# STUDY ON PARTIAL DISCHARGE (PD) BEHAVIOUR FOR DIFFERENT TYPE OF INSULATION DEFECTS USING PULSE SEQUENCE ANALYSIS

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**A report submitted**
**in partial fulfillment of the requirements for the degree of**
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**2019**

## DECLARATION

I declare that this thesis entitled "STUDY ON PARTIAL DISCHARGE (PD) BEHAVIOUR FOR DIFFERENT TYPE OF INSULATION DEFECTS USING PULSE SEQUENCE ANALYSIS is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ----------------------------------------

Name : ----------------------------------------

Date : ----------------------------------------

# APPROVAL

I hereby declare that I have checked this report entitled "STUDY ON PARTIAL DISCHARGE (PD) BEHAVIOUR FOR DIFFERENT TYPE OF INSULATION DEFECTS USING PULSE SEQUENCE ANALYSIS" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Electrical Engineering with Honours

Signature : ..............................................................

Supervisor Name : ..............................................................

Date : ..............................................................

# DEDICATIONS

To my beloved mother and father

## ACKNOWLEDGEMENTS

Thanks to Almighty Allah for giving me the strength and ability to understand, learn and complete this report in time.

I would like to express my gratitude to my supervisor, Dr. Nur Hakimah Binti Ab Aziz, whose expertise, understanding, generous guidance and support regarding the topic of my research.

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# ABSTRACT

Partial discharge (PD) is a localized electrical discharge that only partially bridges the insulation between two conducting electrodes. PD acts as a major role in the acceleration of electrical aging and degradation of the insulating oil. PD is a well-accepted indicator of the degradation of electrical insulation, authorizing early detection of insulation faults. Measuring PD and interpreting its pattern helps to identify the different type of defects of high voltage equipment. Regarding to this work, pulse sequence analysis (PSA) has been performed using MATLAB software to identify the behavior of PD occurrence due to different defects such as corona in air, surface discharge and electrical treeing. The instantaneous voltage and voltage difference between two consecutive PD pulses are calculated and plotted. The results show that the three PD sources provide different pattern for the instantaneous voltage and voltage difference. The analysis of discharge sequences is suggested in PSA as an alternative with a more meaningful interpretation of PD phenomenon.

# ABSTRAK

Pelepasan separa (PD) adalah pelepasan elektrik setempat yang hanya sebahagiannya menembusi penebat antara dua elektrod yang menjalankan. PD bertindak sebagai peranan utama dalam mempercepat penuaan elektrik dan kemerosotan minyak penebat. PD adalah penunjuk yang diterima dengan baik dari penolakan penebat elektrik, yang membenarkan pengesanan awal kerosakan penebat. Mengukur PD dan menafsirkan coraknya membantu mengenal pasti jenis kecacatan peralatan voltan tinggi yang berlainan. Berkenaan dengan tugas ini, analisis urutan gerakan (PSA) telah dilakukan dengan menggunakan perisian MATLAB untuk mengenal pasti tingkah laku corak PD kerana kecacatan yang berlainan seperti korona di udara, pelepasan permukaan dan penanaman elektrik. Voltan seketika dan perbezaan voltan di antara dua denyutan PD berturut-turut dikira dan diplot. Hasilnya menunjukkan bahawa tiga sumber PD memberi corak yang berbeza untuk voltan seketika dan perbezaan voltan. Analisa urutan pelepasan disarankan dalam PSA sebagai alternatif dengan tafsiran yang lebih bermakna mengenai fenomena PD.

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| | | |
|---|---|---|
| PD | - | Partial Discharge |
| CBM | - | Condition Based Monitoring |
| PSA | - | Pulse Sequence Analysis |
| PE | - | Polyethylene |
| XLPE | - | Cross-linked Polyethylene |
| EPR | - | Ethylene Propylene Rubber |
| PILC | - | Paper Insulated Lead Cable |
| PVC | - | Polyvinyl Chloride |
| GIS | - | Gas Insulated Substation |
| UHF | - | Ultra-High Frequency |
| PRPD | - | Phase-Resolved Partial Discharge |
| TRPDA | - | Time Resolved Pulse Partial Discharge Analysis |
| CIV | - | Corona Inception Voltage |
| PC | - | Personal Computer |
| MATLAB | - | Matrix Laboratory |
| HV | - | High Voltage |
| FOD | - | Foreign Object Debris |

# CHAPTER 1

# INTRODUCTION

## 1.1 Research Background and Motivation

Partial discharge (PD) is a localized electrical discharge that only partially bridges the insulation between two conducting electrodes. Partial discharge activity can occur at any point in the insulation system, where the electric field strength exceeds the breakdown strength of that portion of the insulating material. PDs play a role in the acceleration of insulation degradation [1]. PD is a well-accepted indicator of the presence of defects in an insulating system, authorizing early detection of insulation faults.

The progressing pattern in the power supply industry is to upgrade asset management strategies. There is a way to monitor the characteristic of partial discharge so that it can detect and diagnose if any abnormal behavior occurred. Condition Based Monitoring (CBM) can be defined as a technique or a process of monitoring the operating characteristics of machine. It can be used to predict the need for maintenance before any serious failure or breakdown occurs and give effect towards machine's health [2].

## 1.2 Problem Statement

High voltage equipment plays an important role in power system due to its capability to transfer a large amount of power to the system. It is important to make sure the system operates with high reliability without any failure occur. The occurrence of PD should not be treated lightly as it can even lead to complete failure. PD can be triggered due to non-uniform of electric field and dielectric strength, existences of bubble in insulation surface, gas surrounded near conductor which known as corona and edge of the conductor. PD activity can cause tracking and treeing phenomenon which lead to insulation breakdown.

To prevent any failure occurs, condition based management of high voltage equipment is a program which widely used to replace the conventional time-based. CBM is conducted based on the assessment of the equipment conditions. The fault that occurred due to PD can be diagnosed through the interpretation of PD pattern which helps to assess the performance and condition of high voltage equipment insulation. Pulse sequence analysis (PSA) has been introduced to give an interpretation of the real physical phenomena involved in partial discharge activity. Hence, PSA is employed in this work to identify the unique characteristics of PD pattern of three different defects: corona in air, surface discharge and electrical treeing. These unique characteristics are the key features that can aid the fault diagnosis.

## 1.3 Objective

The main objective of this project is to:

1. Analyze the PD data from three different PD defects: corona in air, surface discharge and electrical treeing by using pulse sequence analysis (PSA).

2. Identify the potential PSA feature in discriminating the three PD defects.

3. Identify the unique characteristic of the potential PSA pattern for each PD defect.

## 1.4 Scope

The scope of this project is to analyze PD pattern from different type of defects: corona in air, surface discharge and electrical treeing. The PD data were obtained from previous experimental work in the University of Manchester (electrical treeing) and Universiti Teknikal Malaysia Melaka (surface discharge). Also, an experiment was conducted in high voltage laboratory in the Universiti Teknikal Malaysia Melaka for PD data on corona in air. The analysis is performed using pulse sequence analysis (PSA) in the MATLAB platform.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Insulation Material

In electrical insulation, there are three types of insulation material which are solid, liquid and gas insulation. Power cable is the one of insulation materials that uses solid insulator. Types of solid insulation in cable are Cross-linked Polyethylene (XLPE), Ethylene Propylene Rubber (EPR), Polyethylene (PE), Paper Insulated Lead Cable (PILC) and Polyvinyl Chloride (PVC).

Liquid insulation is normally used in transformer equipment known as transformer oil. Transformer insulating oil has a highly refined mineral oil and excellent electrical insulating properties. It helps as a cooling medium which absorb the heat generated by the core and winding and transfer the heat to the last surface of the transformer. PFAE (palm fatty acid ester), and coconut oil are the other of liquid insulation [3].



One of the application that uses gas insulation is gas insulated substation (GIS) where sulfur hexafluoride (SF6) gas is used as the insulating medium. The used of SF6 are mainly due to the electronegative character of its molecule which has a tendency to capture free electrons and heavy ions with low mobility making the development of electron avalanches very difficult [4].

## 2.2 Partial Discharge

According IEC 60270, PD is a “a localized growth of dielectric breakdown in an area within solid or fluid dielectric insulation system under medium or high voltage stress [5]. PD is the most important diagnostic tool to detect fault occur in a system [6].

### 2.2.1 Partial Discharge Detection

Electrical measurement based on IEC 60270 standard is the most common technique in detecting PD pulses. This standard is applicable to measure the occurrence of PD in electrical apparatus, components or systems when tested with alternating voltages up to 400 Hz or with direct voltage [7].

Another technique for PD detection is using UHF (Ultra-High Frequency) sensor. The UHF method has many advantages such as high sensitivity and strong anti-interference ability, thus widely used for PD detection. UHF PD sensors are good in their sensitivity and range for detecting and locating PD sources in power transformers. UHF sensors are capable of detecting PD in transformer oil below DC voltage situations and finding PD sources inner transformer windings [8].



PD activity also can be detected by using a piezoelectric transducer sensor. A piezoelectric sensor detects the acoustic signal produced by PD. The piezoelectric transducer sensor is required to detect PD activity due to sound-wave propagation. This method is non-destructive and may be a noninvasive test technique that can be used to assess PD activity in high-voltage asset. However, noise can be added due to wave reflections inside a power equipment, mechanical vibrations and external noise. The main frequency of components detected by the piezoelectric transducer sensor were 9.5 kHz and 16 kHz [9].

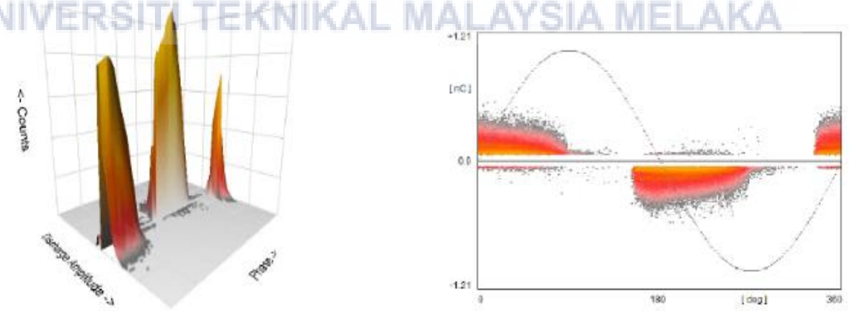
### 2.2.2 Partial Discharge Data Representation

There are many ways to represent partial discharge data analysis, for example, Phase-Resolved Partial Discharge (PRPD), Pulse Sequence Analysis (PSA) and Time Resolved Pulse Partial Discharge Analysis(TRPDA).

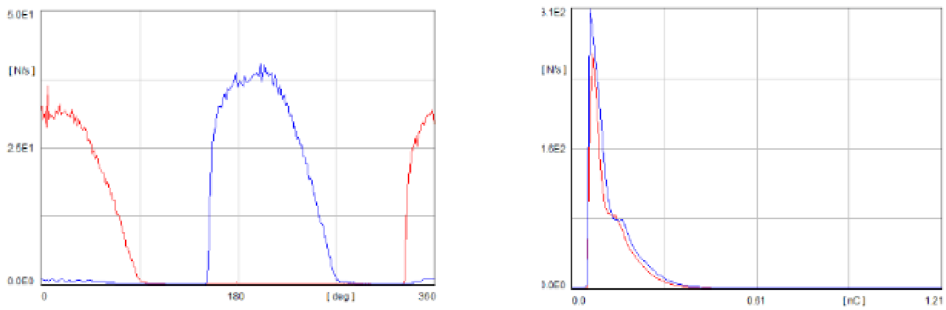
Phase-resolved partial discharge (PRPD) is a technique with three known parameters, charge magnitude of PD, phase occurrence and voltage cycle. The phase axis (x-axis) consists of one complete cycle of the applied voltage while the PD charge magnitude axis (y-axis) consists of the range of magnitude detected [10]. Therefore, a PRPD pattern shows PD occurrences at a specific phase of the applied voltage with certain charge magnitude within certain number of the applied voltage cycles.

Figure 2.1 shows different types of patterns provided by PRPD method such as ψ-n pattern (the phase of occurrence versus the number of PD), ψ-qm pattern (the phase of occurrence versus the maximum apparent charge), the ψ-qa pattern (the phase of occurrence versus the average apparent charge), the q-n pattern (the apparent charge versus the number of discharge) and the φ-q-n pattern which is a 3D pattern and shows the number of PD, phase of occurrence and magnitude of PD [11].






a) ψ-q-n pattern        b) ψ-q pattern




c) ψ-n pattern d) q-n pattern

Figure 2.1: Different PD patterns from PRPD

PSA is the technique makes use of the applied voltage amplitude when a PD occurs and the time of the PD occurrence. It does not consider the phase and charge magnitude of the PD occurrence. In a PSA pattern, the y-axis is the voltage difference between the next and current PD occurrences while the x-axis is the voltage difference between the current and previous PD occurrences. It is similar for the time difference between consecutive PDs pattern. In general, PSA patterns make use of the sequence of PD occurrences [12].

Figure 2.2 shows the basic principle of the generation of PSA method which schematically with three impulses PD with different voltage values $U_{n-1}$, $U_n$ and $U_{n+1}$and the phasing $Ø_{n-1}$, $Ø_n$ and $Ø_{n+1}$respectively where the n denotes the current PD pulse, n-1 the previous pulse and n+1 the next pulse. The analysis employed three parameters; voltage difference, $\Delta u$, phase difference, $\Delta Ø$, and voltage gradient, m. These features are calculated using equations 2-1 to 2-3 and plotted in respect to its consecutive value i.e $\Delta u_n$ vs $\Delta Ø_n$ vs $\Delta Ø_{n-1}$, and $m_n$ vs $m_{n-1}$.

$$\Delta u_n = u_{n+1} - u_n \tag{2-1}$$

$$\Delta \emptyset_n = \Delta \emptyset_{n+1} - \emptyset_n \tag{2-2}$$

$$m_n = \frac{\Delta u_n}{\Delta \emptyset_n} \tag{2-3}$$

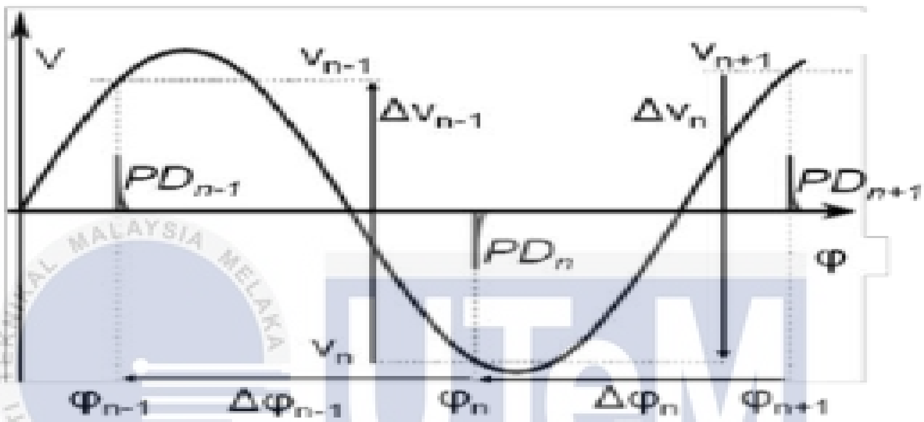



Figure 2.2: Principle of the generation of PSA



Each PD defects shows a unique PSA patterns which could be used for PD diagnosis [13]. PD classification is performed by comparing the patterns or by extracting useful features of unknown defects with known defects. Thus, extracting useful features is important to make sure important properties such as number of clusters, their location and relative densities for these patterns are not influenced. The PSA results pattern for voltage difference, $\Delta u_n$ vs $\Delta u_{n-1}$, phase difference, $\Delta \emptyset_n$ vs $\Delta \emptyset_{n-1}$, and voltage gradient, $m_n$ vs $m_{n-1}$ from [14] are shown in Table 2.1 to 2.3 respectively.

Table 2.1 shows void discharge forms seven clusters with consecutive PD pulses at either maximum or zero voltage. The PSA pattern for surface discharge do not shows any cluster when both axes are at maximum compared with void pattern. Corona discharge on the other hand, only forms one cluster at the origin.

For Table 2.2, the $\emptyset_n$ vs $\Delta\emptyset_{n-1}$ pattern for corona, surface discharge and void discharge are similar to $\Delta u_n$ vs $\Delta u_{n-1}$ patterns. Table 2.3 shows corona forms one cluster with more scatter distribution. Void forms two clusters with data points lined up in horizontal and vertical directions, and it is totally different from the previous patterns. For surface discharge, four clusters are generated with more disperse points. Based on the PSA patterns from the three table, the PD defects are clearly distinguish using either $\Delta u$ or $\Delta\emptyset$.

Table 2.1 : PSA patterns by using voltage difference, $\Delta \boldsymbol{u}_n$ vs $\Delta \boldsymbol{u}_{n-1}$.

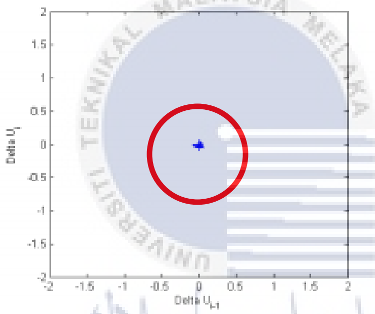
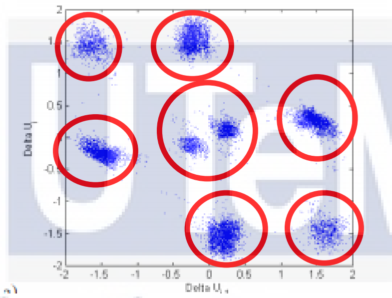
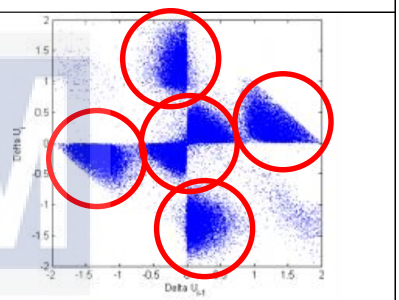
| Corona | Void | Surface discharge |
|---|---|---|
|  One cluster in the middle |  Seven clusters; on the edges, the axis and at the origin |  Five clusters; four on the axis and one in the middle. |

Table 2.2 : PSA patterns by using phase difference, $\emptyset_n$ vs $\Delta\emptyset_{n-1}$.

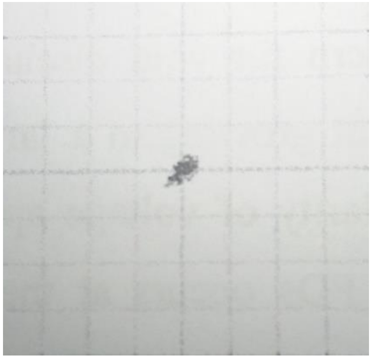
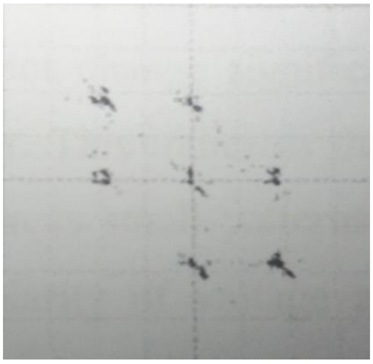
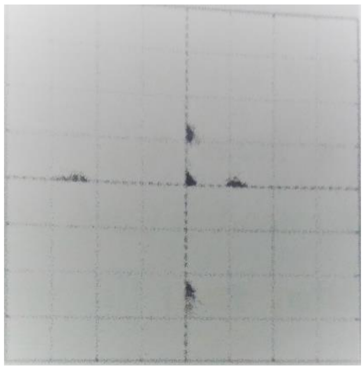
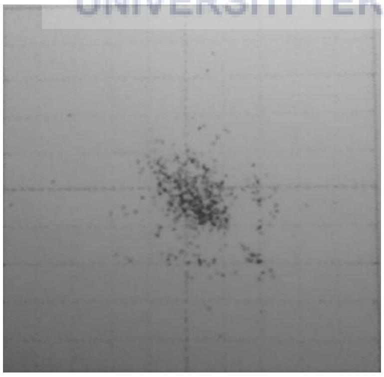
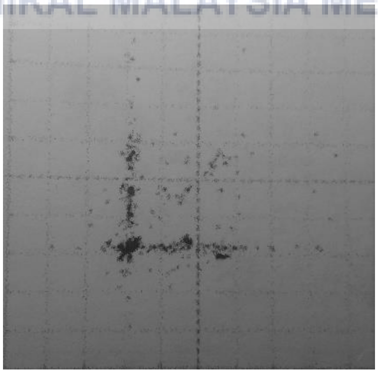
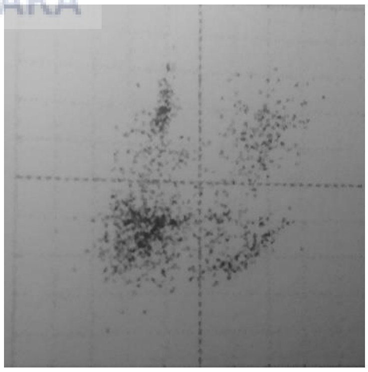
| Corona | Void | Surface discharge |
|---|---|---|
| <br>One cluster in the middle | <br>Seven clusters; on the edges, the axis and at the origin | <br>Five clusters; four on the axis and one in the middle. |

Table 2.3 : PSA patterns by using phase difference, $m_n$ vs $\Delta m_{n-1}$.

| Corona | Void | Surface discharge |
|---|---|---|
| <br>One cluster in the middle with scatter points. | <br>Two clusters with data points line up in horizontal and vertical directions. | <br>Four clusters with more scatter points |

The same investigation is done in [15]. Table 2.4 and 2.5 show the PSA patterns for void, corona and surface discharges by plotting the voltage difference, $\Delta u_n$ vs $\Delta u_{n-1}$, and the time difference, $\Delta t_n$ vs $\Delta t_{n-1}$ respectively.

For corona discharge in Table 2.4, the number of cluster is increased from one cluster in origin to four larger clusters when the applied voltage is increased. The points in cluster B is due to the change of voltage polarity between consecutive PD. For the points A, it is due to negative voltage between consecutive PD which shows negative corona discharge. This region indicates that the voltage between consecutive PD are almost the same with each other. The points in cluster C and D indicates that the consecutive PD occurred at different polarity of applied voltage which resulting in large voltage differences between consecutive discharge. PSA pattern of corona discharge is different from void and surface discharges because PD is concentrated more at certain region than dispersed.

The general pattern for void discharge did not change when the applied voltage increased, but have larger cluster. Thus, this indicates that consecutive PD occur at the opposite polarity of voltage applied whereas small patterns of $\Delta u_n$ vs $\Delta u_{n-1}$ indicates that consecutive PD occurs at the same polarity of applied voltage. All these patterns indicate PD sequences. For surface discharge, when the applied voltage is increased, PD occurrence increased at the same region and produce large pattern which indicates that consecutive PD are positive and negative surface PD.

Table 2.4 : PSA patterns by using voltage difference, $\Delta \boldsymbol{u}_n$ vs $\Delta \boldsymbol{u}_{n-1}$.

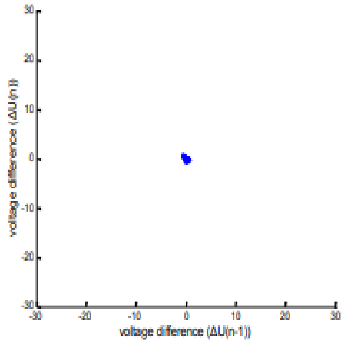
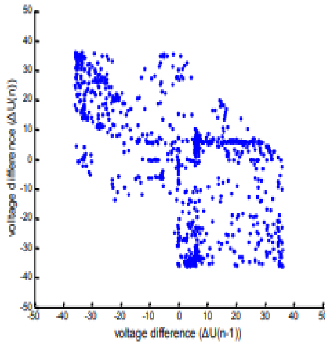
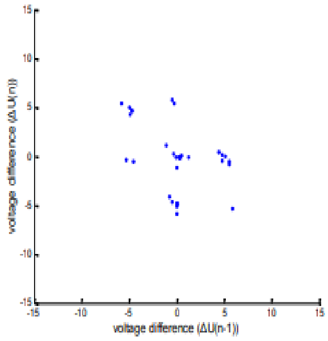
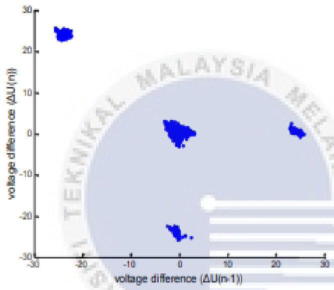
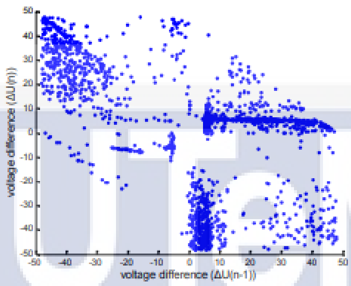
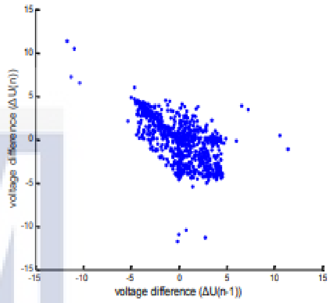
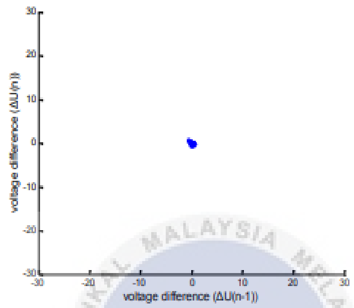
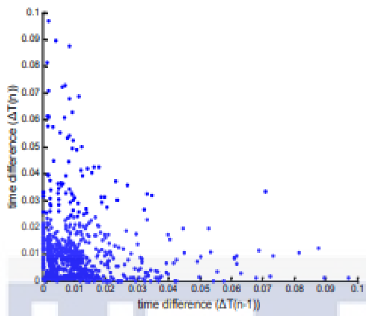
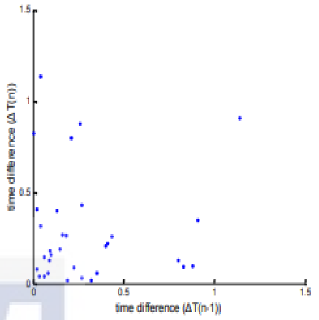
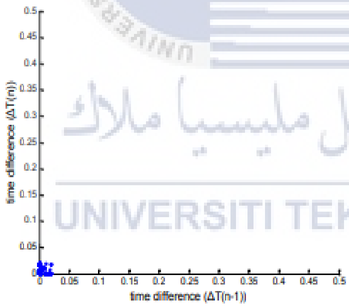
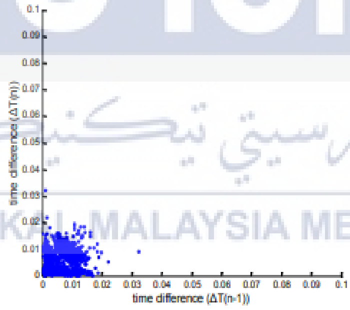
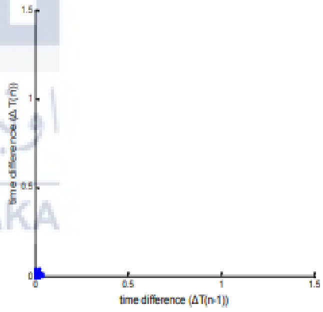
| Corona | Void | Surface discharge |
|---|---|---|
|   a) 10 kV |   a) 18 kV |   a) 3kV |
|   b) 14 kV |   b) 24 kV |   b) 6kV |
| Regions of PD occurrence increased from one small region in the middle to four larger regions. | Pattern scattered at both positive and negative sides. | Pattern increased at the same region. |

Table 2.5 shows the time difference between consecutive discharges. All data points are concentrated to the origin for all PD sources regardless the value of the applied voltage. For a high voltage, the points are less scattered compared to the lower voltage.

Table 2.5 : PSA patterns by using voltage difference, $\Delta t_n$ vs $\Delta t_{n-1}$.

| Corona | Void | Surface discharge |
|---|---|---|
|  a) 10 kV applied voltage. |  a) 18 kV applied voltage. |  a) 3 kV applied voltage. |
|  b) 14 kV applied voltage. |  b) 24 kV applied voltage. |  b) 6 kV applied voltage. |

## 2.3 Diagnosis of Partial Discharge Defect

### 2.3.1 Corona in air

A corona is a self-sustained electrical discharge where an electric field limits the ionization processes to regions close to high-field electrodes or insulators [16]. Corona occurs caused by disturbing noise, radio interference and increased power loss around the high voltage conductors of power transmission lines. It is not a dangerous discharge. However, the characteristics of corona is similar to other kinds of PDs and it can appear as a disturbance in on-line measurement.

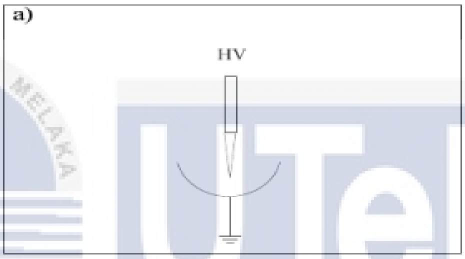



Figure 2.3 : Corona in air



### 2.3.2 Surface Discharge

Surface discharge is an electrical discharge that occurs on the surface of the insulators that can cause failure in electrical insulation system. It can occur in gas, liquid or a vacuum where it is closed to a solid dielectric surface. One of the causes of surface discharge is the presence of high voltage stress. Surface discharge is one of the electrical discharges and it has always become an initial stage of ageing process of the insulator materials. It can be stated that the definition of the surface discharge is the discharge occurring at the surface of the dielectric. It occurs when the surface conductivity is increased due to a combined action of humidity and the dissociation product of air [17].

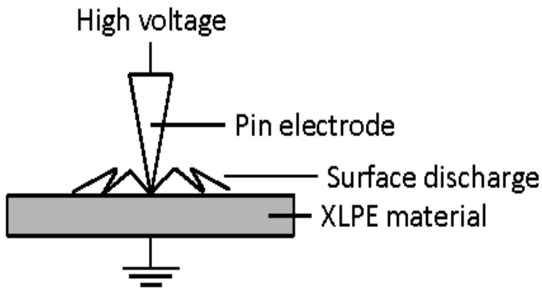



Figure 2.4 : Surface Discharge

### 2.3.3 Electrical Treeing

Electrical treeing is a phenomenon of electrical crack that occur in polymer materials. The shape of electrical treeing is quite similar to the nature trees. The electrical treeing is a one of main cause for the deterioration of electrical equipment such as high voltage polymeric cable. Its shape will grow splitting once an electrical treeing occurs. Therefore, the treeing phenomenon is not acceptable to exist in high voltage insulation equipments. The electrical tree is a complicated electro-erosion phenomenon and a consequence of several processes including charge injection extraction, collision ionization, oxidation decomposition, partial discharge, partial high temperature, electro mechanical stress, physics deformation, chemical decomposition and etc [18].



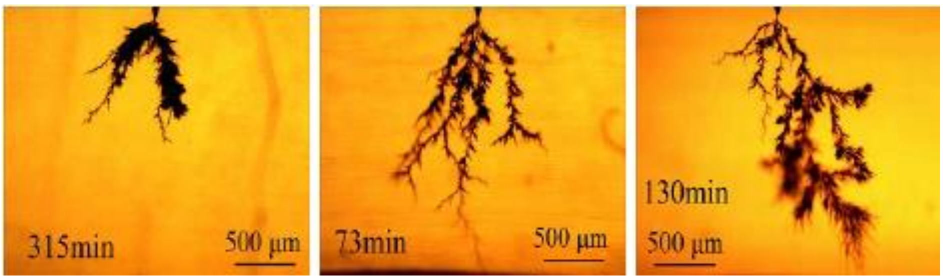



Figure 2.5 : Electrical Treeing

### 2.3.4 Summary of Literature Review

Based on the overview of literature review, there are three types of insulation which are solid insulation, liquid insulation and gas insulation. Each of insulation have different type of material used. PD activity may occur in any types of insulation and that is important to detect PD in an early stage. Based on the research, there are three techniques for PD detection which are IEC 60270, UHF sensor and piezoelectric transducer sensor. PD data can be represented in such many ways such as Phase-Resolved Partial Discharge (PRPD), Pulse Sequence Analysis (PSA) and Time Resolved Pulse Partial Discharge Analysis (TRPDA). So, the chosen PD data representation is by using PSA method.

From the research, PSA is the best method compare with other method because PSA can give better images of pattern and can differentiate clearly the characteristics of PSA pattern for each defects. There is different pattern for different defects in terms of number of clusters, the dispersion of data points and the location of data points in PSA plots.

# CHAPTER 3

# METHODOLOGY

## 3.1 The framework of PSA

This chapter describes the methodology applied in this research project for the study on PD behavior of corona in air, surface discharge and electrical treeing using pulse sequence analysis (PSA). Figure 3.1 shows the flowchart of project implementation. The explanation on each step is given in the following sections.

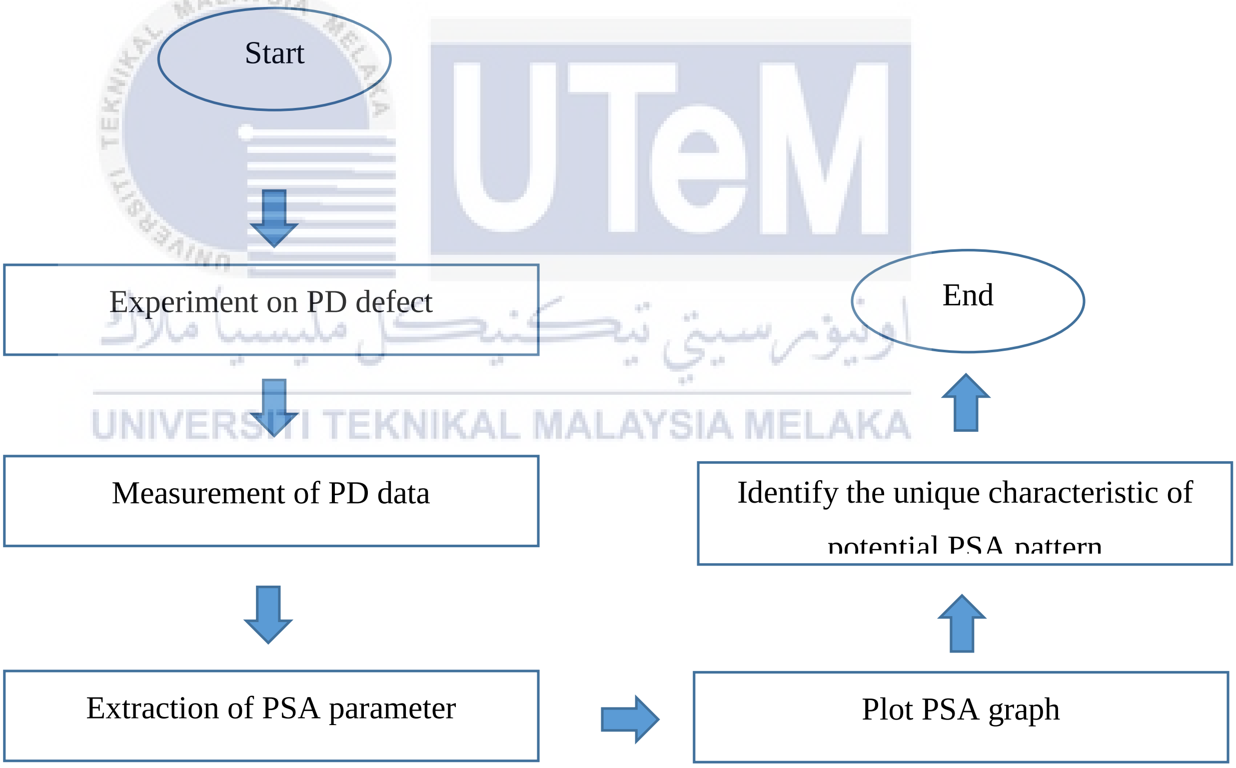




Figure 3.1 : Flowchart of project implementation

### 3.1.1 Experimental setup.

The experimental setup of PD defect experiment is based on IEC 61294 technical report. IEC 61294 is a standard that shows a test procedure to characterize the ability of insulating liquids to prevent PD when the liquids are submitted to high electrical stress.The experiment is setup for PD defect of corona in air . The PD data for other PD defects are obtained from previous experimental work in the University of Manchester (electrical treeing) and Universiti Teknikal Malaysia Melaka (surface discharge). The equipment needed for PD experiment are step up transformer which supply high applied voltage, a coupling device, a test cell, a coupling and measuring capacitor, a USB controller and a PD detector. The PD detector is needed to detect the occurrence of PD during experiment. The PD detector MPD600 used in this project and connected to a personal computer (PC) . The software used to identify the occurrence of PD is OMICRON software. The digital measuring instrument (DMI 551) is used for voltage measurement. Figure 3.2 shows a block diagram of PD measurement setup for PD experiment.

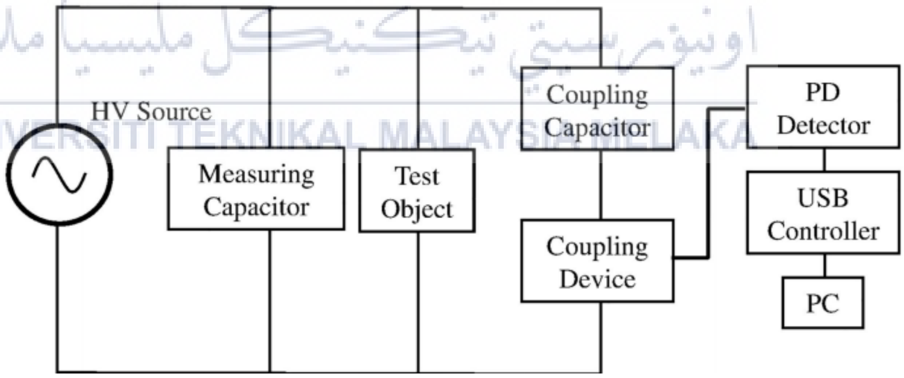



Figure 3.2 : Block diagram of PD measurement setup

Figure 3.3 shows how the equipment are setup for the PD experiment at high voltage laboratory in the Universiti Teknikal Malaysia Melaka.

Figure 3.3 : Setup for PD experiment

Figure 3.4 shows a test cell that has been used for PD experiment of corona in air and this is the only PD defect that can be conducted. The test cell contains a spherical electrode and needle electrode. The test cell shall consist of a vessel containing a vertical gap. The test cell shall be discharge free at 70 kV. The distance from needle to sphere is set at 40 ± 1 mm. The extension of the needle from the holder is set at 25 ± 1 mm. For this corona in air experiment, the test cell is filled with air. The copper rod is connected with test cell to transfer current from power supply.



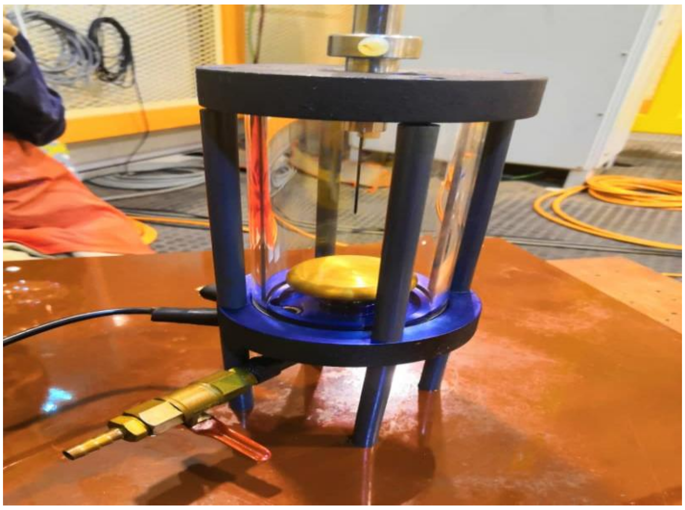


Figure 3.4 : The test cell

Figure 3.5 shows the digital measuring instrument (DMI 551) which is used for measurement of AC, DC and impulse peak voltages by means of 3 independent channels. Also, a high voltage amplifier (TREK) are protected against output short circuits and over voltages.

Figure 3.5 : Digital Measuring Instrument DMI 551

Figure 3.6 shows the MPD 600 detector that used for measuring the PD.  This device is highly recommended by IEC 60270 for PD measurement.

Figure 3.6 : The MPD600 detector

Based on IEC 61294, the lowest voltage at which a PD occurs of an apparent charge equal to or exceeding 100 pC when the sample is tested under the specified conditions.

**Test procedure for corona in air**

1) The test cell is cleaned without containing any foreign object such as dust, water droplets, oil, and etc.

2) The cell is connected to the ac (power frequency) transformer. The voltage is increased from zero at a rate of 1 kV/s until a partial discharge occurs of apparent charge equal to or greater than 100 pC. The voltage Vi is recorded. The voltage down to zero is decreased rapidly.

3) The measurements are repeated on the same filling of the cell to record at least 10 values (V1 to V10) and allow an interval of 1 min between each voltage application.

### 3.1.2 Measurement of PD data.

The PD omicron setup is needed for measurement of PD data. The first step is the apparent charge at MPD 600 is set up 100 pC and the value of apparent charge in omicron software should be similar as MPD 600. Next, the rated voltage required for the experiment is slightly less than 11 kV. If higher rated voltage is applied to operate the experiment, it will increase the possibility of insulation breakdown at cable joint defect, which will cause permanent damage to the test sample. So, for this experiment the suitable rated voltage is about 9 kV and the PD measurement can be taken after the PD reached steady state condition. The PD measurement was taken for every 1 minute and the results are shown in term of pulse sequence analysis (PSA) patterns.

### 3.1.3 Extraction of PSA parameter.

Two parameters are employed in this project, i.e instantaneous voltage, $u$ and the voltage difference, $\Delta u$ .The PD data from omicron software is extracted to the MATLAB. The PD data from MATLAB then will extracted to the excel as shown in Table 3.1 by using R software.

Table 3.1 shows the PD data for corona in air obtained after extraction data to excel. From the PD measurement system, five parameters are known to describe each PD pulse i.e the voltage cycle, phase of occurrence, time of occurrence, discharge magnitude and the instantaneous applied voltage.

Table 3.1 : PD data for corona in air.

| Cycle | Voltage | Time | Phase | Charge |
|---|---|---|---|---|
| 1 | 3397 | 3600.003352 | 12.86 | -124.7097 |
| 1 | 24810 | 3600.007121 | 80.68 | 1410.1147 |
| 1 | 25543 | 3600.008135 | 98.93 | 1428.7389 |



### 3.1.4 Plot PSA graph.

The two parameters, u and $\Delta u$ are plotted according to their consecutive values i.e $u_n$ versus $u_{n-1}$ and $\Delta u_n$ versus $\Delta u_{n-1}$. By taking $\Delta u$ versus $\Delta u_{n-1}$ for example, column $\Delta u_{n-1}$ data is taken for the $x$-axis while column $\Delta u$ data is taken for the $y$-axis. The calculation is performed in MATLAB. Equations 2-1 explain how $\Delta u$ are calculated from the data while u is obtained directly from the original data. Table 3.2 shows the instantaneous voltage and voltage differences between consecutive discharges for surface discharge. The n is the number of pulse or current pulse and n-1 is the previous pulse. For example, if n = 2, the $\boldsymbol{u_2 = u_{3-1}}$ and $\Delta \boldsymbol{u_n}$ is the difference between consecutive discharge, for example if n=2, $\Delta \boldsymbol{u_2} = \Delta \boldsymbol{u_{3-1}}$.

Table 3.2 : Instantaneous voltage and voltage differences between consecutive discharges for surface discharge.

| n | $u_{n-1}$ | $u_n$ | $\Delta u_{n-1}$ | $\Delta u_n$ |
|---|---|---|---|---|
| 1 | 3397 | 24810 | 21413 | 733 |
| 2 | 24810 | 25543 | 733 | -21814 |
| 3 | 25543 | 3729 | -21814 | 20489 |

### 3.1.5 Identify the unique characteristic of potential PSA pattern.

Based on the plots of PSA pattern, the unique pattern can be identifying for each PD defects. The unique pattern can be identifying by observing the total number of clusters, the location of clusters is located either at origin or maximum voltage and the dispersion of data points in clusters plotted in the PSA plots. Potential features for PD defects identification is can be observed.

# CHAPTER 4

# RESULTS AND DISCUSSIONS

## 4.1 Project Achievement

In this chapter, PSA features are extracted and plotted. The potential PD features are then indentified where the unique characteristic of the selected features for each PD sources are described. These characteristics can be used in identifying the fault due to PD, as long as the PD data is available during the unknown faults occur.

## 4.2 PSA plots

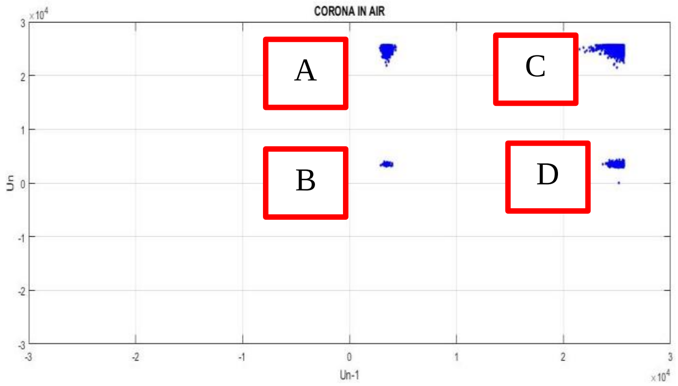
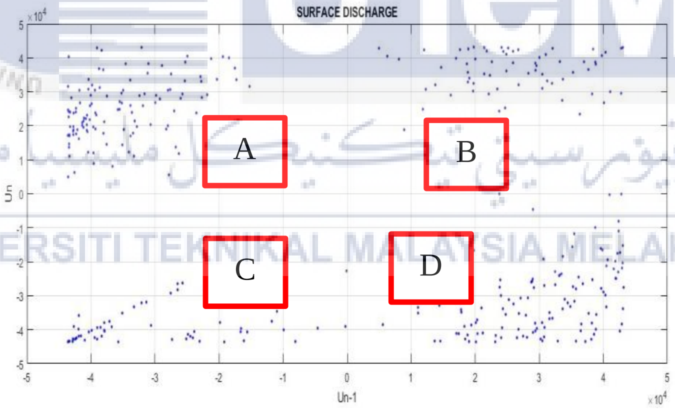
All the result of PSA plots are arranged in Table 4.1 and 4.2 which shows the results of PSA pattern with unique characteristics for different types of defects. Table 4.1 shows the plots of PSA patterns using instantaneous voltage for corona in air, surface discharge and electrical treeing where x-axis represented $u_{n-1}$ and y-axis represented $u_n$. The n is represent as number of pulse or current pulse and n-1 is represent as previous pulse. The $\Delta u_{n-1}$ is the voltage difference between current pulse ($u_n$) and previous pulse ($u_{n-1}$). The $\Delta u_n$ is the next voltage difference after $\Delta u_{n-1}$. The plotted clusters are named as A,B,C,D, E, F and G to make it clear and ease for identifying pattern.

For corona in air, the data points are more dispersed only one side at cluster C compare to other clusters and not scattered at the axis of plotted PSA plots. For surface discharge, the data points more dispersed on each edges of PSA plots and slightly scattered on x-axis of the plotted PSA plots. Cluster A and D has more scattered data points compared to B and C. Electrical treeing shows a different result compared with corona in air and surface discharge which is all the clusters are dispersed with more data points. Cluster A and B are lined up in diagonal directions and cluster C and D are located on the x-axis.

Table 4.2 shows the plots of PSA patterns using voltage differences for corona in air, surface discharge and electrical treeing where x-axis represented $\Delta u_{n-1}$ and y-axis represented $\Delta u_{n.}$ Corona in air shows different PSA pattern compared to previous pattern, where seven clusters are located on the edges, axis and at the origin of the plotted PSA plots. Corona in air has more data points produced at the origin compared to the axis. From the results for corona in air, the PD pattern shows different results as expected in research paper of literature review for the graph of $\Delta u_n$ vs $\Delta u_{n-1.}$ By refering to research paper, the PD pattern for corona in air should be both $\Delta u_n$ and $\Delta u_{n-1}$ are located at the origin or zero voltage of PSA plots. This is because some error such as physical error might be occur during experiment is conducted. The test cell is set up based on IEC 61294 accurately and all the equipment such as HV transformer, PD detector and else are set up accurately as stated in standard. Eventhough all variables for the experiment are set up according to the standard, there are still error occur and affected the PD pattern results.

Based on the results, corona in air shows the PSA pattern slightly same as surface discharge which is both of the defects have the same disperse locations of data points and same number of clusters but more scattered data points on surface discharge. For electrical treeing, it can be seen that six clusters with more disperse points are located on the edges, axis and at the origin of the plotted PSA plots. It is totally different in terms of number of clusters and the location of dispersed data points compared to previous pattern. The clusters are located differently compared to corona in air and surface discharge.

Table 4.1 : Plot of PSA pattern using instantaneous voltage, $u_n$ vs $u_{n-1}$.

| Type of defects | PSA plots | Characteristic of PSA pattern |
|---|---|---|
| Corona in air |   | Four clusters are plotted in PSA plot with named A, B, C and D. Cluster B is located nearly both $u_n$ and $u_{n-1}$ at zero voltage. Cluster C has both $u_n$ and $u_{n-1}$ at maximum voltage. At cluster C has more dispersed of data point compared to A, B and D. |
| Surface Discharge |   | Four cluster are plotted in PSA plots with named A, B,C and D. All four clusters are located at all edges. Cluster A and D has more scattered data points compared to B and C. Cluster B is located both $u_n$ and $u_{n-1}$ at maximum voltage. |

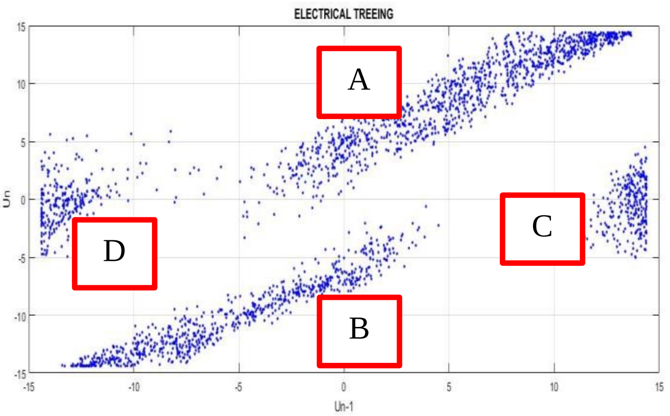
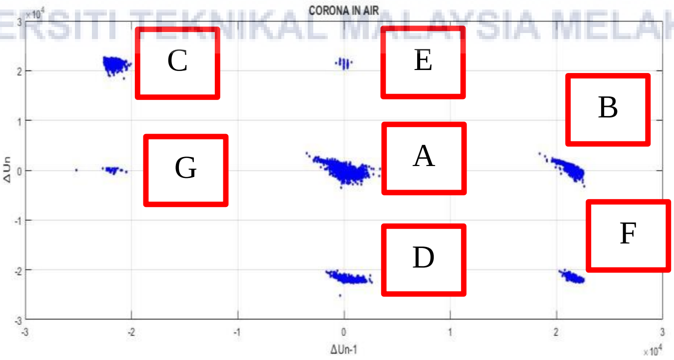
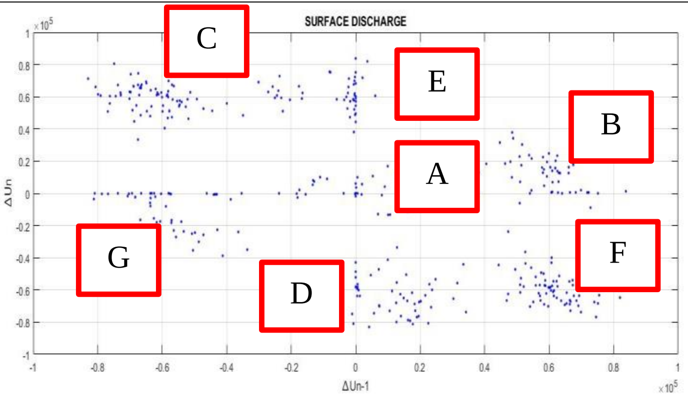
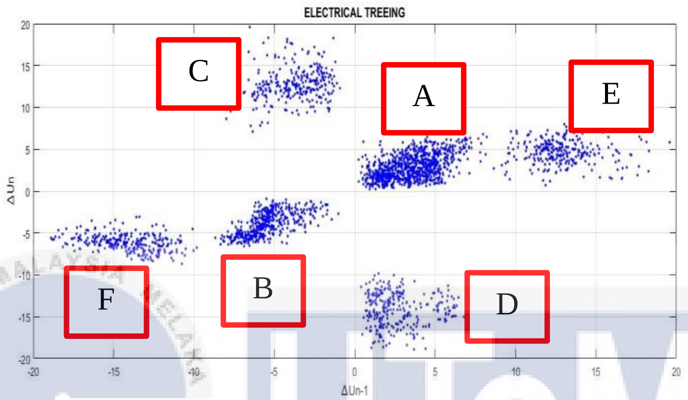
| | | |
|---|---|---|
| Electrical Treeing |  | Overall there are four clusters on the PSA plots with named A,B,C and D. Cluster A and B are lined up in diagonal directions and cluster C and D are located on the x-axis. The four clusters has more dispersed data points. Cluster A and B is located both $u_n$ and $u_{n-1}$ at origin and minimum and maximum voltage. |

Table 4.2 : Plot of PSA pattern using voltage difference, $\Delta u_n$ vs $\Delta u_{n-1}$.

| Type of defects | PSA plots | Characteristic of PSA pattern |
|---|---|---|
| Corona in air |  | Seven clusters are plotted in PSA plots. Cluster A has more dispersed data points with both located both $\Delta u_n$ and $\Delta u_{n-1}$ at origin. Cluster C and F are located at the edge of PSA plots while cluster D, E and G are located at the axis of the PSA plots. |

| | | |
|---|---|---|
| Surface Discharge |   | Seven scattered clusters which are located on the edges, axis and at the origin of the plotted PSA plots similar as corona in air but the data points are more scattrered. |
| Electrical Treeing |   | Six clusters are plotted in PSA plots. Cluster A and B are more dispersed compared to other clusters. Cluster E is located both $\Delta u_n$ and $\Delta u_{n-1}$ at maximum voltage difference while cluster F is located both $\Delta u_n$ and $\Delta u_{n-1}$ at minimum voltage difference. |



### 4.3 Summary for results and discussions

Based on the observation, it can be seen that the three defects gives different figures of PSA pattern. The data points shows the same number of clusters but in different location. Also, the data points has differently dispersed and scattered in the PSA plots. So, from the characteristics above helps to identify the PSA pattern and the unique pattern identification. There are several plotted clusters shows similar pattern with other defects. For the conclusion is by using the results of PSA pattern can helps engineer to identify the fault at power plant because different insulation defect fault have different PD principle. Futhermore, PSA pattern is such as best method because the pattern can be seen clearly and can be differentiate the pattern for different type of defects. From the results above can helps engineer to diagnose the PD activity at early stage.

# CHAPTER 5

# CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusion

In this work, PD activity can occur in different types of defects such as corona in air, surface discharge and electrical treeing. It is important to detect the PD activity at early stage before it goes to the worst case such as breakdown. This work recommended PSA for diagnosis a unique characteristics of PD pattern and potential features of PD pattern which can helps for detection of PD activity more clearly. From the data obtained from PD experiment can be analyze using PSA pattern for each defects.

The experiment conducted should be accurately setup and the existence of error should be fixed so that the results obtained can be well used to do analysis for identification of PSA pattern. Other than that, breakdown voltage should be noticed to trace well the occurrence of PD activity. The parameter used in this work such as instantaneous voltage and voltage difference between consecutive PD is the best for PSA analysis because PD can be detected easily and the pattern can be identified based on the applied voltage.

From the results, it can be concluded that different defect shows different characteristics in terms of number of clusters, locations of clusters is located and the dispersion of data points in PSA plots. The PSA pattern is different regarding different parameter used. Among the three features, $\Delta u$ shows the clearest pattern and easily to understand the pattern. This helps to identify the pattern unique characteristics so that there is differentiation between the three defects. Lastly, the recommendation method is acceptable and can be used for future work.

## 5.2 Future Works

There are several recommended ways to provide more accurate PSA results. Firstly, it is important to make sure that the equipment for experiment is setup according to IEC 60270. Next, ensure that the test cell is design accurately as stated in IEC 61294 standard. Lastly, the voltage breakdown should be known to avoid complete failure occurs.

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