Study of breakdown behaviour of ester oil with suspended cellulose particles under direct current voltage

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ABSTRACT – Nowadays, ester oil has become a potential replacement for mineral oil due to biodegradable and renewable factors. Due to the increasing demand for High Voltage Direct Current (HVDC) system to meet the energy requirement, further studies on the performance of ester oil under Direct Current (DC) electric field is sensible. For an HVDC system, a phenomenon called dielectrophoresis (DEP) may occur if the oil-filled equipment such as the HVDC converter transformer is contaminated with suspended solid particles. This paper investigates the breakdown behavior of ester oil with the presence of DEP phenomenon under non-uniform DC electric field.

1. INTRODUCTION

Most of high voltage transformers are oil-immersed and the primary function of the oil are to dissipate heat and to serve as an insulator. The insulation oil is also useful as carrier information in power transformers for diagnostic purposes [1]. For decades, the insulation oil used in high voltage transformer is petroleum-based (mineral oil). Nowadays, due to stringent environmental protection regulations, future scarcity and environmental effect, ester oil has been regarded as a potential replacement for mineral oil in high voltage application. Nevertheless, their dielectric properties and performance are still unknown in the case of DC energization. In response to that, further studies concerning the dielectric behavior of ester oil under DC electric stress are necessary.

It has been reported that the rate of failure of HVDC converter transformer is 5-10 times higher compared to the normal HVAC transformers [2]. Previous studies have shown that cellulose bridging may happen in mineral oil in HVDC converter transformers [3]. The formation of cellulose bridge is due to the non-uniform electric field that leads to the motion of particles. Such phenomenon is called dielectrophoresis (DEP). DEP tends to force the particles into a high field region during a normal transformer operation and this force will form cellulose bridge conduction between two different potentials after certain period of time [4]. To make it worse, transformer failure may occur due to the formation of conducting path between two different potentials. Hence, this project is conducted to study the breakdown behavior of ester oil contaminated with cellulose particles.

2. EXPERIMENTAL SETUP

Figure 1 shows the experimental setup for this study. The test cell is a rectangular glass filled with 1 litre of synthetic ester oil (MIDEL 7131). A pair of spherical brass metal electrodes with 13 mm diameter is immersed in the oil. One of the spherical electrodes is attached to the HVDC and the other one is grounded. Nikon D5300 digital camera was used for throughout the experiment for monitoring and recording purposes.

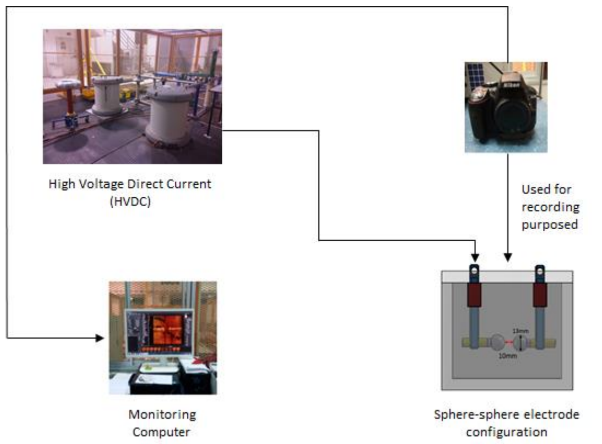


Figure 1 Experimental setup for bridging experiment.

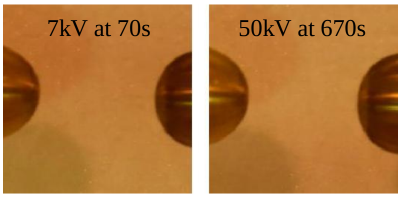
3. EXPERIMENTAL PROCEDURE

The experiment was conducted by applying HVDC in steps of 5 kV with 1 minute interval for each step until breakdown occurs. The breakdown occurs when the high voltage test system tripped. However, for the first 3 steps, the voltage was increased to 2 kV, 7 kV and 10 kV. In order to simulate the presence of cellulose contaminants, a piece of new cellulose pressboard is scraped and the dust obtained from this action is inserted into the oil sample. The breakdown behaviour of three different distances, i.e. 10 mm, 15 mm and 20 mm had been investigated by measuring the bridging time and the values of breakdown voltage. The experiment was repeated three times for validity and reliability in obtaining the results.

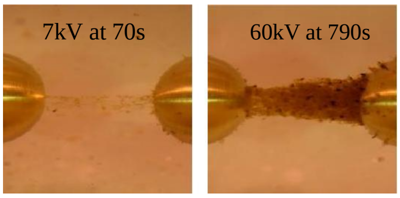
4. RESULTS AND DISCUSSION

Figure 2 shows the images obtained from the experiment. Figure 2 (a) depicts the experiment condition without cellulose particles. For samples with cellulose particles, cellulose bridging is observed for all distance until breakdown occurs. In the beginning, after applying the 2 kV of HVDC supply, the cellulose particles start to move between the electrodes because of polarization effects. This effect is called DEP that may occur under the influenced of a non-uniform DC electric field. The DEP phenomenon causes the cellulose particles to align themselves parallel to electric field lines until breakdown occurs.

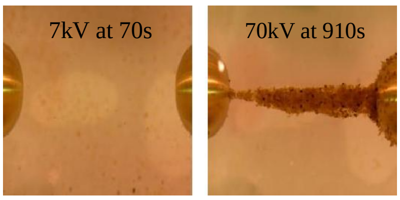
From observation, during the formation of cellulose bridge, some of the particles are seen moving towards the electrodes surface and a few seconds later, they get off and travel towards the other electrodes. This can be explained by the following argument. Once the particles touch the electrode surface, they acquire some amount of charges. After the charge reaches a certain level, the particles will get away and travel towards the other surface. This phenomenon is believed due to the higher value of Coulomb force between the cellulose particles and electrodes compared to the attractive DEP force. It is worthwhile noting that the movement of these particles is also affected by drag force from viscous oil [5].



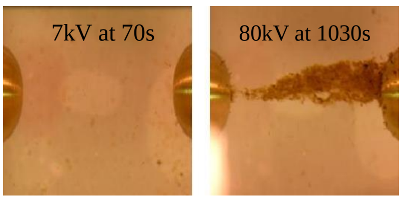
(a) Without contaminant at 10 mm electrode gap



(b) 10 mm electrode gap



(b) 15 mm electrode gap



(c) 20 mm electrode gap

Figure 2 Bridging behavior during the experiment.

As the voltage increases closer to the breakdown level, the oil condition becomes corrugated and the bridge formation becomes denser and thicker as shown in Figure 2. During the occurrence of breakdown, no luminous flashover are observed for all three distances. The values of breakdown voltage and bridge formation time for each distance are given in Table 1. It appears that the distance of cellulose contaminants has significantly increased the value of breakdown voltage and bridge formation time.

Table 1 Bridging formation behavior under different distances.

Distance (mm)		**10**	**15**	**20**
Bridge formation time (s)	with	70	250	370
	w/o	N/A	N/A	N/A
Breakdown Voltage (kV)	with	62	73	83
	w/o	51.57	60.55	71.06
Luminous Flashover	with	No	No	No
	w/o	No	No	No

5. CONCLUSION

In conclusion, for contaminated oil, cellulose bridge is observed throughout the experiment until breakdown occurs. The results suggest that the presence of DEP force affects the breakdown voltage behavior. Morever, with the increment of distance, it siginificantly influences the time taken to form a complete bridge and the value of breakdown voltage

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