Oil Aging due to Partial Discharge Activity

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Abstract

Oil is the main insulation in power transformers and over long time of ageing its insulation properties can change. In this paper ageing of oil due to the exposure to electric discharges was investigated. The effect of high energy discharges (complete arc) and low energy discharges (partial discharges) on oil properties such as breakdown strength and oil conductivity was investigated.

An experimental setup consisting of two spherical electrodes was designed. The adjustable distance between the two electrodes made it possible to have PD with different magnitude.

The oil conductivity and breakdown strength was measured for three sets of experiments. The first group of experiments was performed on new oil in order to have a reference for comparison. In the second group of experiments the new oil samples was exposed to 1000 and 3000 lightning impulses. In the third group of experiments new oil samples was exposed to partial discharge for different duration of time. Oil conductivity and breakdown strength of these aged samples were compared with new oil. The results show that after exposure to lightning impulse oil conductivity increases and breakdown strength decreases, However PD activity for short time does not change the oil conductivity but it reduces the breakdown strength.

1. Introduction

The power transformer is a critical component of the power system. Any failure in transformer could be very expensive because the transformer itself is expensive and the cost of power shut down is high. Previous studies show that the leading cause for transformer failure is insulation failure [1]. Insulation failures may occur at very short time such as surface flashover on power line insulator due to lightning overvoltage. However, since a transformer is expensive, during design process the safety margin which has been considered is quite high so the probability to get complete insulation breakdown at very short time is quite low. On the other hand, the insulation failure may occur over long time. This means ageing of insulation over time weakens the insulation which finally may lead to a complete breakdown. The aging process of insulating material can be due to thermal, mechanical or electrical stresses.

In most cases, the insulation deterioration can initiate partial discharge activity inside insulation. If partial discharge continues inside insulation it can deteriorate the insulation further, and finally lead to complete breakdown. It is possible to correlate the insulation condition with the partial discharge activity. PD monitoring over time can show any change in insulation and this means that if the insulation condition getting worse and worse over time, the operator can repair transformer before it is too late.

Most of transformers in use are oil filled transformer. The main insulations in these transformers are paper which covers conductor, pressboard which is used as support between disks and winding, and oil which is used both as a cooling fluid and insulation between windings. Many authors have investigated the effect of thermal ageing on paper and pressboard and correlate it with the mechanical strength of paper and pressboard [2]. Thermal ageing has also been applied to oil and the change of the oil parameters such as conductivity, breakdown strength, and acidity was reported [3-4].

In order to understand ageing process because of partial discharge it is necessary to investigate the effect of partial discharge on oil parameters such as breakdown strength and oil conductivity.

The effect of carbon particle produced because of breakdown in oil was investigated in [5]. The main conclusion from that paper is that carbonization of oil lead to reduction of breakdown strength.

In this paper transformer oil was aged by partial discharge activity for different duration of time and also by means of complete discharge produced by lightning impulses. Change in partial discharge parameters (number of discharge and average magnitude of discharge) over time is reported. Change of polarization and depolarization current, oil conductivity and oil breakdown strength due to application of impulse and partial discharge was compared with new oil.

2. Experimental setup

In order to investigate the effect of partial discharge on oil parameter a setup was designed that is shown in figure 1. The setup simulates a metal conductor at floating potential which was used as a source of partial discharge. Partial discharge occurs between two metallic spheres with 20 mm diameter. One sphere is connected to high voltage electrode while another one is at floating potential. The oil gap between two electrodes was fixed to about 200 micro meters. The top lead of the container made of Teflon and is sealed with two O-rings in order to keep the generated gases inside the container and let them dissolved in oil in order to analyze the dissolve gases in oil as a function of ageing time (However this result is not presented in this paper). A magnetic stirrer is used to mix oil during ageing of oil with partial discharges.

Oil Breakdown strength was measured by using two metallic spheres with the oil gap of 1 mm. for each oil sample with different level of ageing the breakdown strength was measured 20 times in order to get statistic in data.

In order to measure oil conductivity a setup consists of two parallel electrodes with a distance of exactly 1 mm was used. The setup placed inside a metallic box in order to eliminate the effect of external charges on the measurement. Polarization and depolarization current and oil conductivity was measured by using a DC voltage source with maximum 3 kV output and a Keithley 6514 electrometer. The schematic of this measurement setup is shown in figure 2.

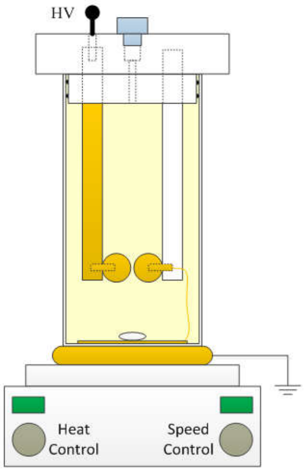

Figure 1. Setup for oil ageing through partial discharge activity

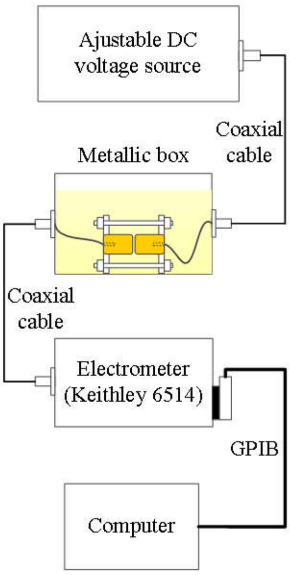

Figure 2. Schematic used for polarization and depolarization current measurement

3. Experimental procedure

The Oil that is used for this experiments was NYTRO 10XN, which is a common oil in Swedish transformers. First the new oil was dried and degasses under vacuum at 60 °C for 24 hours. 6 samples of oil with the volume of 1.5 litres were used for the experiments. Two samples, one for 1000 and one for 3000 impulse experiment and 3 other samples for partial discharge experiment and one sample for new oil breakdown strength experiment. Prior to each experiment polarization and depolarization current of each sample of the processed oil was measured first in order to make sure the starting point is similar for all cases. While depolarization current showed very consistent result in all cases the polarization, or in other words, the time dependent conduction, was not consistent even for measurements on the same sample.

For the measurement of the breakdown strength the voltage on the test sample was increased with rate of 1 kV/s until breakdown occurred. For each sample the experiment was repeated 20 times in order to get statistic in data. Mean value and standard deviation of the breakdown voltage was determined for each experiment.

4. PD ageing

A voltage equal to 150% of the PD inception voltage was applied to the test cell and PD activity was monitored up to desired time. Figure 3 shows the trend of number of PD over time and figure 4 shows the trend of average magnitude of PD over time. While the number of PD decreases over time the average magnitude of PD is almost constant during ageing time.

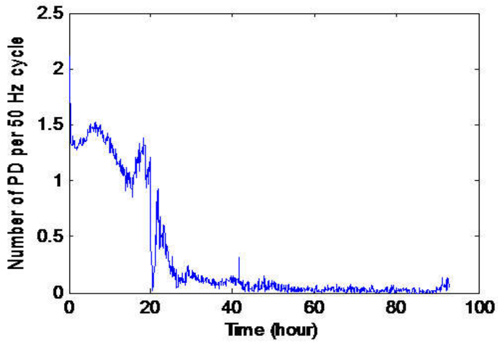

Figure 3. Number of PD as a function of ageing time

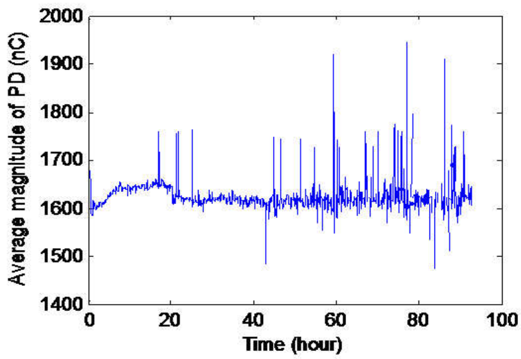

Figure 4. Average magnitude of PD

5. Polarization and depolarization current measurement

Measurement of polarization and depolarization current was performed on new oil samples several times. While all samples taken from the same container, still there was some variation in measurement especially on polarization current. All measurement performed for the electric field of 1 kV/mm. Measurement of polarization and depolarization current performed only up to 1 hour after connection and disconnection of the voltage. A general waveform of polarization and depolarization is shown in figure 5.

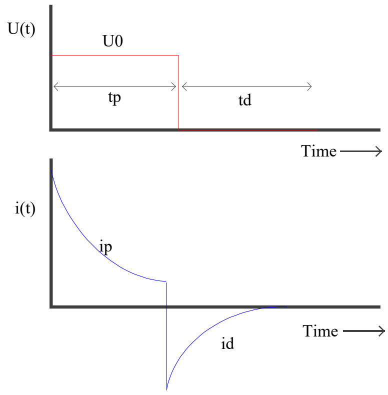

Figure 5. waveform of polarization and depolarization

According to figure 5, if we assume that the material has only constant DC conductivity, in this case the polarization current should be equal to a constant conduction current minus depolarization current. However for oil, the measurement results show that depolarization current decay to zero very fast while polarization current still is decaying. This means that oil conductivity is time dependent and it decrease until it reach to the dc conductivity.

For each oil sample polarization and depolarization current was measured 3 times. The first experiment performed 1 hour after oil was poured into the metallic box, second and third experiment was performed 4 and 7 hours after oil was poured into the metallic box.

Figure 6 shows the polarization current and figure 7 shows the depolarization current for new oil (dried and degassed). As it is clear in figure 6 the polarization current (time dependent conduction) is varying (decreasing) for each measurement however according to figure 7, depolarization current shows a good consistency. For most of experiment the same trend was observed. This behavior can be explained by particles in oil. The more time that the oil is resting in the metallic box the more particles can settle so because of that the conduction current decreases.

The average of polarization (and depolarization) current obtained from the two last measurements on each oil sample is used in part 5.1 and 5.2.

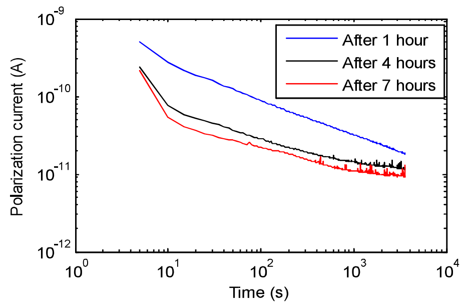

Figure 6. Polarization current for three consecutive measurements

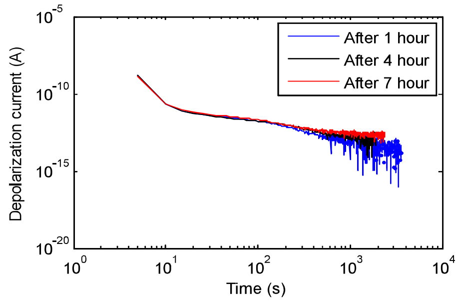

Figure 7. Depolarization current for three consecutive measurements

5.1. Effect of impulse on polarization and depolarization current

Figure 8 and 9 show that polarization current (time dependent conductivity) increases by applying impulse to oil. Even though that there is a little change in depolarization current, however it is not a big change.

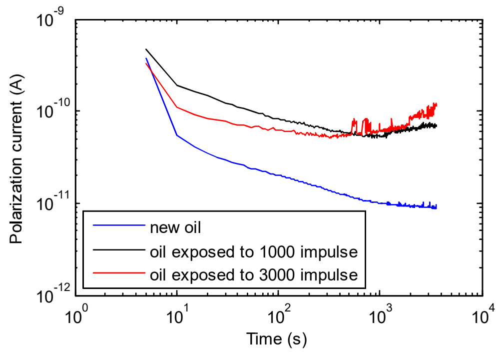

Figure 8. Comparison between polarization current of new oil and oil exposed to impulse

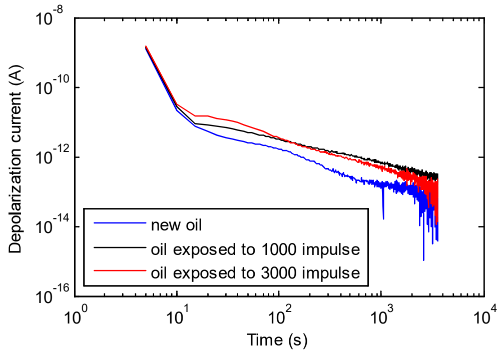

Figure 9. Comparison between depolarization current of new oil and oil exposed to impulse

5.2. Effect of PD on polarization and depolarization current

Figure 10 and 11 show that polarization current (time dependent conductivity) is not varying a lot, however in the case of exposure to intense PD activity the polarization current decreases. The change on depolarization current is not significant similar to the case of exposure to impulse. Changing of oil conductivity for different experiment is shown in table 1.

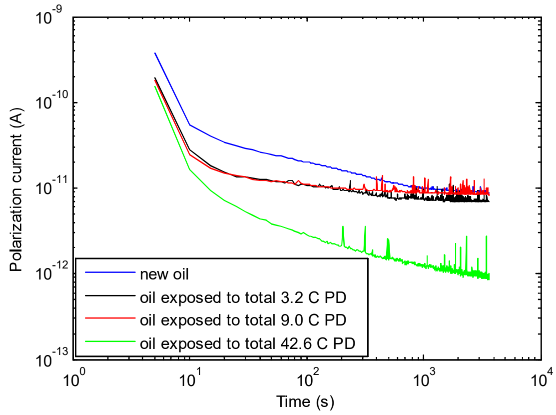

Figure 10. Comparison between polarization current of new oil and oil exposed to PD

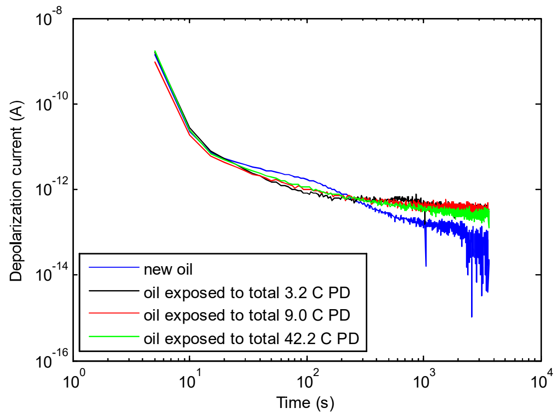

Figure 11. Comparison between depolarization current of new oil and oil exposed to PD

Table 1. Variation of oil conductivity

New oil exposed to	Conductivity (10^{-14} S/m)	
	60 s	3000 s
-	4.6	1.8
1000 impulse	19.5	13.8
3000 impulse	13.5	19
total 3.2 C PD	2.3	1.4
total 9.0 C PD	2.3	1.7
total 42.2 C PD	0.7	0.2

6. Oil breakdown strength

The breakdown voltage for six oil sample is shown in figure 12. Mean value and standard division for 20 experiments on each sample was used to calculate the breakdown strength of the specific sample.

From the figure 12 it is clear that both PD activity and impulse cause reduction of breakdown voltage. The results show that while by increasing the number of impulse injected to oil the breakdown strength decreases, if the oil sample exposed to much more PD activity the breakdown strength may increase again.

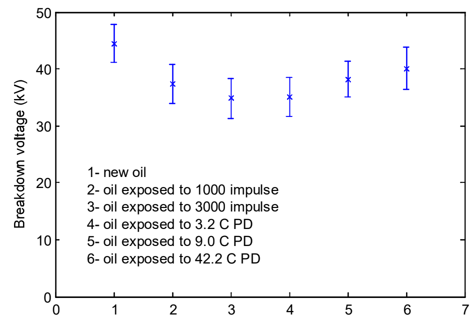

Figure 12. Breakdown strength of different oil sample (new oil, aged with impulse and aged with PD)

6. Conclusion

In this paper oil ageing because of PD activity and lightning impulse was investigated. The results from PD activity show that while the number of PD decreases over time, the average magnitude of PD stays constant.

Oil conductivity increases when it is exposed to complete breakdown, however when the electrical discharge is small it cause an increase in oil conductivity. Oil Breakdown strength decreases after it exposed to PD activity or complete breakdown due to lightning impulse.

7. Acknowledgment

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8. References

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