Faculty of Electrical Engineering

EFFECTS OF CELLULOSE BRIDGING PHENOMENON ON BREAKDOWN VOLTAGE AND CONDUCTION CURRENT CHARACTERISTICS IN MINERAL AND ESTER TRANSFORMER OILS

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DECLARATION

I declare that this thesis entitled “Effects of Cellulose Bridging Phenomenon on Breakdown Voltage and Conduction Current Characteristics in Mineral and Ester Transformer Oils” 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.

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Date : 23 NOVEMBER 2018

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Electrical Engineering.

Signature	:…….
Supervisor Name	: ASSOC. PROF. DR. HIDAYAT BIN ZAINUDDIN
Date	: 23 NOVEMBER 2018

DEDICATION

To my beloved parents and family,

Zainoddin Bin Jamari and Rokiah Binti Mee,

Filzah Farah, Hani Nadhirah and Haziq Ahmad Hazwan

To my prestige wife,

Nur Adibah binti Ghazali

To my outstanding Lecturers and friends,

Thanks for being a great supporter during the journey

ABSTRACT

Dielectric liquid plays a vital role in High Voltage (HV) system. This liquid is used as an insulator, as well as in cooling method to dissipate heat generated from transformer windings and cores. Failure to maintain the condition for insulation will lead to transformer failure and significant losses of power electricity system. Almost 30% of the transformer failures from all over the world are caused by insulation failure and most of the cases are due to contaminant presence in the dielectric liquid. One of the major defects caused by the contamination is bridge phenomenon, potentially act as a conducting current path between two different potentials and lead to insulation failure. In order to understand the bridging phenomenon effects on dielectric liquid, this thesis presents the investigation on the breakdown voltage (BdV) and conduction current path characteristics in three types of dielectric liquid namely Gemini X (mineral oil), MIDEL 7131 (synthetic ester) and MIDEL eN (natural ester) contaminated with cellulose particles. These experiments were conducted in test cell using sphere-sphere electrode configuration under DC voltage stress. Three different contaminant sizes, i.e. 100, 300 and 500 µm, and three different gap distances, i.e. 10, 15 and 20 mm with two types of experiment conditions, i.e. stirred and without stirred were used in BdV and conduction path experiments. Three voltage levels were used for conduction current path experiment, i.e. 2, 7, and 15 kV for 25-minutes and for the BdV experiment, the voltage was applied in steps of 5 kV with a 1-minute interval for each step until BdV occurs or maximum 25-minutes. The formation of cellulose particles bridge have been analysed by taking the time taken for the particles to start attach on the electrodes surface and time taken to completely form cellulose particles bridge between electrodes. The results show that the presence of contaminant in dielectric liquid and the level of dielectric liquid viscosity play important roles in all experiments. In general, the cellulose bridge formation time, conduction current path and BdV increased as the size of particles increased. However, no cellulose bridge is observed when low voltage was applied to lower particle size during conduction current path experiment. In addition, the bridge condition is also different for each experiment, i.e. bridge condition in without stirred condition is always thicker and dense regardless the particle size used and gap distance compared with stirred condition. As a whole, MIDEL eN has a better performance compared to MIDEL 7131 and Gemini X as the BdV recorded is higher regardless the particle size, gap distance and experiment condition. Furthermore, it is obvious that all dielectric samples with contaminant presence will increase the BdV value with no correlation with particle size and gap distance. On the contrary, conduction current path recorded in Gemini X is always the highest which is believed due to the effect of viscosity, as lower viscosity level of dielectric liquid would increase the collation between oil molecules and cellulose particles which contribute to faster bridging formation and higher conduction current path.

ABSTRAK

Cecair dielektrik memainkan peranan penting dalam sistem Voltan Tinggi (HV). Cecair ini digunakan sebagai penebat dan kaedah penyejukan untuk menghilangkan haba yang dihasilkan daripada belitan pengubah dan teras. Kegagalan untuk mengekalkan keadaan penebat di tahap optimum akan membawa kepada kegagalan pengubah dan kesan besar kepada sistem kuasa elektrik. Hampir 30% daripada kegagalan pengubah dari seluruh dunia disebabkan oleh kegagalan penebat dan kebanyakan kes adalah disebabkan oleh pencemaran di dalam cecair dielektrik. Salah satu kesan utama yang disebabkan oleh pencemaran adalah fenomena titian, berpotensi bertindak sebagai jalan yang menjalankan antara dua potensi yang berbeza dan menyebabkan kegagalan penebat. Untuk memahami kesan fenomena penyambungan pada cecair dielektrik, tesis ini membentangkan penyiasatan mengenai ciri-ciri voltan rosak (BdV) dan arus konduksi dalam tiga jenis cecair dielektrik, Gemini X (minyak mineral), MIDEL 7131 (ester sintetik) dan MIDEL eN (estetik semulajadi) yang tercemar dengan zarah selulosa. Eksperimen ini dijalankan dalam sel ujian menggunakan konfigurasi elektrod sfera-sfera di bawah tekanan voltan DC. Tiga perbezaan saiz pencemaran, iaitu 100, 300 dan 500 μm, dan tiga jarak perbezaan jarak, iaitu 10, 15 dan 20 mm dengan dua jenis keadaan, iaitu, dikacau dan tanpa dikacau dalam BdV dan arus konduksi. Tiga tahap voltan digunakan untuk percubaan arus pengaliran, iaitu 2, 7, dan 15 kV selama 25 minit dan untuk eksperimen BdV, voltan yang ditingkatkan sebanyak 5 kV dengan selang 1 minit untuk setiap langkah sehingga kerosakan berlaku atau maksimum 25 minit. Pembentukan titian zarah selulosa telah dianalisa berdasarkan masa yang diambil untuk zarah-zarah mula melekat pada permukaan elektrod dan masa diambil untuk membentuk titian selulosa di antara elektrod. Keputusan menunjukkan bahawa kehadiran kontaminan dalam cecair dielektrik dan tahap kelikatan cecair dielektrik memainkan peranan penting dalam semua eksperimen. Secara umum, masa pembentukan titian selulosa meningkat serta arus konduksi dan BdV direkodkan meningkat apabila saiz zarah yang lebih tinggi digunakan berbanding dengan saiz yang lebih rendah. Walau bagaimanapun, tiada titian selulosa yang diperhatikan apabila voltan rendah digunakan pada saiz zarah yang lebih rendah semasa eksperimen arus pengaliran. Sementara itu, keadaan titian adalah berbeza bagi setiap eksperimen, iaitu keadaan titian tidak dikacau sentiasa lebih tebal tanpa mengira saiz zarah dan jarak yang digunakan berbanding keadaan yang dikacau. Keseluruhannya, MIDEL eN mempunyai prestasi yang lebih baik berbanding dengan MIDEL 7131 dan Gemini X kerana BdV yang direkodkan lebih tinggi tanpa mengira saiz zarah, jarak dan keadaan eksperimen. Di samping itu, dapat dilihat dengan jelas di semua sampel dielektrik bahawa kehadiran bahan pencemar meningkatkan BdV tanpa mengira saiz zarah dan jarak. Sebaliknya, laluan pengaliran yang direkodkan dalam Gemini X sentiasa tertinggi yang dipercayai kerana kesan kelikatan, sebagai tahap kelikatan rendah cecair dielektrik, ia meningkatkan pengagregatan antara molekul dan zarah minyak yang menyumbang kepada pembentukan penyambungan lebih cepat dan arus konduksi yang lebih tinggi.

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A	-	Ampere
AC	-	Alternating Current
ASTM	-	American Society for Testing and Materials
BdV	-	Breakdown Voltage
BS	-	British Standard
°C	-	Celsius
CIGRE	-	International Council on Large Electric Systems
CSC	-	Current Source Converter
DC	-	Direct Current
DEP	-	Dielectrophoresis
DT	-	Distribution Transformer
e.g.	-	For example
Gemini X	-	One of the Mineral Oil brands
HV	-	High Voltage
HVDC	-	High Voltage Direct Current
i.e.	-	That is
IEC	-	International Electrotechnical Comission
IEEE	-	Institute of Electrical and Electronics Engineers
ISO	-	International Organization for Standardization

KFC	-	Karl Fisher Coulomat
kV	-	Kilo Volt
LCC	-	Line-Commutated Converter
LV	-	Low Voltage
M	-	Minutes
MATLAB	-	Engineering Software
MIDEL 7131	-	One of the Vegetable Oil brands (Synthetic)
MIDEL eN	-	One of the Vegetable Oil brands (Natural)
mm	-	Milimetre
MPa	-	MegaPascal
NEI	-	Natural Ester Insulation
PCB	-	Polychlorinated Biphenyls
PD	-	Partial Discharge
Ppm	-	Part per million
PT	-	Power Transformer
s	-	Seconds
VB	-	Visual Basic
VSC	-	Voltage Source Converter