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Dielectric breakdown in mineral oil ITO 100 based magnetic fluid

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Abstract

The development of dielectric breakdown and the DC dielectric breakdown voltage of magnetic fluids based on inhibited transformer oil ITO 100 were investigated in parallel orientations of external magnetic field. It was shown that the breakdown voltage is strongly influenced by the magnetic nanoparticles. The magnetic fluids with the volume concentration 1and 0.2 % had better dielectric properties than pure transformer oil. The increase of breakdown voltage was interpreted on the base of the bubble theory of breakdown.

Keywords: mineral oil ITO 100; magnetic fluid; magnetic properties; breakdown voltage; bubble model

1. Introduction

Magnetic fluids based on inhibited transformer oil ITO 100 have been shown to provide thermal and dielectric benefits to the power transformers. They can improve transfer of heat by enhancing the fluid circulation within transformer windings [1], while also minimizing the effect of moisture on typical insulating fluids. The better dielectric properties of magnetic fluids than pure transformer oil and the use as a high-voltage insulation was founded for low volume concentration 0,1% [2,3]. Such transformer oil shows the strong dependence of dielectric breakdown strength on the aggregation effects of magnetic particles [3].

The aim of the research reported in this article was to study the dielectric properties and DC dielectric breakdown voltage of magnetic fluids based on transformer oil ITO 100. The effect of external magnetic field induced structuralization of magnetic particles on these properties was studied too.

2. Experimental methods

Fig. 1 shows the schematic diagram of the experimental setup, which includes High voltage DC power supply TESLA BS 221 (max voltage 10 kV and current 3 mA), electrode system, electric diagnostics and electromagnet. Sphere-to-sphere Cu electrodes with radius 1 cm and plane-to-plane Cu electrodes with radius 2,7 cm were used as

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the electrode system. The distance of electrodes was measured by metric gauge blocks with accuracy of 0.01 mm. New and unfiltered transformer oil - ITO 100 was filled into discharge chamber (0.2 dm^3) and electrodes were again cleaned after series of 7 breakdowns. The capacitor value of 1 nF and resistance of 1 MΩ were chosen. The applied voltage and current were measured using high voltage probe (E253/01, 10 MHz) voltage and current were measured using a high voltage probe (E253/01, 10 MHz) (E253/01, 10 MHz) and Rogowski coil (Pearson Current monitor 110A, 10 kA, 20 MHz, 20 ns). The signals were recorded on Agilent technologies DSO3202A, 200 MHz digital oscilloscope.

The magnetic fluids used in experiments consisted of magnetite particles (Fe_3O_4), the mean diameter D = 10.6 nm, coated with oleic acid as a surfactant, dispersed in inhibited transformer oil ITO 100. The magnetic properties of prepared magnetic fluids were examined by SQUID magnetometer at room temperature. In our experiment we have used magnetic fluids with 2, 1 and 0.2% as volume concentration of magnetite nanoparticles with saturation magnetization at room temperature 6.1, 3.2 and 0.62 emu/g, respectively. Each value of the breakdown voltage was measured seven times and the maximum and minimum values were omitted in the calculation of its mean value, according to the rules of high voltage techniques. Time intervals between breakdowns were 5 minutes. The experimental error of the breakdown voltage determination was ±10%.

The signal from the Rogowski coil was connected to the digital oscilloscope, which was to set in single mode with minimal trigger value for arc current. In the single mode sweep runs after trigger signal occurred. The applied voltage was measured together with the characterized by under-damped oscillation with angular frequency. The angular frequency is function of arc current. The breakdown voltage was determined in time when trigger signal occurred. The arc current is electrode distance, type of liquid, applied voltage and outer parameters. At the change of applied voltage, when angular frequency was constant, only amplitude and duration of arc current was changed. As it can be seen from figure the angular frequency is smaller for magnetic fluids and decreased with volume concentration of magnetic fluid. The measurements were also made at various electrode distances (0.1 - 0.6 mm) and similar developments and characteristics of arc currents were observed.

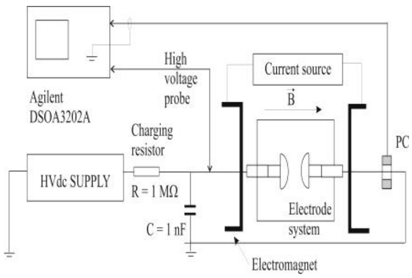

Fig. 1. The experimental setup.

3. Experimental results

Development of the arc currents in oil and magnetic fluids are presented in Fig. 2. The arc current is characterized by under-damped oscillation with angular frequency [6, 7]. The angular frequency is function of electrode distance, type of liquid, applied voltage and outer parameters. At the change only of applied voltage, when angular frequency was constant, only amplitude and duration of arc current was changed. As it can be seen from Fig. 2 the angular frequency is smaller for magnetic fluids. The angular frequency also decreased with volume concentration of magnetic fluid. The measurements were also made at various electrode distances (0.1 - 0.6 mm) and similar developments and characteristics of arc currents were observed (Fig. 2).

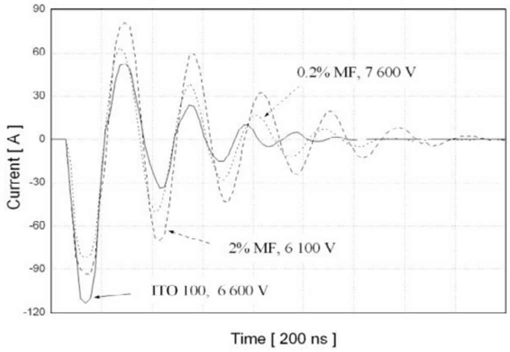

Fig.2. The time dependence of arc current in transformer oil, 0.2 and 2 % magnetic fluid, respectively in applied voltage.

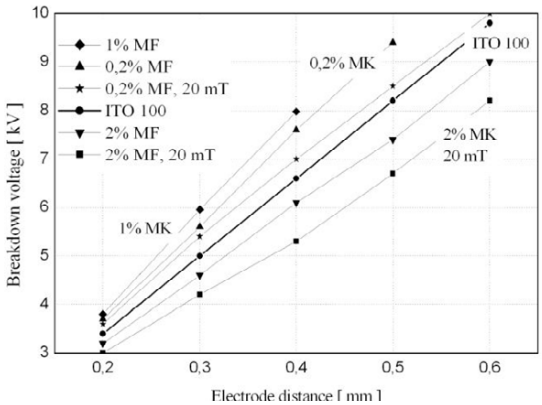

Fig.3. The breakdown voltage versus electrode distance for transformer oil ITO 100 and magnetic fluids with various volume concentration without and with magnetic field of 20 mT.

The breakdown voltage or dielectric strength is the main measured parameters for determination of quality of insulating fluids. Fig. 3 illustrates the dependencies of the DC breakdown voltage on the distance between the electrodes for transformer oil and magnetic fluids.

4. Discussion

The change of the breakdown voltage of magnetic fluid with different volume concentration can be interpreted using theory of breakdown transformer oil. This theory is based on the bubble mechanism of breakdown, which is supported by various experimental works [8-13]. The main aspect is formation of bubbles (small channels [7]), regions with smaller density as surrounding liquid. These bubbles are formed by local heating and field-emitted electron injected in electrode space. By increasing voltage these regions growth and expansion until their local density is reduced under a critical density [8] enough to take place in electron impact ionization. In next phase, electron avalanches growth and their formation into an ionizing front - primary streamer or streamers. When one of the streamers bridges the inter-electrode gap, plasma channel is generated and the breakdown can be observed. In the final stage of breakdown, the energy stored in capacitor is transformed to arc discharge and under damper oscillation of arc current can be observed [6,7].

From previous, we know that the value of breakdown voltage depends on creation of bubbles and processes running inside. When magnetic nanoparticles (e.g. magnetite Fe_3O_4) are added to transformer oil, there is negative effect on the formation of bubbles. The magnetite nanoparticles in transformer oil have extremely short charging time [13], so they are excellent electron traps. Trapped fast electrons are lost for ionization process and slow negative nanoparticles are produced. These negative ions also caused the decrease of electric field what has negative effect on ionization process. Nanoparticles are polarizable and are of higher permittivity than the surrounding liquid, so their move by electrical force directed towards the place of maximum stress. This place is also the place of the creation and existence of bubbles. Therefore, when the formation and existence of bubbles are affected by magnetic nanoparticles, it results in the increase of breakdown voltage. This is observable only for small concentration of magnetic fluid, as in our case 0.2 % and 1% (Fig. 3) For the higher volume concentration of magnetic particles (2%, Fig. 3) we have to take into account one more effect. The magnetic nanoparticles are again moved to place of maximum stress but their high concentration is presumed to be initiated by the surface irregularities on the electrodes and formation of the chains, which give rise to local field gradients. The accumulation of particles continues and tends to form a bridge across the gap, which leads to the breakdown initiation. In external magnetic field is the decrease of the breakdown voltage due to the magnetic dipol–dipol interaction between the particles and formations of the chains and chain-like elongated clusters [4, 5].

5. Conclusion

The insulating properties of magnetic fluid based on transformer oil with small volume concentration (0,2% and 1%) of magnetite nanoparticles were better in compared with pure transformer oil. The presence of small concentration of magnetic nanoparticles has a profound effect on the breakdown voltage. The opposite situation was observed at higher concentration (2%), where the insulation properties were worse and breakdown voltage was also smaller as for pure oil. The change of breakdown voltage was interpreted on the base of the bubble theory of breakdown.

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