

Classification of Partial Discharge Sources using Statistical Approach

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Abstract

In high-voltage (HV) power equipment, degradation of insulation has been main concern for protection of equipment. This is due to occurrence of partial discharges (PD) activity within HV insulating systems which can be initiated from different types of local internal or external defects. Thus, partial discharge (PD) identification and classification are important for diagnostic insulation systems problems in order to ensure maintenance process can be carried out effectively and hence improve reliability and durable operation of HV equipment. In this work, the relation of the observable statistical characteristics from PD data with the characteristic of the defect is an important factor to determine the defect inside insulation system. Ultimately, the statistical parameters obtained from PD data can be used to classify different PD sources occur inside HV insulation system. Thus, the objective of this paper is to produce a unique pattern according to discharge source using statistical method. Several statistical parameters such as mean, variance, standard deviation, skewness and kurtosis have been used and analysed.

Keywords: partial discharge, classification, condition monitoring, statistics

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1. Introduction

Modern condition monitoring of partial discharge (PD) via on-line condition monitoring techniques offer increased accuracy, continuous cost reduction and ultimately diagnostic improvement compared to traditional time based condition monitoring [1]. This is due to sensor development and development of appropriate solutions in terms of data acquisition, information technology and intelligent diagnostic software [2]. A detailed survey on high voltage plants condition monitoring can be found in [3]. Currently, there are a range of PD measurement techniques which can be subdivided with respect to the form of energy being detected such as thermal, chemical, acoustic, optical or electrical means and these approaches have been widely reported [4]-[6]. PD is define as a localized electrical discharge that partially bridges the insulation between conductors and which may or may not occur adjacent to a conductor [7]. It is categorised as preliminary failure as if there is no proper maintenance or replacement process is carried out, it can lead to a catastrophic failure in insulation systems. Generally, PD closely related with insulation materials that used for insulation and this become the main reason for the electrical ageing and insulation degradation of high voltage equipment. The insulation may consist of solid, liquid, or gaseous materials, or any combination of them. PD may occur in gas, in a cavity within insulating material which named void, and on a surface subject to high electric field strength which called surface discharge. While corona discharges usually occur around a sharp electrode or along conductor of high voltage power equipment. The health of the insulation systems play an important role in high voltage power equipment and existing of PD activity indicates danger to the life of insulation of high voltage power equipment in physically and chemically. Effect from insulation performance are different as a result from different sources of PD. Since there is particular degradation mechanism for each defect, it is important to know the correlation between discharge patterns and the kind of defect [8]. Therefore, PD classification is important in order for recognition of discharges of unknown origin that can bring harmfulness to the insulation system. In the past, PD classification was performed by investigating the pattern of the discharge by observe the phase angle in AC cycle. Nowadays, there has been extensive published research to identify PD sources by using intelligent technique such as artificial neural networks and fuzzy logic [9]. The recent research on PD

activity have shown that development of computer-based techniques can be used to analyse signals from PD measurements in order to gain new insight into the characteristic of PD [10]. This techniques is the able to process to transform a large amount of information into an understandable output [11]. On the other hand, data mining technique and dimensional reduction technique using Wavelet Transform and Principal Component Analysis is also used to analyse PD signal in diagnostic study [12]. From PD activity for an example in underground cables, the energy can be dissipated through the cable and there are differences in terms of cable capacitances [13]. There are many approaches have been carried out in identification of partial discharge sources using PD waveforms and one of the approaches is using statistical analysis [14]. Through this technique, different types of patterns can be used for identification of source of PD by using statistical parameter such as mean, variance, standard deviation, skewness, and kurtosis.

2. Research Method

The data are measured from artificial discharge activities under laboratory based experiments. The experiments consist of three different PD activities from three different sources which are corona, void and surface discharge. The data measured using radio frequency current transformer (RFCT) with bandwidth of 20 KHz to 150 MHz and stored using digital storage oscilloscope. Hence, the measured signals are pre-processed in order to remove disturbances and to separate each discharge signal and post-processed to extract useful statistical information from raw data. The common parameters to characterize partial discharge are phase angle 'φ', PD charge magnitude 'q', Number of PD pulses 'n' and applied voltage 'V'. Partial discharge (PD) distribution patterns are composed of these three parameters. Statistical parameters are obtained for statistical pattern. Statistical analysis using cumulative distribution function is applied for the computation. The profile of all these discrete distribution functions can be put in a general function and the statistical operators can be computed as follows:

$$\text{Mean value } (\mu) = \frac{\sum_{i=1}^N (x_i) f(x_i)}{\sum_{i=1}^N f(x_i)} \quad (1)$$

Where, $f(x)$ is Cumulative distribution function of PD magnitude and x is the random variables of PD magnitude.

In probability and statistics, mean value is used synonymously to refer to one measure of the central tendency either of a probability distribution or of the random variable characterized by that distribution.

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

Variance is the expectation of the squared deviation of a random variable from its mean, and it informally measures how far a set of (random) numbers are spread out from their mean.

$$\text{Standard Deviation } (\sigma) = \sqrt{\frac{\sum_{i=1}^N (x_i - \mu)^2 f(x_i)}{\sum_{i=1}^N f(x_i)}} \quad (3)$$

The standard deviation is a measure that is used to quantify the amount of variation or dispersion of a set of data values.

$$\text{Skewness } (S_k) = \frac{\sum_{i=1}^N (x_i - \mu)^3 f(x_i)}{\sigma^3 \sum_{i=1}^N f(x_i)} \quad (4)$$

Skewness is a measure of asymmetry or degree of tilt of the data with respect to normal distribution.

If the distribution is symmetric, $S_k=0$;

If it is asymmetric to the left, $Sk > 0$;
 If it is asymmetric to the right, $Sk < 0$.

$$Kurtosis(K_u) = \frac{\sum_{i=1}^N (x_i - \mu)^4 f(x_i)}{\sigma^4 \sum_{i=1}^N f(x_i)} \quad (5)$$

Kurtosis is an indicator of sharpness of distribution.

If the distribution has the same sharpness as a normal distribution, then $K_u = 0$;

If it is sharper than the normal then $K_u > 0$;

If it is flatter than the normal then $K_u < 0$;

3. Results and Analysis

Analysis involves determining partial discharge (PD) patterns from different source which is void, corona and surface discharge by comparing of statistical parameters which have been obtained from the analysis of each dataset. It is anticipated that from the sets of parameters, they can produce a plot which enable to distinguish the discharge sources. In this paper, three known PD data from different discharge sources were compared and from comparison that have been made, there are two plots show significant difference from each data. Thus, the plot as shown in Figure 1-3 may provide possible information towards identification of PD sources.

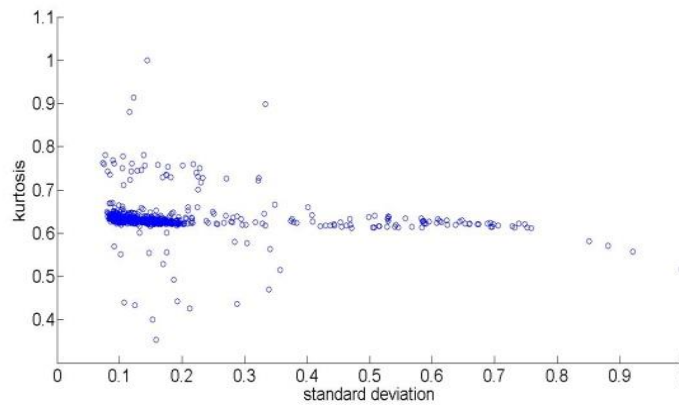


Figure 1a. Kurtosis plot of corona discharge

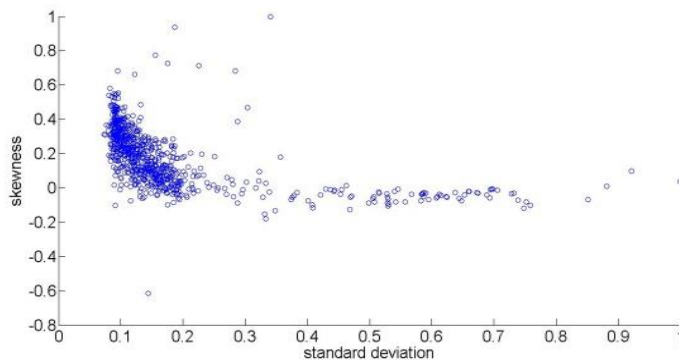


Figure 1b. Skewness plot of corona discharge

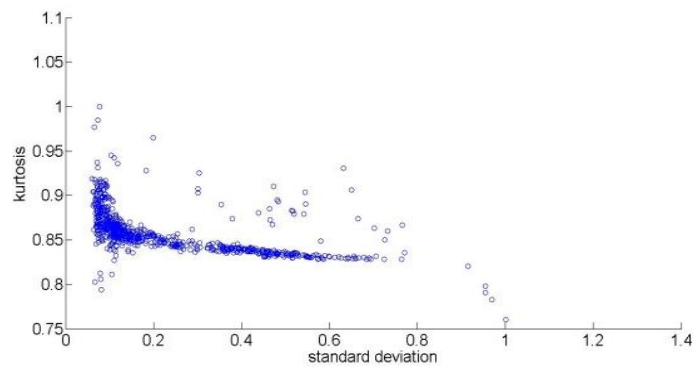


Figure 2a. Kurtosis plot of surface discharge

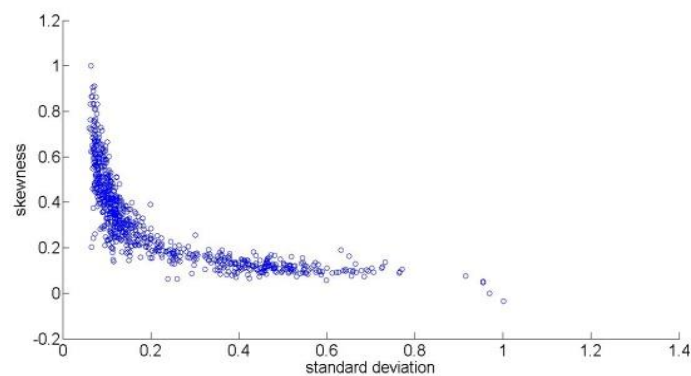


Figure 2b. Skewness plot of surface discharge

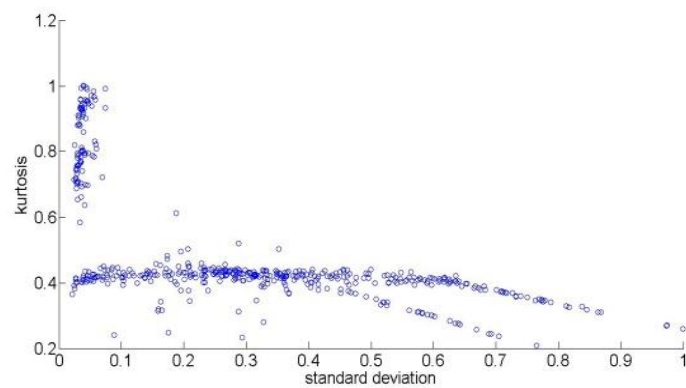


Figure 3a. Kurtosis plot of void discharge

Figure 1a and Figure 1b show there is a concentrated PD pulses for corona discharge a short interval along with standard deviation in positive region of both graph. The density of the pulse is highest compared to others. Meanwhile, in Figure 2a and Figure 2b, PD pulses are only lie for a long interval along with standard deviation in positive region of the graph and the density of the pulse is lower compare to corona discharge. Figure 3a and Figure 3b, PD pulses are distributed more scattered and also the density of the pulses is the lowest compared to all data along standard deviation and there is noticeably separation in skewness and kurtosis.

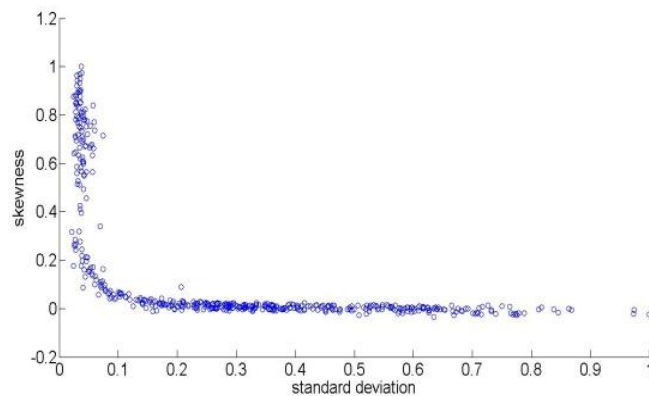


Figure 3b. Skewness plot of void discharge

The pulse is generated with respect to the reference signal of the applied voltage and their amplitudes and repetition rate are influenced by the nature of the types of partial discharge sources. For partial discharge classification, each statistical parameter such as mean, variance, standard deviation, skewness and kurtosis need to be normalised in order to standardize the data. Waveform enveloping functions and modelled pulses for the pulse-shaped signals of different PD sources model is formed by the measurement and the frequency of each PD sources has been analysed using Fourier Transform and the values are given in Table 1.

Table 1. Frequency of PD Sources

PD sources	f(MHz)
Void Discharge	20.6
Corona Discharge	7.12
Surface Discharge	9.05

From the characteristic of each discharge source, the frequency of void discharge is the highest, follow by surface discharge and corona discharge. Thus, in order to show characteristic of the each data ,two randomly pick pulse waveform is taken from each data set as shown in Figure 4a, 4b and 4c respectively.

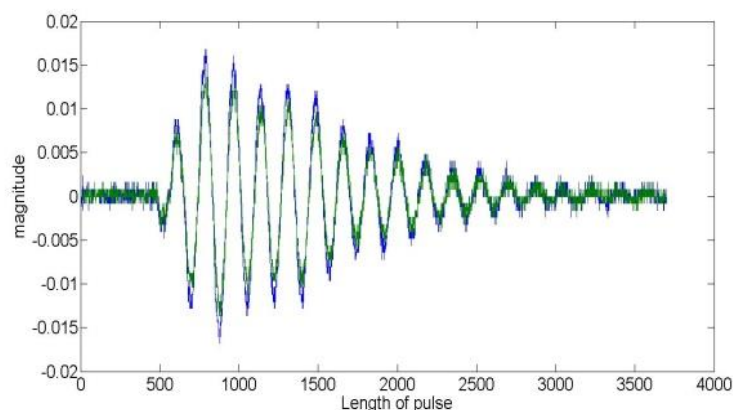


Figure 4a. Corona discharge signals

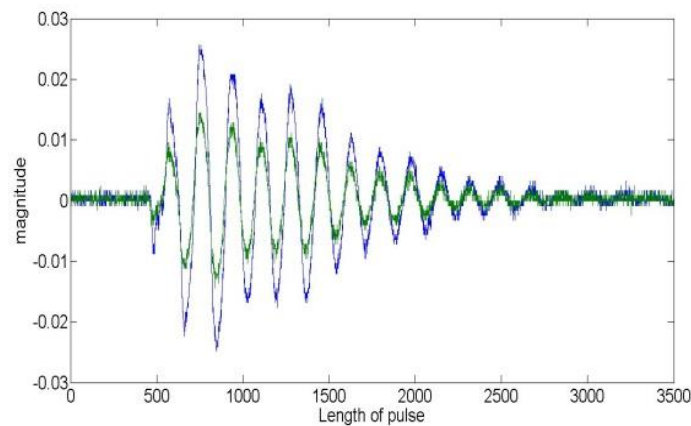


Figure 4b. Surface discharge signals

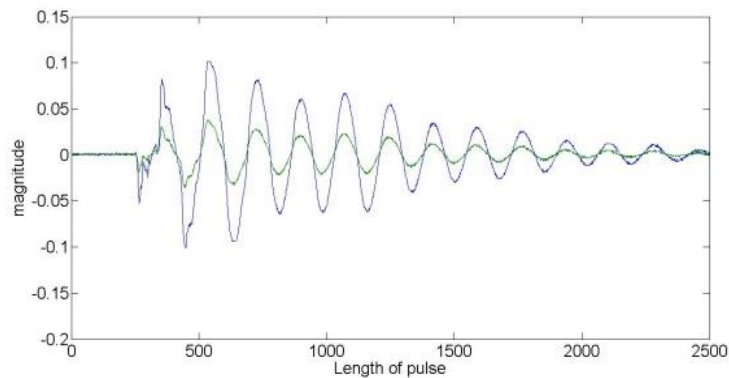


Figure 4c. Void discharge signals

It is shown that the deviation of waveform between each pulse of corona discharge is very small. This is agreed by the comparison of standard deviation graph with a short interval. For surface discharge, the deviation of waveform between each pulse is bigger compared to corona discharge. Thus, referring to the plot of standard deviation, the standard deviation is more scatter with a longer interval. Lastly, for void discharge, the deviation of waveform between each pulse is biggest compare to other PD sources thus it is showed by long distributed pulse of standard deviation graph. The results show that the high frequency PD signals will cause high deviation of PD magnitudes. While on the other hand, it is observed that PD signals with low frequency displayed a low deviation of PD magnitudes. Therefore, decreasing PD magnitudes at higher frequencies was noticed in the experiments [14]. One possible explanation is due to de-trapping of starting electrons. Occurrence of PD will only take place once the starting electron is initiated for ionization to cause avalanche. Therefore, after occurrence of PD, the electrons trapped at the cavity surface which act as a store of starting electrons. Since the number of de-trapping electrons decreases in time, the probability of a starting electron will be highest immediately after PD occurrence and will decrease in time [15]. When a PD occurs, the field strength inside the defect collapses to the residual value and then it increases again. This is mean by the time for reaching the minimal value necessary for the next PD inception shortens with increasing frequency. The probability of starting electron to be present when the inception conditions are fulfilled is relatively high at higher frequencies. Therefore, PD at higher frequencies will presumably be ignited at a field quite close to the minimal inception field and a lower PD magnitude is to be expected at higher frequencies. Ultimately, the deviation of PD magnitudes will be high at high frequency and vice versa. In addition, the presence of nanoparticles within the insulation materials will restrict the chain mobility and result in increasing electric insulation as such restriction limited the production of

free charge carriers and the movement and accumulation of the charges in dielectrics especially in low frequency range less than 30 MHz [16].

4. Conclusion

The analysis was done from PD waveforms of corona discharge, surface discharge and void discharge in order to produce different statistical operators such as standard deviation, skewness and kurtosis. Hence the statistical operators can be plotted for visualisation of a unique pattern for different PD sources. Therefore the results may be useful for PD recognition. This paper shown that the analysis using statistical parameters can be done for various types of PD and the classification of PD sources look promising. Ultimately, this process can be applied to others classification methods such as neural network, Fuzzy logic or other dimensional reduction technique to aid visualisation.

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