Faculty of Electrical Engineering

A FUNDAMENTAL STUDY OF SURFACE DISCHARGE CHARACTERISTICS ON PRESSBOARD IMMERSED IN ESTER OIL FOR POWER TRANSFORMER APPLICATION

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DECLARATION

I declare that this thesis entitled "A Fundamental Study of Surface Discharge Characteristics on Pressboard Immersed in Ester Oil for Power Transformer Application" 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 : ……

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Date : 2 NOVEMBER 2017

APPROVAL

I hereby declare that I have read this dissertation/report and in my opinion this dissertation/report is sufficient in terms of scope and quality as a partial fulfilment of Master of Science in Electrical Engineering.

Signature : ……

Supervisor Name : DR. HIDAYAT BIN ZAINUDDIN

Date : 2 NOVEMBER 2017

DEDICATION

This thesis is dedicated to,

my loving parents,

Othman bin Mohamad Noor and Nor Haizan binti Embong,

my beloved husband,

Muhammad Zhafri bin Mokhtar,

all of my siblings,

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and all my lecturers and friends.

Thank you for supporting me during ups and downs in finishing the master study.

ABSTRACT

Surface discharge at the oil-pressboard interface is known as the development of a conducting path which is characterized by white and carbonized marks. This phenomenon tends to cause damage on the cellulose pressboard insulation which is subsequently promotes catastrophic failure in transformer's insulation. One of the major defects that may cause surface discharge to occur along the pressboard surface is an excessive moisture content in pressboard insulation. In order to increase the understanding on this failure, this thesis presents the investigation on the degradation behaviour of surface discharge along dry and wet pressboard samples (3 % and 6 %) immersed with different viscosity of natural ester insulation (NEI) oils, i.e. palm fatty acid ester (PFAE) and MIDEL eN oil. There are three types of experiments that were discussed in this thesis, i.e. surface breakdown, partial discharge inception voltage (PDIV) and surface discharge experiments. These experiments were conducted in oil bath by using a needle-bar electrode configuration under AC voltage stress. Three differences gap distances between the needle tip and earth electrode, i.e. 20 mm, 30 mm and 40 mm were used in surface breakdown and PDIV experiments. On the other hand, surface discharge experiment was conducted under a long duration of constant AC voltage (30 kV) with a fixed 30 mm gap distance. The development of surface discharge have been analysed by correlating the visual records of surface discharge and phase-resolved partial discharge (PRPD) pattern. The results show that the moisture contents in the pressboard and viscosity of insulation oils play important roles in all experiments. In general, as moisture increases, the PDIV and surface breakdown voltage decreases, whilst the PD number from the surface discharge experiment increases. However, unexpected results are observed when pressboard of 6 % moisture content are used in MIDEL eN oil, whereby the surface breakdown voltage was unexpectedly increased and no PD data was recorded in the surface discharge experiment. This might be due to the trapped vaporised moisture and dissolved gases in the pressboard structure as a result of higher viscosity of MIDEL eN oil compared to PFAE oil. Another effect of high viscosity of MIDEL eN oil is also observed when the MIDEL eN oil-impregnated pressboard has a higher surface breakdown voltage by approximately 27.82 % on average and lower PDIV approximately by 8.98 % on average compared to PFAE oil-impregnated pressboard, regardless the moisture contents in pressboard. In addition, the maximum PD magnitude for the MIDEL eN oil-impregnated pressboard is in the order of 1×10^{-12}C which is lower than PFAE oil-impregnated pressboard that is in order of 1×10^{-9}C. On the other hand, the number of PD is observed higher for MIDEL oil-impregnated pressboard compared to PFAE oil-impregnated pressboard.

ABSTRAK

Nyahcas permukaan pada antara muka minyak-pressboard dikenali sebagai pembentukan laluan konduktif yang dicirikan sebagai tanda putih dan berkarbon. Fenomena ini akan menyebabkan kerosakan pada penebat pressboard selulosa yang kemudiannya mengakibatkan kegagalan dalam penebat pengubah. Salah satu punca utama yang boleh menyebabkan nyahcas permukaan berlaku sepanjang permukaan pressboard adalah kandungan kelembapan yang berlebihan di dalam penebat pressboard. Dalam usaha untuk meningkatkan kefahaman mengenai kegagalan ini, tesis ini membentangkan kajian terhadap kelakuan nyahcas permukaan di atas sampel pressboard kering dan basah (3% dan 6%) yang direndamkan di dalam minyak ester semulajadi (NEI) dengan kelikatan yang berbeza, iaitu minyak ester asid lemak sawit (PFAE) dan minyak MIDEL eN. Terdapat tiga jenis eksperimen yang telah dibincangkan dalam tesis ini, iaitu eksperimen kerosakan permukaan, eksperimen voltan permulaan nyahcas separa (PDIV) dan eksperimen nyahcas permukaan. Eksperimen ini telah dijalankan di dalam bekas minyak dengan menggunakan konfigurasi elektrod jarum-bar di bawah voltan AU malar. Terdapat tiga perbezaan jarak di antara hujung jarum dan elektrod bumi digunakan dalam eksperimen kerosakan permukaan dan eksperimen PDIV, iaitu 20 mm, 30 mm dan 40 mm. Sebaliknya, eksperimen nyahcas permukaan telah dijalankan dalam tempoh yang panjang di bawah voltan AU malar (30 kV) dengan jarak yang tetap, iaitu 30 mm. Pembentukan nyahcas permukaan telah dianalisa dengan menghubungkaitkan rekod visual nyahcas permukaan dan corak nyahcas separa resolusi fasa (PRPD). Kajian menunjukkan bahawa kandungan kelembapan dalam pressboard dan kelikatan minyak memainkan peranan yang penting dalam semua eksperimen. Secara umumnya, PDIV dan voltan kerosakan permukaan berkurangan dengan kenaikan kelembapan dalam pressboard, manakala bilangan nyahcas separa meningkat dalam eksperimen nyahcas permukaan. Walau bagaimanapun, keputusan yang tidak dijangka telah diperolehi apabila pressboard dengan kandungan lembapan 6 % digunakan dalam minyak MIDEL eN, di mana voltan kerosakan permukaan telah meningkat dan tiada data nyahcas separa dicatatkan dalam eksperimen nyahcas permukaan. Ini mungkin disebabkan oleh kelembapan dan gas yang terperangkap dalam struktur pressboard akibat daripada kelikatan yang lebih tinggi dalam minyak MIDEL eN berbanding minyak PFAE. Kesan lain kelikatan minyak yang tingi di dalam minyak MIDEL eN juga ditemui apabila muka minyak-pressboard MIDEL eN mempunyai voltan kerosakan permukaan yang lebih tinggi kira-kira 27.82 % secara purata dan PDIV yang lebih rendah kira-kira 8.98 % secara purata berbanding dengan muka minyak-pressboard PFAE, tanpa mengira kandungan kelembapan di dalam pressboard. Di samping itu, magnitud maksimum nyahcas separa bagi muka minyak-pressboard MIDEL eN ialah pada kadar 1×10^{-12} C 1, iaitu lebih rendah daripada muka minyak-pressboard PFAE yang pada kadar $\times10^{-9}$ C. Sebaliknya, bilangan nyahcas separa didapati lebih tinggi untuk muka minyak-pressboard MIDEL eN berbanding muka minyak-pressboard PFAE.

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LIST OF EQUATION

LIST OF ABBREVIATIONS

PD	:	Partial Discharge
NEI	:	Natural Ester Insulation
PFAE	:	Palm Fatty Acid Ester
FR3	:	One of the brands of vegetable oil
MIDEL eN	:	One of the brands of vegetable oil
MIDEL 7131	:	One of the brands of vegetable oil
PRPD	:	Phase Resolved Partial Discharge
AC	:	Alternating Current
PDIV	:	Partial Discharge Inception Voltage
CTI	:	Comparative Tracking Index
LI	:	Lighting Impulse
MVA	:	Mega Volt Ampere
DGA	:	Dissolve Gas Analysis
IEC	:	International Electrotechnical Comission
MI	:	Measurement Instrument
PDEV	:	Partial Discharge Extinction Voltage
STDEV	:	Standard Deviation
BS	:	British Standard
RH	:	Relative Humidity
HV	:	High voltage

LV	:	Low voltage
fps	:	frame per second
ppm	:	parts per million
i.e.	:	that is
e.g.	:	for example

LIST OF SYMBOLS

ℓ	:	Volume
ε_r	:	Relative permittivity of material
d	:	Gap distance

LIST OF PUBLICATIONS

Conference Paper:

1. Othman, N.A., Zainuddin, H., Aman, A., Ghani, S.A., Khiar, M.S.A., Chairul, I.S. and Talib, M.A., 2015. Moisture Effect on the Creepage Discharge Phenomena on Cellulose-Based Pressboard Immersed in Palm Fatty Acid Ester. In: International Conference on Power, Energy, and Communication Systems. Universiti Malaysia Perlis.

Journal Papers:

1. Othman, N.A., Zainuddin, H., Aman, A., Ghani, S.A., Khiar, M.S.A., Chairul, I.S. and Talib, M.A., 2016. Investigation on the Degradation Behavior of Creepage Discharge on Pressboard Immersed in Palm Fatty Acid Ester (PFAE) oil. *Inspiring Future Technology through Knowledge Collabration, Jurnal Teknologi*, 78(10-3), pp.31-36.

2. Othman, N.A., Zainuddin, H., Aman, A., Ghani, S.A., Khiar, M.S.A. and Chairul, I.S., 2017. The Correlation between Surface Tracking and Partial Discharge Characteristics on Pressboard Surface Immersed in MIDEL eN. *International Journal of Electrical and Computer Engineering (IJECE)*, 7(2), PP.631-640

CHAPTER 1

INTRODUCTION

1.1 Background of the research project

The fundamental of power transformer insulation comprises of the combination of liquid insulation and cellulose-based pressboard. Practically, besides of being a medium that insulates the components of transformer, liquid insulation also acts as a coolant that maintains the temperature inside a transformer (Heathcore, 2007). The common insulating liquid that has been widely used in a transformer is mineral oil which is formulated from natural occurring petroleum or also known as crude oil. However, mineral oil is poorly biodegradable which can contaminate the soil if there is serious oil spillage occur due to the ruptured and failure equipment. Thus, owing to high fire resistance to fire risks and high biodegradable oil, fully biodegradable oil including synthetic ester and natural ester have increasing demand for replacement of the present mineral oil. It will also reduce the environmental pollution, i.e. reduce the toxicity to the living organisms. For the present, they have been widely used in distribution transformer. However, the application of ester oils as an insulating liquid for a high voltage level and large power transformer is quite low due to the lack of understanding on its performance especially when combined with solid insulation.

In general, the use of solid insulation in oil-filled transformer which is called cellulose-based pressboard allows increment in the dielectric strength of oil gap by dividing the large oil gap into smaller ones (Kulkarni and Khaparde, 2004). The comprehensive design of the composite insulating system consisting both oil and

pressboard insulations allows reduction in the transformer size as well as reduction in the manufacturing costs of the transformer. However, the design of composite insulating system had raised problem related to the surface discharge which can occur at the oil-pressboard interface. The oil-pressboard interface is also highlighted as the 'weak point' of insulation as it consists of electric charges deposition and boundaries which promote the surface discharge and hence causes damage of the insulation system (Mitchinson et al., 2008; Yi, 2012). Besides that, it is also suspected that the oil discharge initiated at the junction between high voltage electrode and the pressboard insulation is due to the imperfection of their contact (Dai et al., 2010). Such contact is also called as oil wedge that are inevitable for insulation system in a transformer which is subsequently lower the creep strength on pressboard surface.

Surface discharge along solid-liquid insulation tends to cause reduction in dielectric strength of the insulation medium. Once the discharge activity is initiated, the electric discharges phenomenon (tracking) will start to develop over a period of time even under normal operating condition and hence leaving a conductive path. This conductive path is usually observed in the form of carbonized mark which will slowly deteriorate the material and consequently damage the solid insulation. Surface discharge is also known as creepage discharge that can be categorized into a tracking fault. It is regarded as a serious failure mode in large power transformer as it can lead to a catastrophic failure.

Previously, there are many research works investigating the behaviour of surface discharge towards the degradation on the pressboard material in oil-filled transformer based on the various factors (Yi and Wang, 2013; Zainuddin et al., 2013; Tshivhilinge, 2014). There are many factors that contribute to the deterioration of pressboard due to the surface discharge activities, i.e. excessive moisture content in pressboard, surface contamination, oil contamination, etc. (Sokolov et al., 1996; Emsley et al., 2000). The

factor that focused in this research is the effect of excessive moisture in pressboard. Formerly, there is an extensive of research concerning the surface discharge behaviour based on difference moisture levels in pressboard samples in mineral oil (Mitchinson, 2008; Dai et al., 2010; Yi and Wang, 2013; Zainuddin, 2013). However, as far as literature is concerned, there are no previous researchers have been focussed the effect of moisture in pressboard immersed in esters oil on the degradation of pressboard due to surface discharge. For instance, the research to date has tended to focus the surface tracking on dry pressboard samples in ester oil and not even considered for wet pressboard samples (Yi and Wang, 2013; Murdiya et al., 2014). Thus, the result from this research work will contribute towards the knowledge on the condition monitoring for surface discharge on both dry and wet ester oil-pressboard interface.

1.2 Problem statement

Carbon conductive path left on the pressboard surface due to the surface discharge will create a weak link in the solid insulation. As a result, it creates the permanent electrical conductive path that will slowly degrade the pressboard material until it damages. It is definitely a challenge to evaluate the condition of the pressboard material caused by surface discharge activities through the physical observation at inspection cover of a transformer tank during the operational time. Therefore, condition monitoring on data and diagnostics tests are essential in order to assess the degradation of surface discharge on pressboard surface. However, sometimes, such failure occurrence on an old transformer was unexpected due to wrong interpretation on the condition monitoring data. In monitoring system, the severe condition of partial discharge (PD) depends on the seriousness of the surface degradation of the insulation. The level of the surface degradation can be acquainted with the number and magnitude of measured apparent