Pre-breakdown Characteristics of Contaminated Power Transformer Oil

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Abstract: In this paper we have studied pre-breakdown characteristics of transformer oil in the presence of different levels of contamination. The contaminant is fibrous dust from pressboard insulation used for high voltage transformers. The contamination level investigated in the present study ranges from 0.0025 to 0.0075% by weight. The conduction current under dc voltages were recorded and bridging effect was monitored using optical images. It has been found that the conduction current typically increases with the applied voltage, the duration of the voltage application and the level of contamination. Optical images revealed that bridging occurs when oil is subjected to the voltage and bridge dimension increases with the contamination level and the duration. The current flowing between the two spherical electrodes is closely related to the bridging dynamics.

1 INTRODUCTION

Transformer oil plays very important roles in the power transformer as insulation and heat transfer medium, many researches and studies have been reported and examined for decades to understand its physical and molecular characteristics, behaviour under certain condition such as high temperature, techniques to procure the best transformer oils, and so forth [1-3].

Although contaminant compounds have been removed from transformer oil during its production, in reality, transformer oil can be contaminated during the storage and shipping. When transformer oil is introduced in a power transformer, oil will be in contact with many solid materials within transformer such as paper insulation, metal, iron core etc. In addition during operation, impurities (i.e. cellulose paper) can be dissolved in the transformer oil due to electrical and thermal stresses. Since high voltage generates a strong electric field within the transformer, the contaminants will move towards the area of relatively high field intensity due to dielectrophoresis hence develop a bridge. In the case of conducting particles, a current is conducting through the bridge, which means transformer oil does not served its purpose as insulation anymore. As a result, this will initiate the breakdown of power transformer oils. However, in the case of non-conducting particles, the effect on electrical performance of the oil is not well studied [4-5]. It is known that solid particles in suspension in transformer oil affect its breakdown strength. The oil breakdown strength depends on the nature, concentration and size of the particles in suspension as well as their shape [6].

In this paper pre-breakdown characteristics of transformer oil in the presence of different levels of contamination have been investigated. The contaminant is fibrous dust from pressboard insulation used for transformers. The contamination level investigated in the present study ranges from 0.0025 to 0.0075% by weight. The conduction current under dc voltages was recorded and bridging effect was monitored using optical images.

2 EXPERIMENTAL DETAILS

2.1 Sample preparation

To simulate the presence of contaminants in a real high voltage transformer, a predetermined amount of pressboard dust was prepared. Levels of contaminants used in this experiment were 0.0025%, 0.0050% and 0.0075%. These 3 different levels of contaminants are prepared as a percentage of mass rather than volume. The pressboard dusts were prepared by filing the pressboard disc sample which is used as a solid insulation for high voltage transformers. These contaminants were added into sample tank which was filled with 300 ml of transformer oil.

Before applying high voltage to spherical electrodes, to ensure that no contaminant particles are concentrated in a particular region, transformer oil was stirred thoroughly. To start next test after observing a complete bridge across the gap, transformer oil was stirred once again so that contaminants were well dispersed inside the sample tank. To avoid external dust, contaminants or moisture to enter the sample, a cling film was used to cover the sample tank. The cling film was removed prior to any observation done on the sample.

The sample tank is made from glass where 2 spherical electrodes with a diameter of 10 mm were placed in the middle section. The sample tank can be filled up to 550 ml of liquid, but in the experiment, only 300ml of transformer oil was used (the sphere electrodes completely submerged in the transformer oils). The gap between the electrodes was fixed to 10mm for all tests.

2.2 DC Tests

A DC voltage supply which is capable to supply up to 20kV was connected to one of the sphere electrodes. Three different levels of high voltage were supplied to sample tank which contains various predetermined level of contaminant. The three high voltages applied to the sample tank are 2kV, 7.5kV and 15kV respectively. The current flowing through the electrode gap was measured using a Keithley picoammeter.

The test was carried out until a complete formation of bridge is observed across the gap. A series of pictures of the bridge formation were taken manually throughout the tests at particular desired times.

2.3 Experimental setup

The general setups for observation are consisting of microscope, digital camera, sample tank, fibre optic light sources and a PC. A typical experimental setup used in the present research is shown in Figure 1.

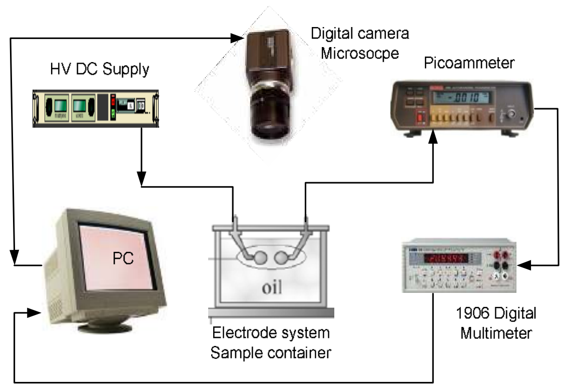

Figure 1 Experimental setup.

3 RESULTS AND DISCUSSION

3.1 Low level of contamination (0.0025%)

Upon switching on the power supply, the contaminant particles move back and forth in the gap between two electrodes. This phenomenon is related to charging and discharging of particles under a dc electric field. After a while, those particles start to attach to the two electrodes first and then connect themselves to form a partial bridge at the surface of the electrodes. At 2.5 kV, the bridge then continues to build-up until a thin elongated complete bridge is formed at 90s. The thickness of the bridge increases with time until a complete bridge is observed around 600s as shown in Figure 2 (a), whereby no apparent change to the bridge is observed after this.

When the applied voltage is increased to 7.5 kV, all the activities are intensified in the oil. A thin complete bridge is created at approximately 30s, faster than the previous test. Thereafter, the thickness of the bridge increased slowly with time until a complete bridge is observed at 600s as shown in Figure 2 (b). It has been noticed that the thickness of the bridge is larger at the surfaces of the electrodes compared to thickness of the bridge at the midpoint of the gap.

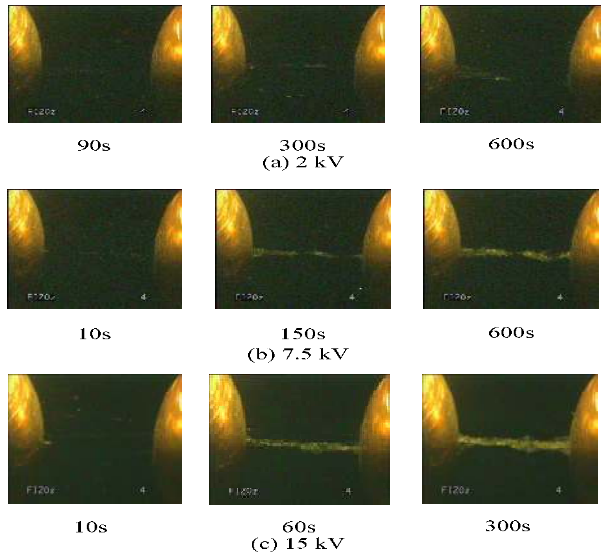

Figure 2 Bridge formation at 2.5 kV.

When 15 kV is applied to the oil gap a thin elongated bridge is observed as soon as 20s upon switching on. Since a higher voltage is applied which leads to a higher field between the electrodes, more particles are attracted in the gap and hence thicker bridge is observed. In this test, single bridge with the same thickness along the gap between electrodes is created. A complete thick bridge is created at 300s as illustrated in Figure 2 (c).

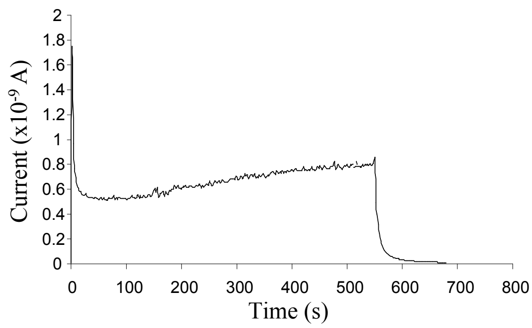

Figure 3 Current at 2 kV.

The current flowing through the gap after switching on 2 kV is shown in Figure 3. It shows a initially fast rise current followed by a gradually rise. The fast current is associated with polairsation. It has been noticed that the current flowing through the gap increases gradually throughout the testing period from $0.5x10^{-9}$A to $0.8x10^{-9}$A. This is due to the fact that the bridge formation in this test is not very significant which results in a small and gradually rise in current. Besides, the increment rate of current throughout the test impeded with time and as a result of that, the current saturates around 600s. It is important to highlight that the current saturates only after a complete bridge is formed, indicating close link between them.

When the applied voltage is increased, the current flowing through the gap increases as well. However, there are two features when the voltage is increases. Firstly, the time required to reach to the saturation current is shorten. Secondly, the saturated current magnitude increases nonlinearly with the voltage. It is also observed that once a bridge is created the current increase rate becomes slower. This may be related to the difference in electrical properties of each individual particle. Although it is difficult to distinguish them in the present study, it is believed that some particles may have a slightly higher conductivity than the others. Those having higher conductivity will form initial bridge due to a strong dielectrophoresis, therefore, make a major contribution to the current. Subsequent addition of less conducting particles to the bridge plays a little role in conducting current.

3.2 Medium level of contamination (0.0050%)

Within the first 90s upon switching on, contaminant particles are attracted to the gap and attached to surfaces of the electrodes. Elongated partial bridges are created at 150s and the thicknesses of the bridges builds up until they joint together to form complete bridges at 300s. The bridge is thicker at the surface of the electrodes and thinning away as it gets to the midpoint of the gap. The bridge process is illustrated in Figure 4 (a) for 2 kV.

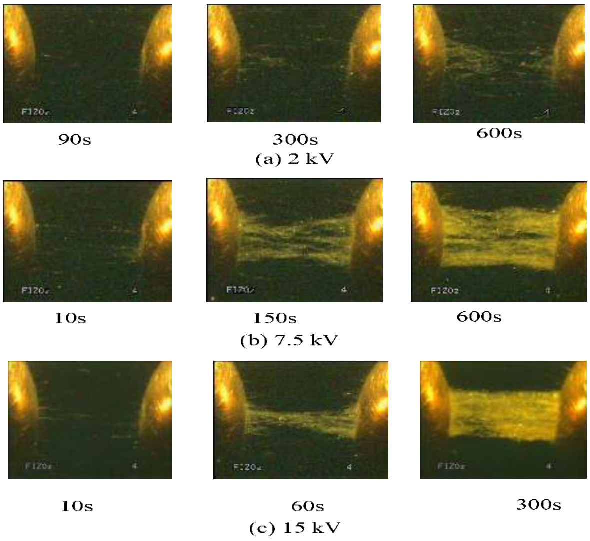

Figure 4 Bridge formation at different voltages.

When the applied voltage is increased to 7.5 kV, multiple thin partial bridges are created very quickly at surfaces of the electrodes at 30s after voltage is switched on. The thickness of the bridges builds up, forming several bridges between the two electrodes at 90s. Then, those bridges merge together, establishing a solid thick bridge in the gap which completed at 600s as shown in Figure 4 (b).

At 15 kV, multiple partial bridges branch out from surfaces of the electrodes at 10s after the voltage is connected. The partial bridges then joint together to form complete bridges connecting the two electrodes, with thicker branches near surfaces of the electrodes and becoming thinner to the midpoint of the gap. With time the bridges then combine together to create a solid bridge in the gap (Figure 4 (c)).

Generally speaking, the magnitude of the current flowing through the gap increases with the level of contamination. The current shows a similar fashion to that in the oil with a low level of contamination. A typical current with time after switching on the dc voltage of 7.5 kV is depicted in Figure 5. In this case, polarisation current is smaller than the steady conducting current. Additionally, the time to a steady current decreases with the level of contamination in the oil.

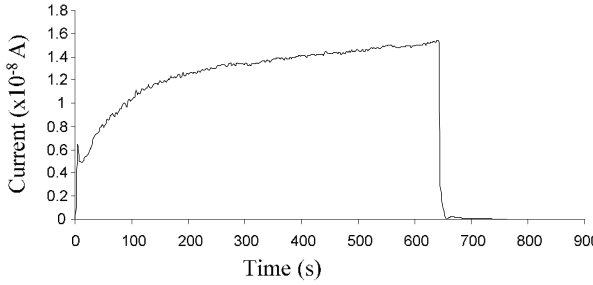

Figure 5 Current at 7.5 kV.

3.3 High level of contamination (0.00750%)

Upon switching on 2 kV, a high concentration of contaminant particles are drawn into the gap and numerous thin partial bridges branch out along surfaces of the electrodes at 90s. Several bridges connecting the electrodes are formed at 120s and accumulation of contaminant particles continue until a thick bridge is formed at 300s. Thickness of the bridge continues to increase as shown in Figure 6 (a).

As the voltage is increased to 7.5 kV, numerous long thin bridges connecting the electrodes are constructed very quickly at 30s. At 90s, those multiple bridges merge together to form a solid bridge. With time, the thickness of the bridge builds up from surfaces of the electrodes and moving towards the midpoint of the gap until a complete bridge which covers almost all space in the gap is formed at 600s.

When 15 kV is applied to the gap, long thin partial bridges are formed at surfaces of the electrodes almost immediately and the bridges keep expanding and extending until multiple bridges connecting the electrodes are constructed in the gap at 20s. The thickness of bridges increase very quickly at this stage until the bridges join together to form a solid bridge at 60s. Then the increment rate of the bridge thickness reduces and until current saturated after a complete bridge is formed at 300s. The process is illustrated in Figure 6 (c).

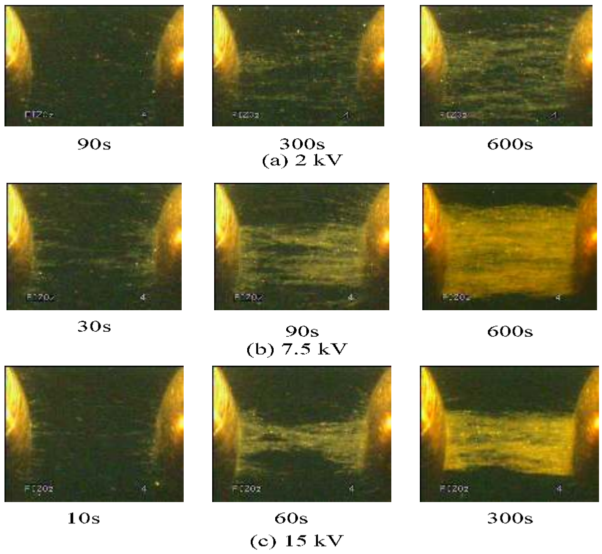

Figure 6 Bridge formation at different voltages.

A typical current after 2 kV dc voltage is applied to the gap in the presence of high level of contamination is shown in Figure 7. The current measured between the electrodes increases drastically from $0.6x10^{-9}$A to $1.6x10^{-9}$A throughout the observation. In this test, current increases almost linearly with time although there is a tendency that the increment rate of current drop at 600s.

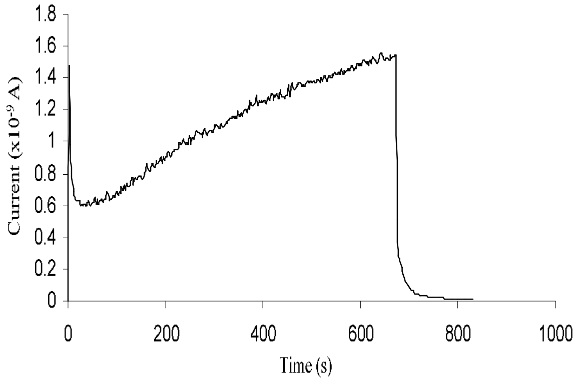

Figure 7 Current at 2 kV

Figure 8 summarises the relationship between current and contamination level in the oil. The current at the end of tests is used. It is clear that at a fixed voltage the current flowing through the gap increases linearly with the contamination level. However, at a fixed contamination level, the current changes nonlinearly with the applied voltage. For an example, at 0.005%, the current increases very rapidly with the applied voltage. This is related to the bridging effect therefore to the force experienced by particles. The force experienced by a particle is not linear in the case of dielectrophoresis.

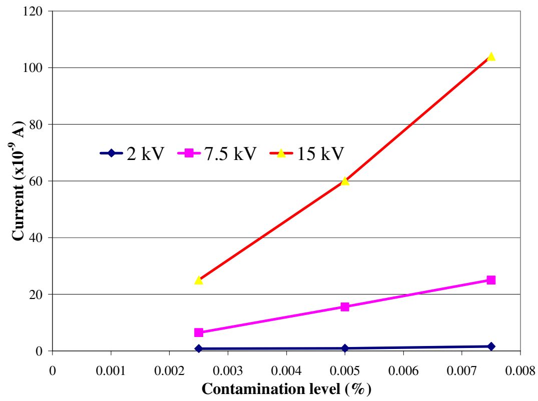

Figure 8 Relationship between current and contamination at different voltages.

4 CONCLUSIONS

Work has been done to understand the pre-breakdown characteristics of power transformer oil and the following conclusions may be drawn:

It is clearly shown from the results that the time taken to form a complete bridge across the gap is shortened with increasing dc voltage. With increasing contaminant particles the thicker bridges are formed which provide a path for the current to conduct.

In term of current flowing through the gap, it increases almost linearly with the contamination level and nonlinearly with the applied voltage. More importantly, the current is closely related to the dynamic behaviour of the bridge formed between the gap.

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