Proceedings of Mechanical Engineering Research Day 2016, pp. 179-180, March 2016

Investigation of surface breakdown on various solid insulation immersed in ester and mineral oils under ac stress

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Keywords: Creepage discharge; permittivity mismatch; liquid-solid interface

ABSTRACT – Liquid-solid interface is common in high voltage (HV) insulation system. Creepage discharge is a phenomenon that usually occurs along the liquid-solid interface that may cause damage to the surface of solid insulation. This paper presents the effect of various types of solid insulation immersed in liquid insulation on the surface breakdown under AC voltage. In this study, surface discharge experiments were conducted on Eproxy Resin G10, Low Density Polyethylene (LDPE), High Density Polyethylene (HDPE), and Bakelite immersed in Palm Fatty Acid Ester Oil (PFAE) and Mineral oil. Needle-bar method was chosen for the electrode configuration. The results suggest that permittivity mismatch between liquid and solid insulation is an influential factors in creepage discharge among similar materials with different density.

1. INTRODUCTION

Creepage discharge has long been discovered as one of the faults condition found in composite insulation of solid and liquid [1]. The occurrence of creepage discharge promotes a decrease in the value of dielectric strength of the affected liquid-solid interface. There are a few speculated reasons found to be contributing to the occurrence of creepage discharges along a solid insulation, that are, the permittivity mismatch, contamination, surface charging and others.

In previous research [2], pressboard was used as the solid material that impregnated in oil to investigate the partial discharge characteristics at oil-pressboard interface. Oil-pressboard interface is common in high voltage transformer whereby the pressboard serves as the interphase barrier. In [3, 4], the breakdown characteristics of different types of solid materials immersed in mineral oil were studied. This paper on the other hand, investigates the effect of various types of solid insulation immersed in mineral and ester oils on the surface breakdown voltage under AC stress. The electrode configuration is different compared to those reported elsewhere [3, 4].

2. EXPERIMENTAL METHOD

Figure 1 shows the setup for creepage discharge experiment to measure the surface breakdown voltage. The experiment was conducted in an oil bath filled with 4 litres of palm fatty acid ester (PFAE) oil or mineral oil (Gemini-X). A needle-bar electrode configuration as shown in the figure was used with a constant gap distance of 30 mm between the needle tip and earth bar electrode. Epoxy Resin G10, Low Density Polyethylene (LDPE), High Density Polyethylene (HDPE) and Bakelite were used as solid insulation. These solid materials were immersed in the oil to promote liquid-solid interface. AC voltage was applied and increased gradually across the needle electrode and the earth bar until breakdown occurs. All the surface breakdown data were recorded for analysis purposes. The experiment was repeated three times for reliability in obtaining the results.

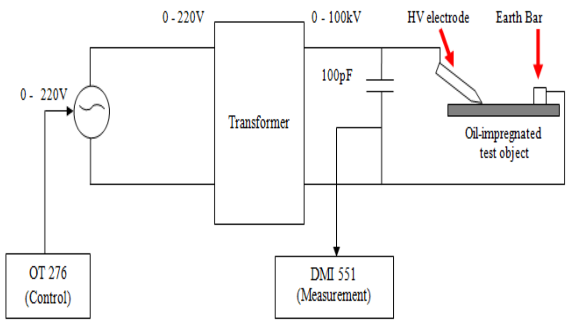

Figure 1 Creepage discharge experiment.

3. RESULTS AND DISCUSSION

Table 1 shows the comparison of average surface breakdown voltage by varying the solid and liquid insulation. The values of permittivity mismatch between oil and solid insulation are also given in the table. The mismatch can be calculated from the permittivity ratio:

$$K = \frac{\varepsilon_{liquid}}{\varepsilon_{solid}} \quad (1)$$

Where, ε_{liquid} and ε_{solid} are the relative permittivity of liquid and solid materials respectively.

From the findings, for a particular solid insulation, it appears that solid immersed in mineral oil has the highest average surface breakdown voltage (BDV) compared to the one that immersed in PFAE oil. This suggests that mineral oil has a better performance compared to PFAE oil regardless the solid materials used in this study and the value of permittivity mismatch.

Generally, for a particular type of oil, the results show that permittivity matching plays important role in improving the breakdown strength of liquid-solid interface except in the case of Bakelite. This means, the closer the permittivity of solid materials to the liquid permittivity, the higher dielectric strength can be obtained. However, it appears that this rule is invalid when comparison is made with Bakelite suggesting that there are other factors that may influence the breakdown voltage of oil-Bakelite interface. This can be due to the effect of surface roughness, chemical structure, chemical reactions between liquid and solid and etc. which can be further studied. Hence, associating permittivity mismatch among different materials with breakdown strength is inconclusive. On the hand, associating permittivity mismatch among similar material-based like LDPE and HDPE seems more convenient. Both solid materials are differentiated by their density that lead to different permittivity. In the case of mineral oil ($\varepsilon = 2.2$), the BDV value is higher for LDPE ($\varepsilon = 2.3$) as it has a closer permittivity to the mineral oil compared to HDPE ($\varepsilon = 2.35$). However, in the case of PFAE oil ($\varepsilon = 2.95$), the result of BDV is contradict whereby, the BDV value is higher for HDPE since its permittivity is closer to the permittivity of PFAE oil compared to LDPE.

Table 1 Average BDV and Permittivity Mismatch.

Solid Materials	**Oil Type**	**Permittivity Mismatch**	**Average BDV (kV)**
LDPE ($\boldsymbol{\varepsilon = 2.3}$)	PFAE Oil	1.28	31.11
	Mineral Oil	0.956	46.8
HDPE ($\boldsymbol{\varepsilon = 2.35}$)	PFAE Oil	1.25	32.08
	Mineral Oil	0.936	42.89
Epoxy ($\boldsymbol{\varepsilon = 3.6}$)	PFAE Oil	0.82	33.54
	Mineral Oil	0.611	35.77
Bakelite ($\boldsymbol{\varepsilon = 5.0}$)	PFAE Oil	0.59	34.12
	Mineral Oil	0.44	44.64

Note: $\varepsilon_{PFAE} = 2.95,\ \varepsilon_{mineral} = 2.2$

4. CONCLUSIONS

Creepage discharge experiment was conducted in an oil bath under AC voltage. Needle-bar method has been used as the electrode configuration. Several types of solid insulation, i.e. LDPE, HDPE, Epoxy and Bakelite immersed in different insulation oils, i.e. PFAE and mineral oils have been tested. Based on the experimental results, it can be concluded that different types of solid and liquids insulation will affect the surface breakdown voltage at liquid-solid interface. The effects of permittivity mismatch between solid and liquid dielectrics tends to influence the flashover strength of liquid-solid interface. However, this observation is more convenient to be correlated among similar materials with different density. The other factors could be the surface roughness and chemical structure of solid materials as well as chemical reactions that may occur once liquid is in contact with the solid material.

ACKNOWLEDGEMENT

The authors wish to extend their utmost appreciation to the Ministry of Higher Education (MOHE) Malaysia for funding this research under FRGS/1/2014/TK03/FKE/02/F00216 and Universiti Teknikal Malaysia Melaka (UTeM) for the financial support.

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