INVESTIGATION OF THE OIL/PRESSBOARD RATIO EFFECT ON DIELECTRIC BEHAVIOUR

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Abstract
Transformers work like the lungs of energy systems. The generated electricity is amplified, distributed or lowered by means of transformers. Mineral oil and pressboard used as insulators in the transformers age and deform slowly during the operating life. For the most appropriate and long-lasting operation of this oil and pressboard, there should be a ratio according to the power and voltage level of the transformer. This ratio is determined by experimental studies and it is important to protect this equipment and prevent financial losses. With the tests performed in the test environment, the strength of the insulators having different oil / pressboard ratios can be measured. In this study, insulators having different oil / pressboard ratio have been tested and the most suitable ratio has been tried to be determined and interpreted.

Keywords: transformers, high voltage testing, pressboard/oil ratio, partial discharge, harmonics.

1. INTRODUCTION

Transformer oil is a refined mineral oil that is stable at high temperatures and has excellent electrical insulation properties. In oiled transformers, it is necessary to use mineral oil in order not to allow air, water and other materials to be placed between the windings, which will reduce breakdown voltage, cooling and insulation. When mineral oil and pressboard age, the insulation quality of the transformer decreases. Through the periodic maintenance, the durability of these insulators can be maintained during the operating life. However, the ratio between oil / pressboard, which plays a good dual role in the transformer, should be optimal. This ratio, which is adjusted according to the power and voltage of the transformer, is yet to be considered during manufacturing phase. Failure to observe this ratio, which has been tested and determined under the test conditions set by the standards, will cause the insulators to breakdown and financial losses will occur.

In a study, the effect of pressboard density on conductivity of oil impregnated pressboard for HVDC insulation systems was investigated. The study focuses on the conductivity of the liquid (gas or oil) impregnated in the pressboard [1]. For this reason, gas and oil are impregnated on the pressboard of different density and conductivity measurements are made. Three different oil / pressboard ratios were used: PB1 (70:30), PB2 (77:23) and PB3 (80:20). They compared the conductivities of 3 pressboard samples. The low density sample with the largest oil volume is PB1. As a result, PB1 has the highest conductivity. Consequently, the pressboard density can be modified during manufacture and the designer can decide which pressboard and conductivity oil will be used in a given HVDC device for the oil / pressboard system.

In another study, the oil-pressboard interface is complex. This interface modeled as layered. In this study it is shown that moisture clearly plays a vital role during the partial discharge. The oil-pressboard interface, which has a layered structure, indicates that there are 2 different options. Part 1 is associated with low energy surface discharge and impression in oil-pressboard transmission and EDL (Electric Double Layer) [2]. The second part is related to the oil boundary layer high energy. This is known as surface discharge. The start and end of PD is insensitive to the clearance distance from the ground to the space. Surface deterioration and surface discharges are sensitive to gap distance in actual oil discharges.

In a study comparing the results of the electric field distribution during the AC voltage test for natural ester oil impregnated pressboard and mineral oil impregnated pressboard, the electrical field in the distance between electrode-pressboard was found to have a similar profile for natural ester oil / pressboard and mineral oil / pressboard. However, the maximum electric field of the natural ester oil / pressboard is much lower than the mineral oil / pressboard. It shows that the natural ester oil / pressboard system has a higher tensile strength than the mineral oil / pressboard system and that the fracture caused by the test occurs in the oil impregnated part. [3].

In addition to the studies in which the transformer paper insulator is tested in different voltage types in oil or impregnated [4], it is also available in studies examining the electrical changes occurring at an interface [5]. Also, there are some studies that the aged pressboard is impregnated with oil. The aged impregnated samples were leaved space on their surface by covering Kraft paper which has a point type space on its mid-point, then these samples are available in both AC and DC voltage tested. [6-7].

In this study; the effect of oil / pressboard ratio was investigated through partial discharge values collected from a non-uniform electric field.

2. EXPERIMENTAL SETUP

During the experiments, the methods of IEC 60641-2 standard for pressboard insulation tests were applied. [8]. The main materials used in the experiment were pressboards with 10x10cm dimensions and a thickness of 1.5 mm, 2.5 mm and 4 mm respectively. For each thickness six specimens, hence a total number of 18 pressboards were tested. With the help of 5kVA Auto Transformer, the mains supply voltage is adjusted to the desired level between 0-230V and used to supply the primary winding of the transformer. An input resistance of 47Ω is connected to the output of the auto transformer and used to receive current signals at the input of the transformer. The Fluke 199C oscilloscope (scope meter) was used to measure the input current signals. This oscilloscope has a bandwidth of 200 MHz and a sampling rate of 2.5 GS/s. A voltage measuring transformer with 230V/40 kV turn ratio and 1.5 kVA power at 50Hz operating frequency was used to obtain high voltage. The 1 MΩ pre-resistor is connected to the high voltage output of the transformer and used. The purpose of using a pre-resistor is to limit the high current flowing during discharge. High current during discharge may damage the transformer windings.

Voltage and Current transformers are only used for measuring. The power of the measuring transformers is very low. When high current flows, the windings become hot and wear out, hence a 1MΩ front resistor is used for protection. Planar copper plate with 150x100 mm dimensions and 3 mm thickness was used as the earth electrode. A copper rod with a diameter of 1 cm and a height of 5 cm was cut to fit the earth electrode to the bottom of the test chamber made of plexiglass material and welded to the center of the copper plate. In order to keep the pressboard to be fixed on this copper plate during the experiment, two holding edges were placed on opposite sides.

Mineral oil and a pressboard are located inside the test chamber. Plexiglass test chamber is sprayed with the help of syringe at the junctions to prevent leakage of mineral oil. In addition, high voltage and earth electrodes are also in this boiler during the experiment. Its dimensions are 15x15x20 cm and it has a wall thickness of 5 mm. The view of the ground electrode inside the test vessel is shown in Figure 1.

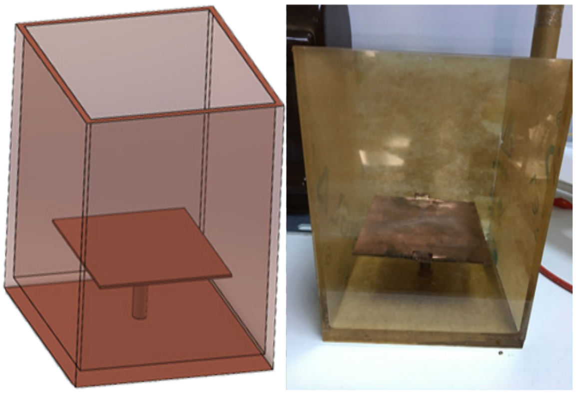

Fig. 1. *Test Chamber and Earth Electrode*

Two electrodes, one rod and the other needle, were used as the high voltage electrodes. The purpose of using a rod electrode is to investigate the partial discharge phenomenon under the non-uniform electric field. The rod electrode has a tip of 1 mm and a length of 140 mm. Electrons formed after ionization during discharge attempt to pass from high voltage electrode to earth electrode [9]. When the electrons move rapidly between the two electrodes try to disrupt the mineral oil and the pressboard insulator.

Partial discharge data was transferred from the oscilloscope to the computer using the Computer Unit and Fluke Scopview software. This data was saved in Excel program. Then, the data were processed by transferring to Matlab software. The schematic representation of the experimental setup is shown in Figure2.

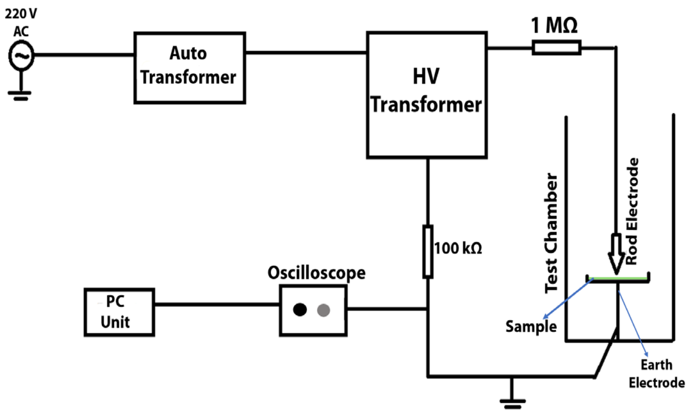

Fig. 2. *The Schematic Representation of the Experimental Setup*

The photograph of the test setup is shown in Figure 3.

Fig. 3. *Test Setup*

2.1. Partial Discharge Experiment

In the experiment, three pressboards having dimensions of 10x10cm and dielectric constant εr = 4.1 were used. Mineral oil, which is generally used as transformer oil and has dielectric constant εr = 2.2, was used during the experiment.

Weights of pressboard samples cut to sizes suitable for earth electrode were measured with precision scales. These weight values are given below.

- 1st Pressboard =17.45g
- 2nd Pressboard =29.75g
- 3rd Pressboard =48.10g

The pressboard samples were then placed in the earth electrode in the plexiglass test chamber according to the test order. Then, the plexiglass container was filled with 1.7 liters and 3 liters of mineral oil respectively and the experiment was started. The distance between the high voltage electrode and the pressboard was set to 1 mm during the experiment. Rod and needle electrodes were used as high voltage electrodes in the experiment. Figure 4 shows the position of the rod and needle electrodes in the test chamber.

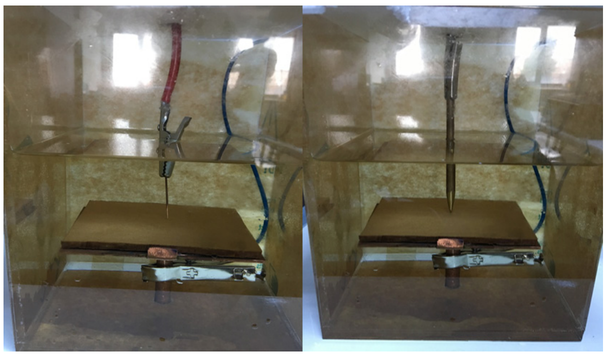

Fig. 4. *The Position of the Needle (left) and Rod (right) Electrodes*

230V voltage from the network to the input of the auto transformer were adjusted as 50V and 100V in the auto transformer and input (low voltage) winding of high voltage transformer was supplied with these two voltage levels. Thus, 9 kV and 18 kV high voltage level is obtained in secondary windings (high voltage) according to transformer turn ratio. The resulting high voltage is first supplied to the high voltage electrode through a 1MΩ pre-resistor. In the meantime, signals were monitored on the oscilloscope screen. Voltage levels at which discharges occur were noted and recorded as data. In this experiment, the harmonic signals of 9 kV and 18 kV voltage for 3 different oil / pressboard ratio were drawn by using Matlab software using 2 different electrodes as rod and needle. The oil / pressboard (O/P) ratios in the tests are as follows:

Ratio A: O/P=1.7L/17,45g = 97,42
Ratio B: O/P=1.7L/29,75g = 57,14
Ratio C: O/P=3L/17,45g = 171,91

3. RESULTS

3 different oil / pressboard ratios were tested at 2 different voltage levels on 2 different high voltage electrode types. The effect of oil / pressboard ratio on electrical breakdown characteristics and also the effect of rod and needle electrodes on breakdown behaviour were investigated. Harmonic analysis of current signals in 1 kHz bandwidth was performed. Figure 5 shows the harmonic and 20 period signals of the rod and needle electrodes at 9 kV voltage level in A ratio.

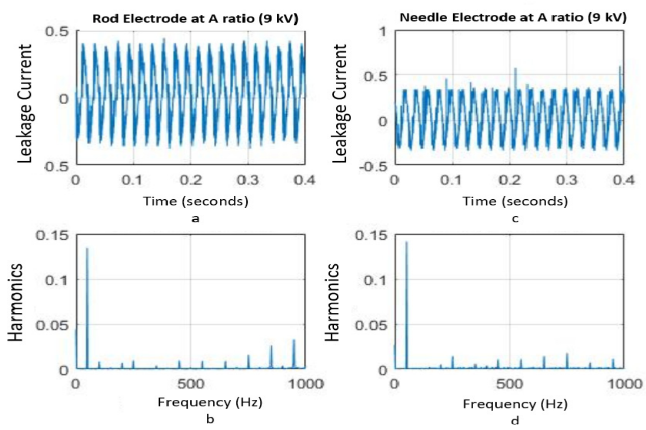

Fig. 5. Comparison of Rod Electrode and Needle Electrode with 9 kV Voltage at A Ratio
a- Leakage Current of Rod Electrode at A Ratio
b-Harmonics of Rod Electrode at A Ratio
c- Leakage Current of Needle Electrode at A Ratio
d- Harmonics of Needle Electrode at A Ratio

The voltage of 50 V in the headings of the graphs in Figure 5 is the input voltage of the transformer. This voltage is obtained as 9 kV high voltage at the output of the transformer. The headings of the following graphs will always have the input voltage. Harmonics reached higher values in the ratio of A at the needle electrode configuration. In addition, the leakage current flown during discharge is at the level of 0.47 A in the rod electrode and this value is around 0.53 A with sudden increases in the needle electrode. Third harmonic current at the needle electrode is very low, while this current at the rod electrode is higher as can be seen on the Figure 5.

The harmonic and leakage current signals in the rod and needle electrode configuration are given in Figure 6 when the voltage doubles in the ratio of A.

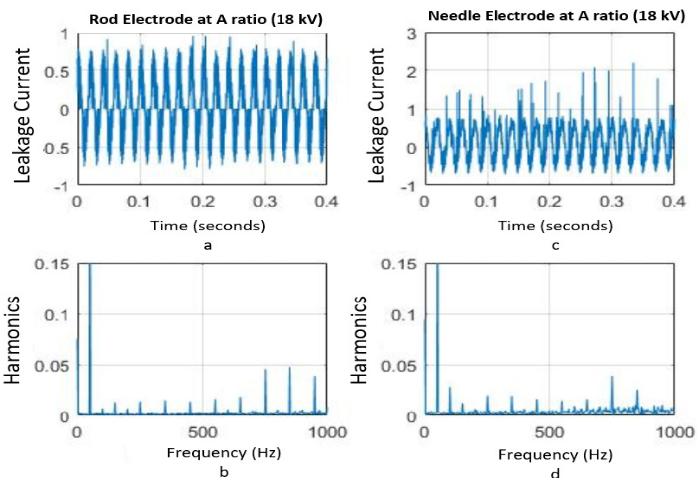

Fig. 6. Comparison of Rod Electrode and Needle Electrode with 18 kV Voltage at A Ratio
a- Leakage Current of Rod Electrode at A Ratio
b-Harmonics of Rod Electrode at A Ratio
c- Leakage Current of Needle Electrode at A Ratio
d- Harmonics of Needle Electrode at A Ratio

As shown in Figure 6, the current in the needle electrode configuration has exceeded level 2A. Furthermore, the 3rd harmonic current is decreased in the rod electrode compared to the previous voltage level, but increased significantly in the needle electrode. Distortion of the leakage current signal at the needle electrode can be clearly seen on the Figure 6.

The harmonic and leakage current signals of two different electrode arrangements at 9 kV voltage level in B ratio are shown in Figure 7.

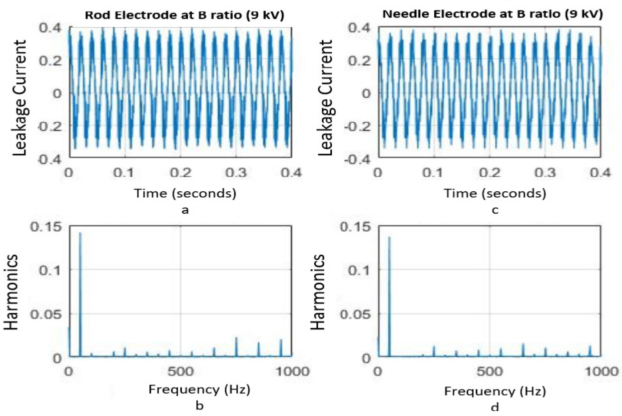

Fig. 7. Comparison of Rod Electrode and Needle Electrode with 9 kV Voltage at B Ratio
a- Leakage Current of Rod Electrode at B Ratio
b-Harmonics of Rod Electrode at B Ratio
c- Leakage Current of Needle Electrode at B Ratio
d- Harmonics of Needle Electrode at B Ratio

Unlike in the A ratio, the difference the leakage currents value between the rod electrode and needle electrode configuration is very small. At this oil / pressboard ratio, the leakage current value in the needle electrode configuration has decreased. However, harmonic values have not changed much. The third harmonic is observed at the rod electrode configuration while like in the A ratio it is not observed in the needle electrode configuration. In addition, less double harmonics occur at this voltage level in the B ratio. The harmonic and leakage current signals in the rod and needle electrode configuration are given in Figure 8 when the voltage doubles in the ratio of B.

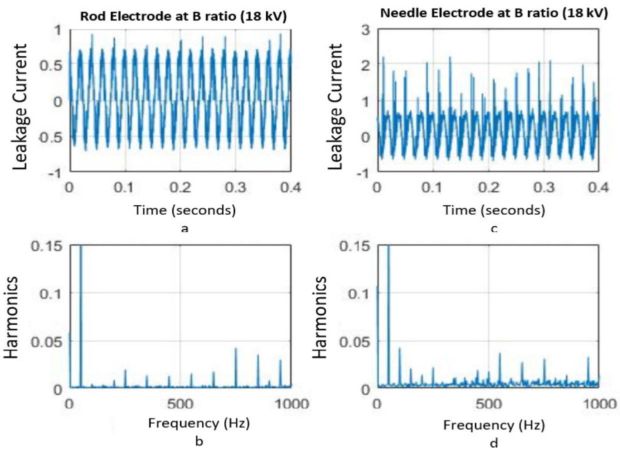

Fig. 8. Comparison of Rod Electrode and Needle Electrode with 18 kV Voltage at B Ratio
a- Leakage Current of Rod Electrode at B Ratio
b-Harmonics of Rod Electrode at B Ratio
c- Leakage Current of Needle Electrode at B Ratio
d- Harmonics of Needle Electrode at B Ratio

When the voltage level is doubled, deterioration of the leakage current and harmonic signals in the needle electrode configuration is increased. The leakage current exceeded 2A level. Unlike in the A ratio, the leakage current value is more than 2A at more points. Harmonic currents have increased significantly compared to A ratio. In particular, while the 3^{rd} harmonic current at the A ratio was 0.25 A for needle electrode configuration, this value increased to 0.4 A at the B ratio. There was no change in the rod electrode arrangement between the A and B ratio to such an extent that it would affect the electrical strength. In this electrode configuration, when the voltage level doubled, like in the previous A ratio, the 3^{rd} harmonic current decreased significantly.

The harmonic and leakage current signals of two different electrode arrangements at 9 kV voltage level in the C ratio are shown in Figure 9.

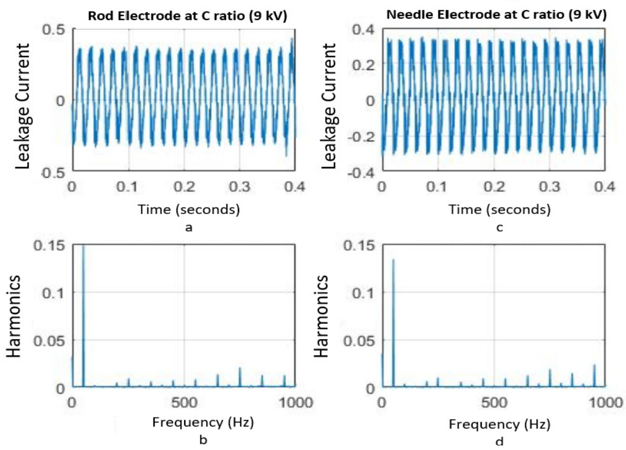

Fig. 9. Comparison of Rod Electrode and Needle Electrode with 9 kV Voltage at C Ratio
a- Leakage Current of Rod Electrode at C Ratio
b-Harmonics of Rod Electrode at C Ratio
c- Leakage Current of Needle Electrode at C Ratio
d- Harmonics of Needle Electrode at C Ratio

At this voltage level in the C ratio, the leakage current in the rod electrode configuration is slightly higher than the leakage current in the needle electrode configuration. The leakage current in the rod electrode did not change much, but with the increase in the oil / pressboard ratio, it reduced the leakage current a value approaching 0.5A in the A and B ratios at the needle electrode was less than 0.4 A. In addition, the harmonic current value of the fundamental harmonic signal in the rod electrode exceeded 0.15 A. This value for this voltage level in the A and B ratios was observed less than 0.15 A. At the A and B ratios, the 3rd harmonic current value in the rod electrode configuration was higher than the current value in the needle electrode configuration, but as shown in Figure 9, the 3rd Harmonic current at this voltage level in the needle electrode configuration is higher than the 3rd harmonic current in the rod electrode configuration. At this voltage level, the deterioration of the leakage current signal in the needle electrode arrangement at the A ratio was not observed at the C ratio. The harmonic and leakage current signals in the rod and needle electrode configuration are given in Figure 10 when the voltage doubles in the ratio of C.

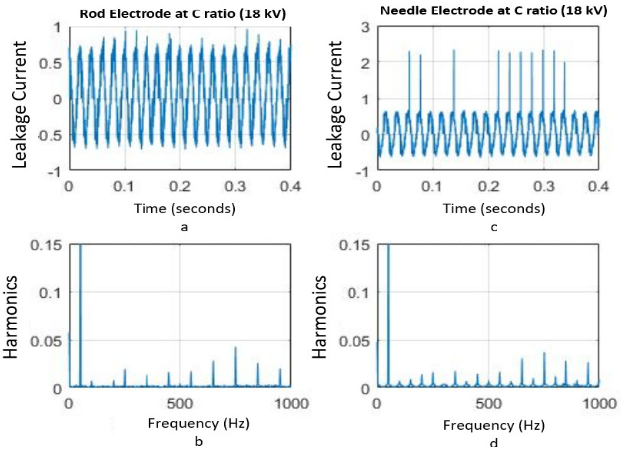

Fig. 10. *Comparison of Rod Electrode and Needle Electrode with 18 kV Voltage at C Ratio*
a- Leakage Current of Rod Electrode at C Ratio
b-Harmonics of Rod Electrode at C Ratio
c- Leakage Current of Needle Electrode at C Ratio
d- Harmonics of Needle Electrode at C Ratio

At this voltage level, the leakage current values in the rod electrode configuration were generally between 0.7-0.95 A, like in the A and B ratio. There was a change in the needle electrode configuration compared to the ratio of A and B. The number of points at which the leakage current exceeds 2 A is greater at the C ratio, but the current signal is smoother than the other two ratios and less disturbing effects on the current wave was observed. Harmonics have both reduced and smoother signals at this voltage level in both electrode configurations compared to the ratio A and B.

4. DISCUSSION

In this study the effect of oil / pressboard ratio on partial discharge in non-uniform electric field is investigated and tested at 2 different voltage levels (9kV, 18kV). As a result of these tests, it was observed that the change of oil / pressboard ratio significantly affected both leakage current and harmonics. It has been observed that the effect of two different type of electrodes (rod and needle) on partial discharge is great. Increasing the oil / pressboard ratio reduced the leakage currents and harmonics, especially at the needle electrode arrangement at a voltage level of 18 kV and improved the leakage current signals. The significant rises in FFTs of leakage currents from 11th harmonic on, indicated that more work need to be done about this issue. It is observed that the rod electrode has higher FFT signals amplitude at all voltage levels and oil / pressboard levels, especially from 15th harmonic is higher than 3rd, 5th and 7th harmonics. This is an issue that we will focus on in the future works.

5. REFERENCES

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