parameters are obtained for phase resolved pattern.

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

The data to be processed obtained from generator includes *φ, q, n and* voltage V. From this data, phase resolved patterns are obtained. PD pulses are grouped by their phase angle with respect to the 50 (± 5) Hz sine wave. Consequently, the voltage cycle is divided into phase windows representing the phase angle axis (0 to 360'). If the observations are made for several voltage cycles, the statistical distribution of individual PD events can be determined in each phase window. The mean values of these statistical distributions results in two dimensional patterns of the observed PD patterns throughout the whole phase angle axis [5]. A two-dimensional (2D) distribution φ-q and φ-n represents PD charge magnitude 'q' and PD number of pulses 'n' as a function of the phase angle 'φ' [6].

The mean pulse height distribution H_{qn} (φ) is the average PD charge magnitude in each window as a function of the phase angle φ. The pulse count distribution H_n (φ) is the number of PD pulses in each window as a function of phase angle φ. These two quantity are further divided into two separate distributions of the negative and positive half cycle resulting in four different distributions to appear: for the positive half of the voltage cycle H_{qn}^+ (φ) and H_n^+ (φ) and for the negative half of the voltage cycle H_{qn}^- (φ) and H_n^- (φ) [5]. For a single defect, PD quantities can be described by the normal distribution. The distribution profiles of H_{qn} (φ) and H_n (φ) have been modeled by the moments of the normal distribution: skewness and kurtosis.

Skewness S_k describes the asymmetry of the distributions with respect to a normal distribution. Sk=0 means a symmetric distribution, Sk = positive means asymmetry to the left and Sk = negative means asymmetry to the right.Kurtosis K_u describes the sharpness of the distributions with respect to the normal distribution.Ku = 0 means a Normal distribution, Ku = positive means a sharp distribution and Ku = negative means a flat distribution [6][7]. The skewness and kurtosis are calculated as shown in equation number 1 and 2 respectively.

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

$$\text{Kurtosis: } (K_u) = \frac{\sum_{i=1}^{N}(x_i-\mu)^4 f(x_i)}{\sigma^4 \sum_{i=1}^{N} f(x_i)} - 3.0 \quad \ldots (2)$$

where,
f(x) = PD charge magnitude q,
μ = average mean value of q,
σ = variance of q.

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.

3.1. Phase Resolved Patterns (φ-q):

The phase resolved patterns are divided into two types: (φ-q) and (φ-n). The phase resolved patterns (φ-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)

3.1.1 2D distribution of (φ-q) for known PD patterns

Fig.1 (a), Fig.1 (b) and Fig.1 (c) are the phase-charge φ-q plot for void, surface and corona discharges respectively.

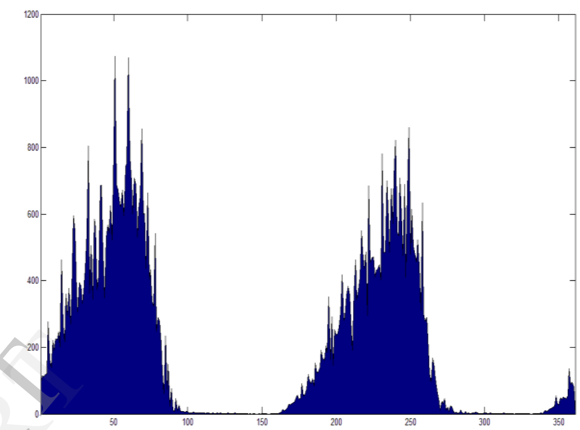

Fig.1 (a) Phase plot (φ-q) of void discharge

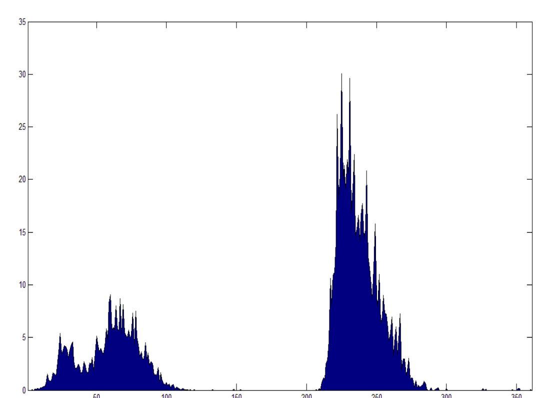

Fig.1 (b) Phase plot (φ-q) of surface discharge

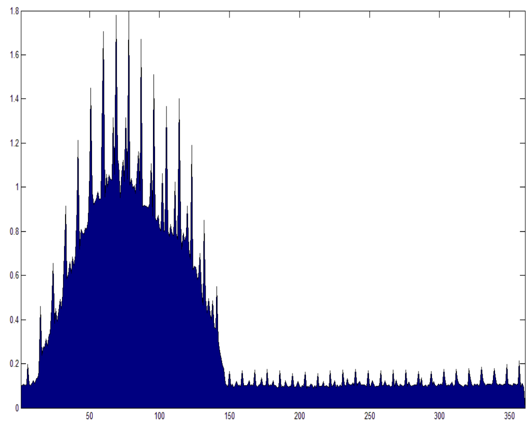

Fig.1 (c) Phase plot (φ-q) of corona discharge

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

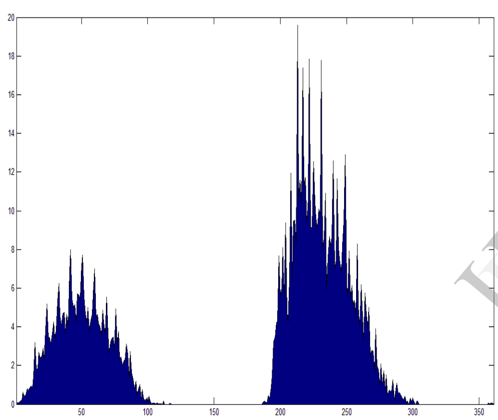

Fig.2 (a) Phase plot (φ-q) of data1

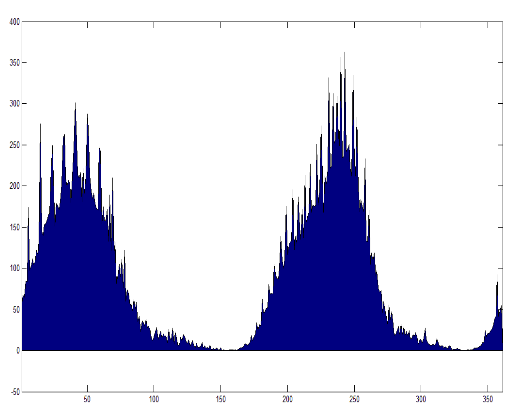

Fig.2 (b) Phase plot (φ-q) of data2

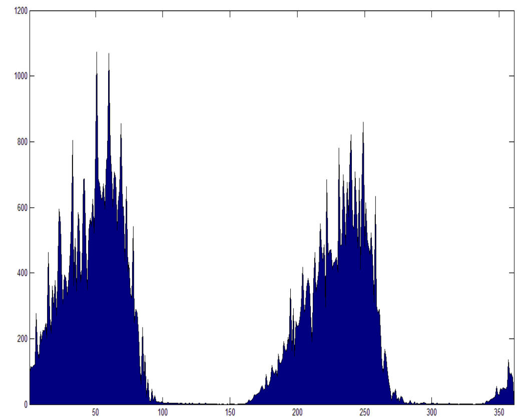

Fig.2 (c) Phase plot (φ-q) of data3

Fig.2(a), Fig.2(b) and Fig.2(c) are the phase φ vs. charge q plot for data1, data2 and data3.

From Fig.2(a), it is seen that the following plot is similar to void and surface discharge. Fig.2(b), is also similar to void and surface discharge and Fig.2(c), is similar to void discharge.

3.2. Phase Resolved Patterns (φ-n):

The phase resolved (φ-n) patterns consist of three known PD patterns: void, surface and corona (as discussed in 3.2.1) and three unknown PD patterns: data1, data2 and data3 (as discussed in 3.2.2). The plots are discussed below:

Fig.3(a), Fig.3(b) and Fig.3(c) are the phase φ vs. number of pulses n for void, surface and corona discharges.

3.2.1 Phase resolved plot (φ-n) of known PD patterns

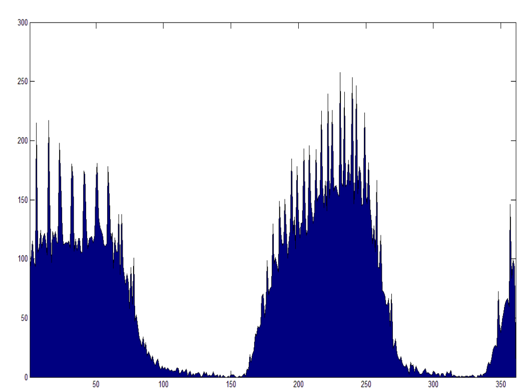

Fig.3 (a) Phase plot (φ-n) of void discharge

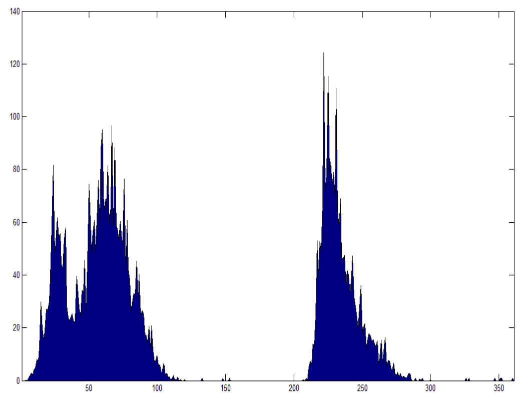

Fig.3 (b) Phase plot (φ-n) of surface discharge

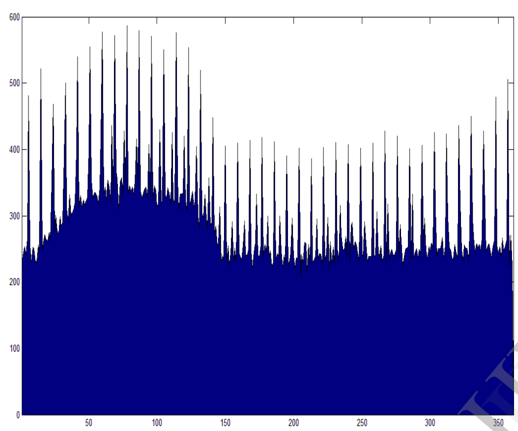

Fig.3 (c) Phase plot (φ-n) of corona discharge

3.2.2 Phase resolved plot (φ-n) of unknown PD patterns

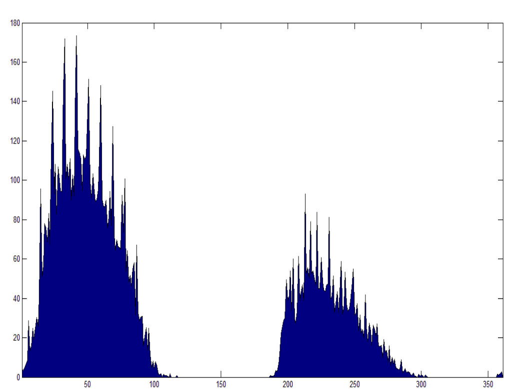

Fig.4 (a) Phase plot (φ-n) of data1

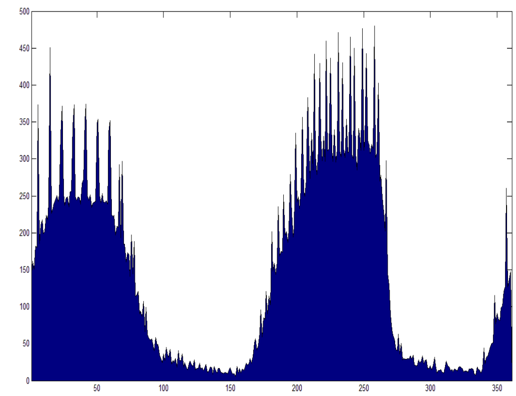

Fig.4 (b) Phase plot (φ-n) of data2

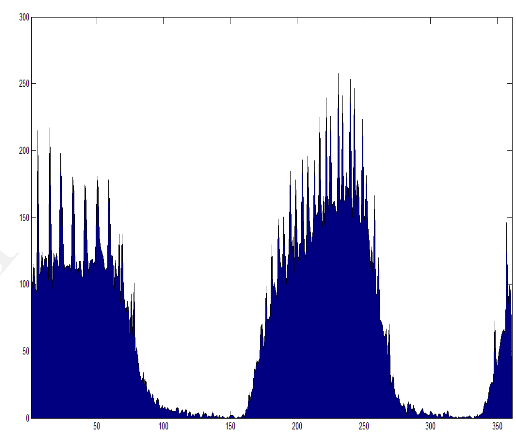

Fig.4 (c) Phase plot (φ-n) of data3

Fig.4(a), Fig.4(b) and Fig.4(c) are the phase φ vs. number of pulses n plot for data1, data2 and data3.

From Fig.4(a), it is seen that the following plot is similar to void and surface discharge. Fig.4(b), is similar to void discharge and Fig.4(c), is also similar to void discharge.

3.3. Statistical Parameters:

Table 1. Parameters of known PD patterns

Parameter	void	surface	corona
Skewness $H_{qn}^{+}(\varphi)$	1.0013	1.2134	0.3555
Skewness $H_{qn}^{-}(\varphi)$	0.9901	1.8219	1.3659
Kurtosis $H_{qn}^{+}(\varphi)$	2.9046	3.6064	2.4354
Kurtosis $H_{qn}^{-}(\varphi)$	2.7872	5.4506	7.5947
Skewness $H_{n}^{+}(\varphi)$	0.4954	1.0082	1.3942
Skewness $H_{n}^{-}(\varphi)$	0.4329	2.3686	1.3798
Kurtosis $H_{n}^{+}(\varphi)$	2.0535	2.871	4.8337
Kurtosis $H_{n}^{-}(\varphi)$	1.9137	8.4788	7.3215

Table 2. Parameters of unknown PD Patterns

Parameter	data1	data2	data3
Skewness $H_{qn}^{+}(\varphi)$	0.8991	0.7456	1.0013
Skewness $H_{qn}^{-}(\varphi)$	1.1833	0.8509	0.9901
Kurtosis $H_{qn}^{+}(\varphi)$	2.5719	2.1814	2.9046
Kurtosis $H_{qn}^{-}(\varphi)$	3.7467	2.6512	2.7872
Skewness $H_{n}^{+}(\varphi)$	0.8016	0.574	0.4954
Skewness $H_{n}^{-}(\varphi)$	1.0169	0.42	0.4329
Kurtosis $H_{n}^{+}(\varphi)$	2.3724	2.1091	2.0535
Kurtosis $H_{n}^{-}(\varphi)$	3.2011	1.8003	1.9137

$H_{qn}(\varphi)$ and $H_n(\varphi)$ distributions of discharges are analyzed by means of statistical operators like skewness Sk (0 to 180 and 180 to 360), and kurtosis Ku (0 to 180 and 180 to 360).

Fig.5 (a) and Fig.5 (b) are the characteristics of skewness Sk and kurtosis Ku ($H_{qn}(\varphi)$ and $H_n(\varphi)$) of data1, data2, and data3 against void discharge. Fig.6 (a) and Fig.6 (b) are the characteristics of skewness Sk and kurtosis Ku ($H_{qn}(\varphi)$ and $H_n(\varphi)$) of data1, data2, and data3 against surface discharge. Fig.7 (a) and Fig.7 (b) are the characteristics of skewness Sk and kurtosis Ku ($H_{qn}(\varphi)$ and $H_n(\varphi)$) of data1, data2, and data3 against corona discharge.

It has been shown that the statistical operators for all these distributions give a more efficient discrimination between different discharge sources.

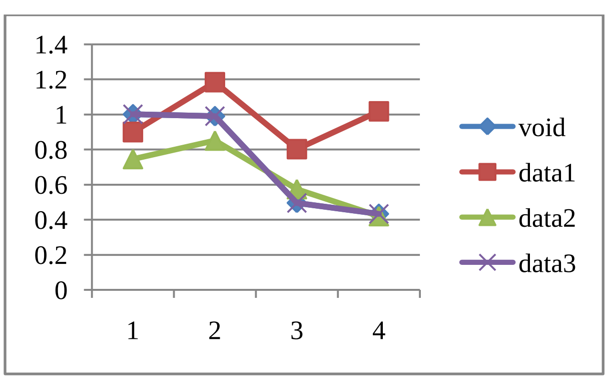

Fig. 5 (a) Characteristics of skewness ($H_{qn}(\varphi)$ and $H_n(\varphi)$) of data1, data2, and data3 against void

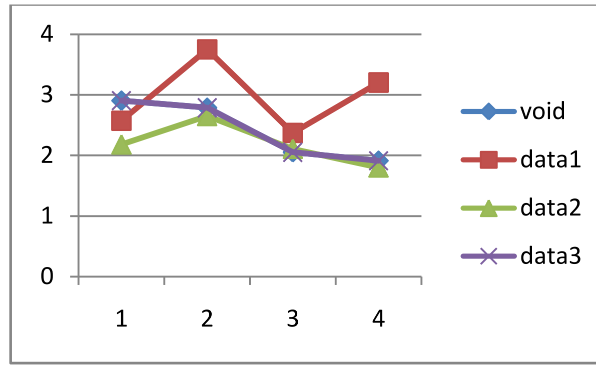

Fig. 5 (b) Characteristics of kurtosis ($H_{qn}(\varphi)$ and $H_n(\varphi)$) of data1, data2, and data3 against void

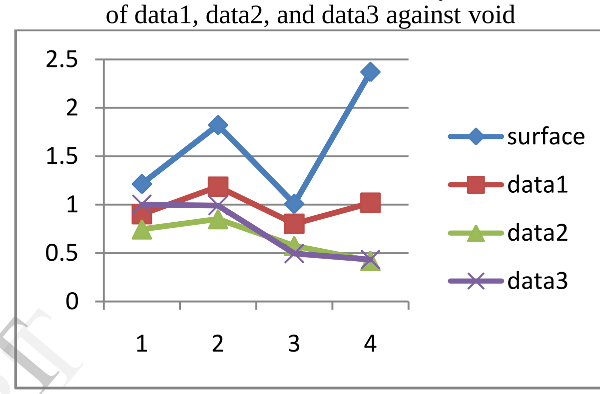

Fig. 6 (a) Characteristics of skewness ($H_{qn}(\varphi)$ and $H_n(\varphi)$) of data1, data2, and data3 against surface

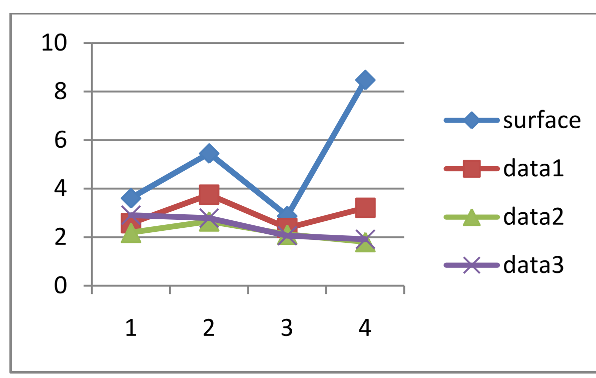

Fig. 6 (b) Characteristics of kurtosis ($H_{qn}(\varphi)$ and $H_n(\varphi)$) of data1, data2, and data3 against surface

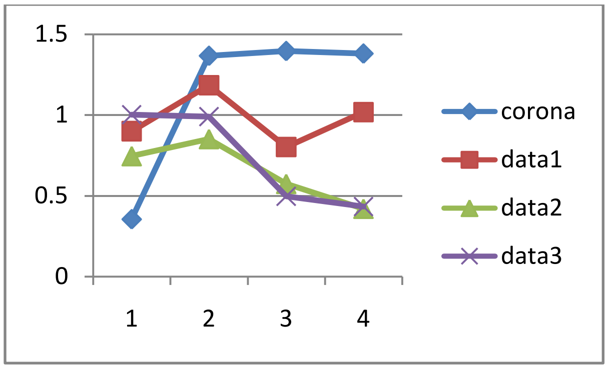

Fig. 7 (a) Characteristics of skewness ($H_{qn}(\varphi)$ and $H_n(\varphi)$) of data1, data2, and data3 against corona

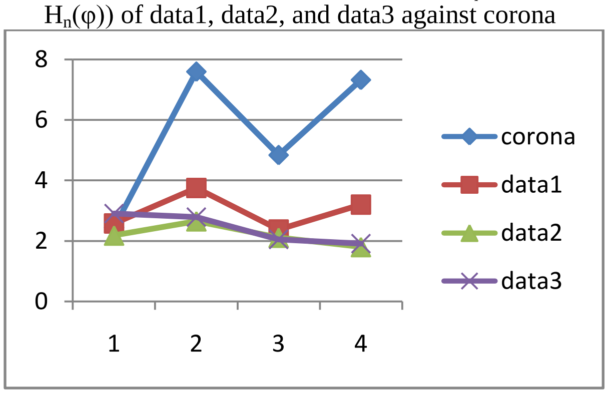

Fig. 7 (b) Characteristics of kurtosis ($H_{qn}(\varphi)$ and $H_n(\varphi)$) of data1, data2, and data3 against corona

4. Observations and Conclusion

The following observations are made from the results:

- By plotting Skewness and kurtosis of $H_{qn}(\varphi)$ and $H_n(\varphi)$ of data1, data2 and data3 against void, varying data3 characteristics overlaps void characteristics, it can be concluded that data3 is void discharge. Data2 characteristics approximately fits against void, it can be concluded that data2 is also void discharge.
- Similarly, for surface discharge, data1 characteristics approximately fits surface discharge characteristics for both skewness and kurtosis (Fig. 6 (a) and Fig. 6 (b)), it can be concluded that data1 is surface discharge.
- For corona discharge, none of the data characteristics matches (Fig. 7 (a) and Fig. 7 (b)), it can be concluded that corona discharge is not present in any data.

The analysis done from statistical parameters are data1 is surface discharge, data2 is void discharge and data3 is also void discharge.

Statistical parameters such as skewness and kurtosis can be calculated from phase resolved distributions. It is important to note that skewness and kurtosis vary with external stress, but fall into a calculable range that can help to determine the type of discharge source and the development of its activity. Therefore the results may be useful for the establishment of PD recognition.

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.

5. References:

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