PARTIAL DISCHARGE MEASUREMENT OF VOID IN INSULATION SYSTEM USING HDPE

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DECLARATION

This thesis is dedicated to:

The sake of Allah, my Creator.

My great teacher, Mohammed (May Allah bless
and grant him), who taught us the purpose of life;

My great parents, who lead me and support;

My soul partner in this life my beloved wife and my children;

My beloved brothers and sisters and all family;

My friends who encourage and support me;

I dedicate this research.

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ABSTRACT

Partial discharge plays important role in decision system of high voltage industry. In measurement of partial discharge test, the exact detection for the void and insulation machine fault in advance is needed in the high voltage equipment to ensure the early maintenance for long durability, to avoid the collapse in the machine and to evade the high cost for machine downtime maintenance. There are many ways to detect the existence of partial discharge such as wire and wireless sensors which are the most popular used. There are many types of wire sensors have been developed such as the high frequency current transformer (HFCT) sensor that detect existence of partial discharge by connected with high voltage (HV) apparatus or equipment. In our partial discharge test experiments, three plates surface of High-Density Poly Ethelene (HDPE) have been used that consist of two plain plates and the third plate with void and the void has three sizes which are (8 mm, 10 mm, and 12 mm). The void location for each size change to different position that include the first position (top), second position (middle), and the third position (bottom) for each plate with its certain size. The partial discharge test in our experiments used the HFCT sensor in order to measure the PD existence at insulation system. In the first phase of our partial discharge test experiments the HFCT sensor detect the PD signal and the signal waveform that performed at oscilloscope as input data for the next phase. While, in the second phase the data analyzed by using MATLAB Software in order to extract the most effected charge values on the insulation system in which the signal waveform analyzed to find the PD charge by calculate the area under the waveform. Finally, the last phase shows the output results of the experiments for all size of voids with its selected values 8 mm, 10 mm, and 12 mm. From the analysis, found that the PD appear at lower voltages when the void is positioned at the top of the layer (position 1) compared to other positions. Our second finding is that if the size of the void is larger, the PD appear at lower voltages.

ABSTRAK

Pelepasan separa memainkan peranan penting dalam menentukan sistem industri voltan tinggi. Dalam ujian pengukuran pelepasan separa, pengesanan tepat untuk kerosakan mesin yang tidak diingini dan penebat terlebih dahulu diperlukan dalam peralatan voltan yang tinggi bagi memastikan penyelenggaraan awal untuk ketahanan yang panjang, mengelakkan keruntuhan pada mesin dan mengelakkan kos yang tinggi pada mesin penyelenggaraan waktu henti. Terdapat banyak cara untuk mengesan kewujudan pelepasan separa seperti dawai dan sensor tanpa wayar yang paling popular digunakan. Terdapat banyak jenis sensor dawai yang telah dibangunkan seperti sensor pengubah arus frekuensi tinggi (HFCT) yang mengesan kewujudan pelepasan separa dengan berhubung dengan radas voltan tinggi (HV) atau peralatan. Dalam eksperimen ujian pelepasan separa, kami menggunakan tiga plat permukaan ketumpatan tinggi poli-ethelene (HDPE) yang terdiri daripada dua plat kosong dan plat ketiga dengan tidak sah dan kekosongan mempunyai tiga saiz iaitu (8mm, 10mm, dan 12mm). Lokasi yang tidak tepat untuk setiap saiz akan berubah ke kedudukan yang berbeza termasuk kedudukan pertama (atas), kedudukan kedua (tengah), dan kedudukan ketiga (bawah) untuk setiap plat dengan saiz tertentu. Dalam eksperimen ujian pelepasan separa ini, kami menggunakan sensor HFCT untuk mengukur kewujudan PD pada sistem penebat. Dalam fasa pertama eksperimen ujian pelepasan separa kami, sensor HFCT akan mengesan isyarat PD dan bentuk gelombang isyarat yang terhasil pada osiloskop sebagai data masukan untuk fasa seterusnya. Manakala, dalam fasa kedua data akan dianalisis dengan menggunakan perisian Matlab untuk mengekstrak nilai-nilai cas yang terkesan di stator di mana bentuk gelombang isyarat akan dianalisis untuk mencari caj PD dengan mengira luas di bawah gelombang. Akhirnya, fasa terakhir akan menunjukkan hasil keluaran eksperimen untuk semua saiz lompang dengan nilai yang dipilih iaitu 8mm, 10mm, dan 12mm. Dari analisis, kami mendapati bahawa PD muncul pada voltan yang lebih rendah apabila kekosongan diletakkan di bahagian atas lapisan (kedudukan 1) berbanding dengan kawasan lain. Penemuan kedua kami ialah jika saiz kekosongan lebih besar, PD akan muncul pada voltan yang lebih rendah.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

AC	Alternating Current
C	Coulomb
CIGRE	Conseil International des Grands Réseaux Électriques (French: International Council for Large Electric Systems; founded in 1921).
DC	Direct Current
EM	electromagnetic
FDTD	Finite-Difference time-domain
GUI	Graphic User Interface
HDPE	High-density polyethylene
HFCT	High frequency current transformer
HV	High Voltage
IEEE	Institute of Electrical and Electronics Engineers
KV	Kilo Volt
KW	Kilo Watt
LV	Low Voltage
LLDPE	linear low-density polyethylene
MHz	Mage Hertz
MnZn	manganese and zinc
NiZn	nickel and zinc
PD	Partial Discharge
PE	polyethylene
PHA	Pulse Height Analysis
PRPD	Phase Resolved Partial Discharge
Q	Charge
TEAM	Thermal, Electrical, Ambient and Mechanical
VPI	Vacuum Pressure Impregnation
VS	Vibration Sparking
XLPE	cross-linked polyethylene

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

The electrical insulation system is one of the most important components in high voltage equipment. Its condition normally limits the lifetime of the equipment and determines the safe and reliable operation of the electrical power system. The failure of the insulation system may cause a complete failure of the equipment, resulting in large financial losses to utilities and end-users. Since electrical insulation is the critical point of the equipment, it must be designed in such a way that it must have high resistance to current flow and be safe during operation. It also should sustain mechanical stress as well as the ambient conditions for long term performance. However, there may exist built-in defects in the insulation system potentially created by various stresses during operation or manufacturing process, even though the insulation system has passed all the required tests before installation and operation. Thus, partial discharge (PD) may arise at these defects when a critical electric field is reached, resulting in the gradual deterioration of insulation properties and increasing the risk of failure of the equipment. PD activity is therefore normally considered as a symptom of degradation and overstress in the insulation system. Wherever degradation occurs in the insulation system, caused by the electrical, mechanical, thermal or ambient conditions

The presence of PD Figure 1.1 can indicate not only the electrical stress, but also the mechanical, thermal or ambient stresses. For instance, in the insulation system of high-voltage rotating machines, voids or delamination within epoxy-mica insulation may occur due to the higher temperature during operation [1]. Mechanical force may cause the vibration of the loose bar in the stator slot, leading to the slot discharge in the air gap between the ground wall insulation and the earthed core [2]. Surface contamination on the stator winding leads to intense surface discharge and tracking.

Figure 1.1: Partial discharges on stator winding of rotating machine

In order to avoid the unexpected breakdown of insulation system and help to reduce the cost and time of maintenance of the equipment, partial discharge measurement has been used for many years as a powerful tool to detect and interpret the signature of the locally confined insulation defects. The ability to detect, localize and interpret the PD activity is of fundamental significance in many applications. PD measurement is commonly performed both in on-line and off-line conditions.

1.2 Problem Statement

Meanwhile in the insulation system there are no agreed partial discharger (PD) specifications for large generators where limits are defined, e.g., as acceptance criteria during commissioning test or operation diagnosis. In addition, the recognition or classification for complex partial discharge signals associated with practical insulation systems of large generator still a tangible difficulty.

In PD measurement for voltage waveform and frequency the PD appearance and its feature specification are greatly influenced by different physical processes that stimulated by different durations of the applied waveform [1]. Each PD activity has memory for characteristics which influence the sequence of PD pulses. The memory activity is replicated for the surface charges that remaining in the proximity of the discharge site after previous discharges [2]. Nowadays the researchers used the Polyethylene (PE) because it is the most popular plastic in the world that has a very simple structure that used in PD measurement. In PE there are many types of materials and HDPE related to the literatures has the advantage to be used among the other types because of its high shrinkage, easy forming, high melt strength, and relatively mature processing technology [12]. This research project used to measure the partial discharge for different size of voids 8mm, 10mm, and 12mm in insulation system for HDPE material. Furthermore, nowadays the researchers used PD measurement to check the insulation systems has either PD appear or not by studying the characteristics of voltage waveform and frequency in order to check the type of PD either has delamination, slot discharge, end winding and void [3]. This research project also, used to measure and analyse the partial discharge of different size of voids that include 8mm, 10mm, and 12mm under many values of high voltage.

1.3 Objectives

The objectives of this research project are:

1. To check the performance of the partial discharge in insulation system.
2. To measure the partial discharge of voids in insulation system using HDPE material.
3. To analyse the partial discharge inception voltages and charge in voids.

1.4 Scope of Study

This research, has the following scopes:

1. This experiment is conducted in the high voltage laboratory of UTHM which located in Parit Raja campus
2. Void in insulation is selected for investigation in this study.
3. The void size is 8 mm, 10 mm and 12 mm.
4. Dimension of HDPE sample
   a. Length 14.5 cm
   b. Width 10.5 cm
   c. Height 0.5 cm
5. The void is placed in three different positions on three layers of HDPE samples.
6. The measurement is performed using:
   a. HV 9105 Test Transformer
   b. HV 9141 Measuring Capacitor
   c. Control desk (TERCO High voltage system)
   d. Oscilloscope to measure the PD signal from HFCT
   e. High frequency current transformer (HFCT)
   f. Test Object (high-density polyethylene, HDPE)
7. The analysis of the results for the collected data is conducted using MATLAB software.

1.5 Thesis Organization

This research presents the work for early detection of PD in insulation of stator winding in rotating machine.

Chapter 1 shows the Introduction, problem statement of the research, research objective, the scope of the study, and the research organization.

Chapter 2 describe literature review and the related work to achieve the research gap.

Chapter 3 provide the description for the research methodology and research framework with its parameters set up.

Chapter 4 shows the testing experiments with its analysis using MATLAB software then shows the results discussion.

Chapter 5 arrange the research by discussing the contribution, findings, limitations, and its recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The main purpose of this chapter is to mention and highlights all the relevant topics and literatures that are relating to this study, starting by summarizing some articles and literatures about Partial Discharge (PD) to gain full information about PD measurement and insulation system and extract the research project problem. Also, to provide a clear view to readers about the concept as well. The methodologies that included in this chapter are PD, phase rotating machines and the construction of rotating machine. However, the main focus in this chapter is how construction and materials of stator winding insulation work. Starting the literature by brief about characteristics of partial discharge. Moreover, the chapter provides a better understanding about propagation of partial discharges pulse in stator winding. This chapter also discussed the. high frequency current transformer (HFCT) sensor. At the last of this chapter, reviews and comparison of main materials types of Polyethylene (PE) have been illustrated and discussed.

2.2 3 Phase rotating machines

For one and three phase rotating machines, any apparatus with a rotating part that creates, converts, transforms, or modifies electric power. Almost all of the world's electric power is generated by rotating electrical generators, with electric motors consuming over 70% of this energy. Generators convert me to electricity; electric machines are electromechanical energy converters.

Three-phase rotating machines are now widely employed in a wide range of industries, including manufacturing (for example, paper mills), transportation (for example, electric vehicles), and power generation (e.g., wind turbines). Because of their durability and inexpensive cost, three-phase induction machines are the most popular. They can be used as electric generators to convert mechanical energy to electrical energy, or they can be used as electric generators to convert mechanical energy to electrical energy. [4].

2.3 Construction of Rotating Machine

A stator, rotor, and the air gap between them make up a rotating electrical machine. Windings are found on both the stator and the rotor. The stem connects to the motor and any other loads, and the rotor is put into it. The electrical current that generates magnetic fields for the electrical load is carried via the windings. It is possible to create voltage closed loops there. Several of the elements.

2.3.1 Stator

The motor's stationary electrical component. When an alternating current (AC) is applied, it has many windings whose polarity is constantly changing. This causes the stator's combined magnetic field to spin. All stators are housed in a housing or frame. For motors up to 22 kW, the stator housing is generally built of aluminium, while motors with higher outputs feature cast-iron stator housings. The stator is encased within the stator housing. It's made out of thin, stacked laminations wrapped with insulated wire. Hundreds of these laminations can be found in the core. An alternating current flow through the windings when power is given, creating an electromagnetic field across the rotor bars. The magnetic field rotates due to alternating current (AC). Figure 2.1.

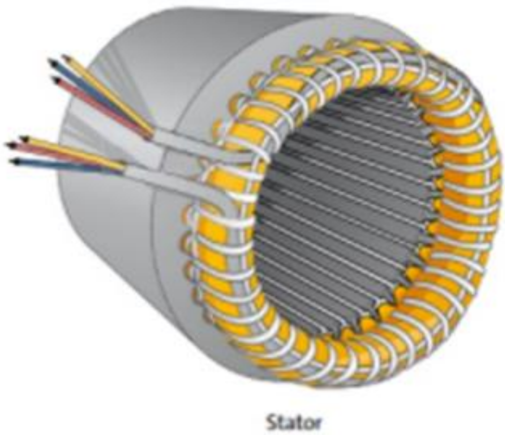

Figure 2.1: The stator winding of rotating machine

2.3.2 Rotor

The rotor is the portion of the motor that rotates. The rotor portion consists of the rotor core and rotor winding. The DC supply energises the rotor winding. The rotor types are squirrel cage and phase wound. A current is produced when the stator's moving magnetic field crosses the rotor conductor bars. This current flows through the bars, creating magnetic fields around each rotor bar. Figure 2.2. The magnetic field in the rotor changes as the magnetic field in the stator changes. The rotor moves as a result of this interaction. The rotor, like the stator, is constructed from a lamination stack. The rotor is filled with cast aluminium or sliming bars that operate as conductors, as opposed to the stator, which is filled with copper wire.

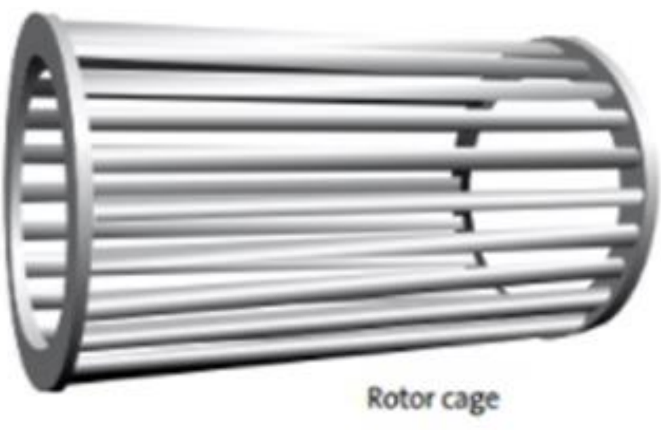

Figure 2.2: The rotor cage of rotating machine

2.3.3 Cooling

The motors are completely enclosed fan cooled and are mounted on an outwardly ribbed frame with free internal air movement caused by the rotation of the rotor blades. From the non-drive end to the drive end, cooling air flows. The direction of rotation of the motor has no effect on the fan. When installing the motor, take care not to prevent the air flow into the motor cowl.

2.3.4 Stator Winding

Copper conductors (aluminium is rarely used), the stator core, and the insulation are the three primary components of a stator. The copper serves as a conduit for the current flowing through the stator windings. As a reaction to the revolving magnetic field from the rotor, the stator output current is induced to flow in the copper conductors in a generator. A current is supplied into the stator of a motor, causing the rotor to move by creating a spinning magnetic field. Copper conductors must have a big enough cross section to carry all of the required current without overheating

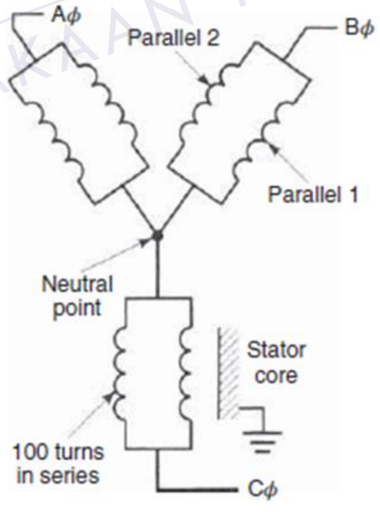

Figure 2.3: Schematic diagram for a three-phase, Y-connected stator winding

In the Figure 2.3 is A typical three-phase motor or generator stator winding circuit schematic. Each phase has one or more parallel current flow pathways, as shown in the diagram. Because a copper cross section large enough to carry the entire phase current would result in an uneconomic stator slot size, multiple parallels are frequently required. Each parallel is made up of several coils that are connected in series. Each coil in most motors and small generators is made up of a loop of copper conductors formed by a number of turns.

2.4 Construction and Materials of Stator Winding Insulation

The stator of an AC rotating machine is a stationary construction which consists of three main components: a core of laminated steel that carries the magnetic fields, the copper conductors for carrying current induced by the stator's magnetic field, and the electrical insulation with a primary purpose of preventing short circuits between the conductors or to ground. The life time of a stator winding is mostly limited by the electrical insulation rather than by the conductors or the steel core [7]. Thus, the stator insulation system is of significant importance

The basic components in the stator insulation system are quite similar. Figure 2.4 shows the cross section of the insulation structure of the multi-turn coil; each part of the insulation is described below:

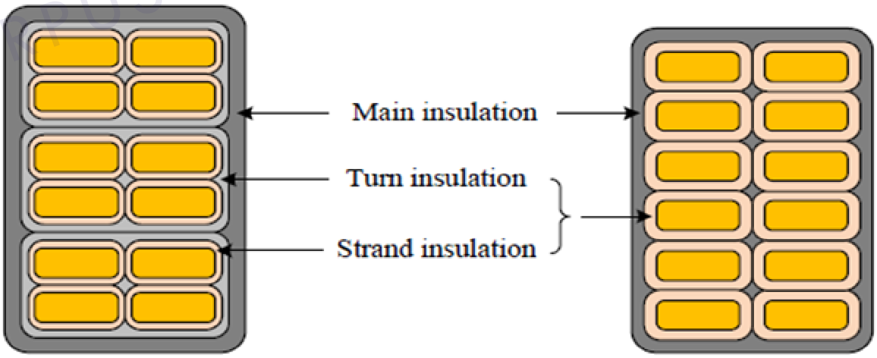

Figure 2.4: Schematic diagram of the cross section of the insulation construction of a multi-turn coil [8]

2.4.1 Ground wall or main insulation

Several turns in a package are then wrapped with a thicker layer of outer insulation, i.e., ground wall insulation, to separate the conductors from the grounded stator core. Ground wall insulation is the main high-voltage insulation in the stator winding. It must meet the requirements to withstand the electrical, thermal and mechanical stresses that it is subjected to. Furthermore, it must also help to prevent the winding from vibrating under the magnetic force in the slot. Failure of the main insulation is the main type of failure, caused by continuous aging rather than by mechanical damage or severe transients [9].

With respect to the materials of ground wall insulation in the stator winding, an overview of some significant developments has been described [5]. Nowadays, the most common materials used for ground wall insulation is as follows, with consisting of three basic components

1. A barrier material that is resistant to PD and tree growth: Mica flakes
2. A support material that gives mechanical strength and heat transfer: Glass fiber
3. A binder material that fills the air gaps between the different layers of barrier and the support material [7]

These materials are produced as mica tapes and wrapped around the surface of the turn or strand insulation to form the main insulation. In order to fill any air gaps between the mica tapes, thermoset binder materials are used. There are three major technologies to get the impregnant into the main insulation [10]

1. Vacuum Pressure Impregnation (VPI) of individual stator windings: Mica tapes with a resin content of 5%-15% are used in VPI. The winding is dried and then put into a vacuum chamber to remove the air. The chamber is then flooded with impregnant under high pressure to force the impregnant into the insulation. The system is then heated to cure after cleaning off the extra impregnant.
2. Global VPI of the complete stator: The entire stator is impregnated after the windings are inserted in their slots in the core. In such a way, the air-gaps between the stator windings and the slot are also filled.

3. Resin-rich processes: The impregnant is combined in the mica tapes, with a resin content

2.4.2 Strand or sub conductor insulation

The conductor of small cross-section is covered with a thin layer of insulation, strand insulation, to withstand the voltage stress in the order of tens of volts. The benefits of a conductor forming from smaller strands can be described from two aspects: mechanically, to improves the flexibility of bending, and for the electrical Reason, to reduce the skin effect and reduce the eddy current losses. Failure of the strand insulation between two strands would cause circulating currents leading to overheating and further deterioration [8].

2.5 Failures of rotating machine

The main components of a rotating machine are the stator winding, rotor winding and bearings that support the rotor. Some surveys of the distribution of failures over components have been undertaken; one study cited [11] shows that the root causes that caused failures in rotating machines are located in bearing (40%), stator (37%), rotor (10%) and other (12%) which describe below. An IEEE working group report of problems for hydro-generators presents [10] that stator winding insulation problems caused 43% of the failure. It is also mentioned as an opinion in that contrary to the case for air-cool machines, hydrogen-cooled machines generally have a higher proportion of failures in rotors than in stators windings.

Another study of damage of rotating machine by CIGRE examined 69% failure incidents in detail and is summarized [10]. It was found that 56% of the failed machines involved insulation damage and other causes were mechanical, thermal and bearing damages, as shown in Table 2.1. Table 2.2 shows the root causes of the insulation damage. Three root causes leading to insulation damage stand out: ageing (32.8%), winding contamination (25%) and internal partial discharge (22%). On the other hand, nature of failure or origin of failure is also surveyed. Material weakness comprises 50% of the occurrence of the failures, followed by design weakness with

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