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

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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

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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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LIST OF SYMBOLS AND ABBREVIATIONS

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].

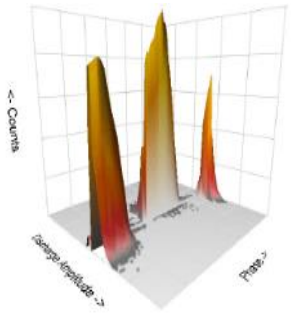
PD activity also can be detected by using a piezoelectric transducer sensor. A piezoelectric sensor detects the acoustic signal produced by PD. The piezoelectric transducer sensor is required to detect PD activity due to sound-wave propagation. This method is non-destructive and may be a noninvasive 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

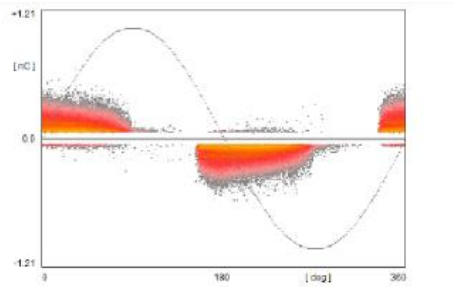
There are many ways to represent partial discharge data analysis, for example, Phase-Resolved Partial Discharge (PRPD), Pulse Sequence Analysis (PSA) and Time Resolved Pulse Partial Discharge Analysis(TRPDA).

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.

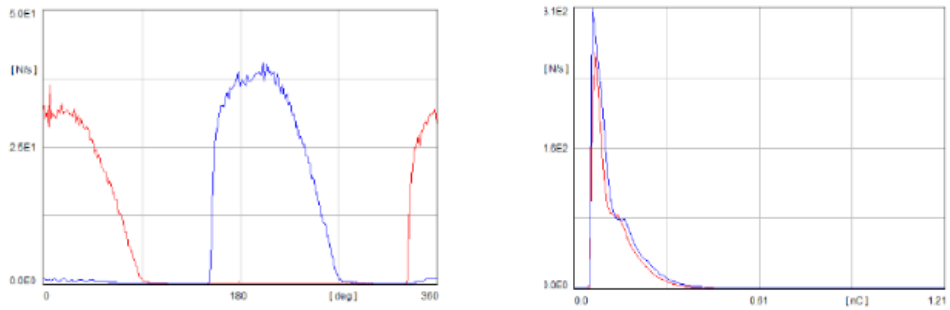
Figure 2.1 shows different types of patterns provided by PRPD method such as ψ-n pattern (the phase of occurrence versus the number of PD), ψ-qm pattern (the phase of occurrence versus the maximum apparent charge), the ψ-qa pattern (the phase of occurrence versus the average apparent charge), the q-n 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 $\emptyset_{n-1}$, $\emptyset_n$ and $\emptyset_{n+1}$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, Δu, phase difference, $\Delta\emptyset$, 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 Δu_n vs $\Delta\emptyset_n$ vs $\Delta\emptyset_{n-1}$, and m_n vs m_{n-1}.

$$\Delta u_n = u_{n+1} - u_n \quad (2\text{-}1)$$

$$\Delta \emptyset_n = \Delta \emptyset_{n+1} - \emptyset_n \quad (2\text{-}2)$$

$$m_n = \frac{\Delta u_n}{\Delta \emptyset_n} \quad (2\text{-}3)$$

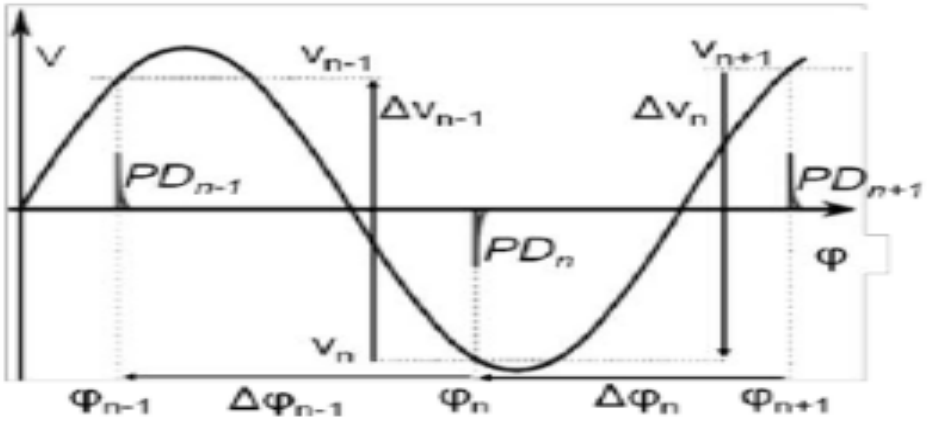


Figure 2.2: Principle of the generation of PSA

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, Δu_n vs Δu_{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 Δu_n vs Δu_{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 Δu or $\Delta\emptyset$.

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

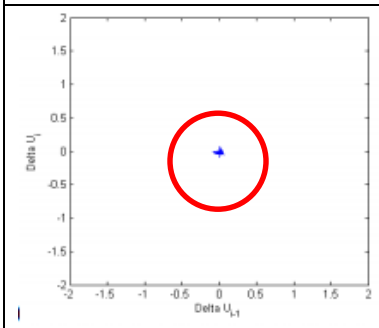
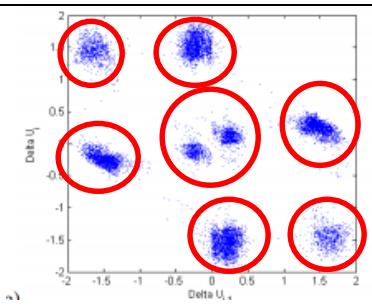
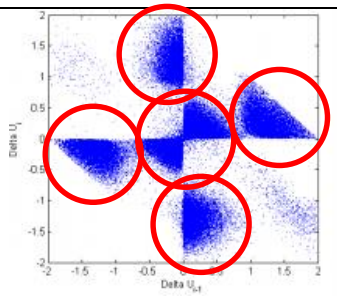
Corona	Void	Surface discharge
 One cluster in the middle	 Seven clusters; on the edges, the axis and at the origin	 Five clusters; four on the axis and one in the middle.

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

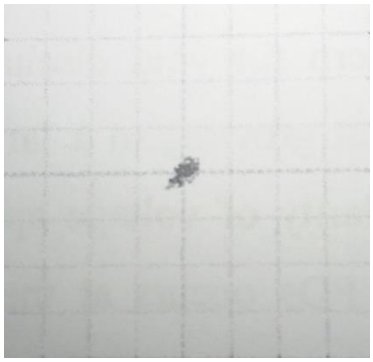
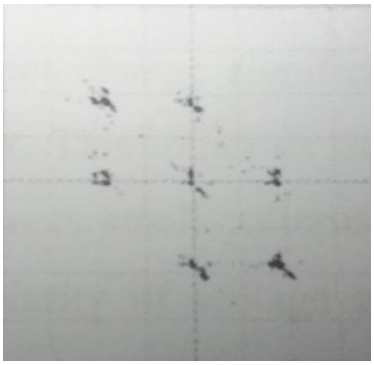
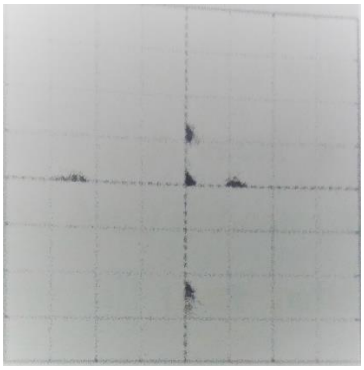
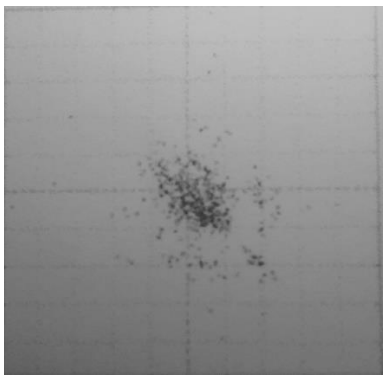
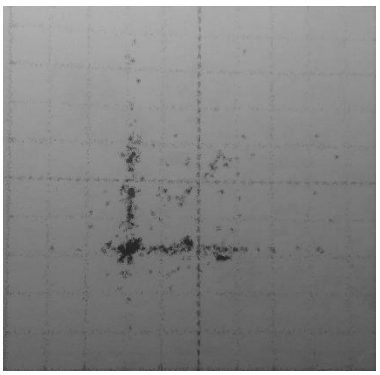
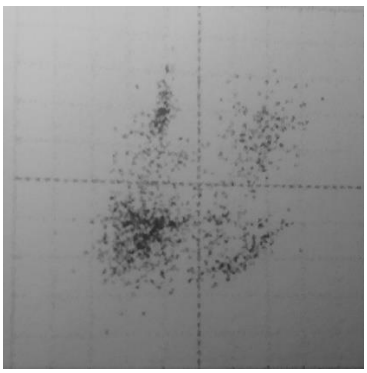
Corona	Void	Surface discharge
 One cluster in the middle	 Seven clusters; on the edges, the axis and at the origin	 Five clusters; four on the axis and one in the middle.

Table 2.3 : PSA patterns by using phase difference, m_n vs Δm_{n-1}.

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