DEGRADATION OF OIL IMPREGNATED PAPER FILM INSULATION UNDER INFLUENCE OF REPETITIVE FAST HIGH VOLTAGE IMPULSES

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Abstract: In modern power networks, due to the rising application of semiconductor switching devices, insulation systems of different power components are faced to voltage stresses, for which the insulation systems are usually not dimensioned and tested. These are normally designed for AC or DC voltage and impulse voltage with a relative low repetition rate. With semiconductor switching the insulation system is associated with a series of very high number of voltage pulses with very short rise times applied to the insulation system with different frequencies/repetition rates. The current study aims to investigate the impact of application of such high voltage impulses to paper insulation impregnated in oil, which are usually used in various power components like as power transformers. For this purpose, square like high voltage impulses with different rise times and repetition rates are applied to a large number of oil impregnated paper film samples for different durations. To get an insight on the aging process of the stressed samples, their electrical characteristics, like as breakdown voltage and loss factor, are measured and impact of different influential parameters on the degradation of the samples is studied in detail. The experimental results show significant changes in loss factor of aged samples especially in the frequency range of 0.1 to 100 Hz. The possibility of space charge generation during degradation process of the samples is discussed as one of the probable physical mechanisms to describe the experimental findings.

1 INTRODUCTION

Increasing use of power electronic switching components in power systems faces the insulation system of high voltage components to new form of stresses. In many cases, pulse width modulation (PWM) technique is used to control the current/voltage waveforms, e.g. in inverter-fed motor drives [1], or to convert the generated power from DC to AC in some renewable energy sources like as wind generators. Accelerated aging of the insulation systems of network components subjected to such repetitive high voltage square pulses have been reported [2].

Investigation of the aging phenomena of the insulation materials subjected to steep voltage pulses has been considered in many previous studies [3 - 5]. Depending on the application in focus, different materials have been taken into consideration. As in many applications in power networks, oil-paper insulation systems are utilized, the aging behaviour of oil impregnated paper has been paid significant attention. In some studies, to age the oil impregnated paper samples, a combined sinusoidal and pulsed stress has been applied [3], while in some other only repetitive pulses are used [4]. Different parameters of the aged specimens are subject to change; these include dissipation factor [4 - 5], partial discharge characteristics [5], breakdown voltage [3] and space charge generation [6].

In the present study, to investigate the impact of different pulse parameters on the aging of the oil impregnated paper insulation subjected to repetitive high voltage pulses, a number of 50 μm oil impregnated paper samples are stressed by repetitive square wave pulses with different parameters. The experimental results indicate significant changes in loss factor of the aged samples, especially dependent on the rise time and repetition rate of the applied high voltage pulses.

2 EXPERIMENTAL SETUP

To apply the pulse voltages to the test samples, a push-pull circuit as shown schematically in Figure 1 is used. This circuit has been developed for earlier investigations and is documented in detail in [7]. In this circuit, two IGBT switches are used to energize and de-energize the test object, which is presented as a capacitor Cb in Figure 1. The resistors Rd and Re in combination with the capacitor of the test object Cb, determine the rise and fall times of the generated square shape pulses. The pulse width as well as repetition rate of the applied voltage pulse is controlled by appropriately timing of the driver signals of the IGBT switches. Using this set up it is possible to produce high voltage pulses with amplitudes up to 5 kV and different pulse parameters.

The test objects were oil impregnated paper films
with a thickness of 50 μm, which were placed between two copper electrodes with Rogowski profile in oil. The upper electrode has a diameter of 40 mm and the lower electrode a diameter of 80 mm diameters (see Figure 2). All paper samples were cut in circular form. The diameter of these samples was 130 mm. For dissipation factor measurements the same test cell with three-electrode arrangement was used. The upper electrode is voltage electrode and the bottom electrodes are guard electrode and measurement electrode locating in the centre. The effective diameter of voltage electrode is 110 mm and the diameter of measurement electrode is 80 mm. The water content of the whole system is kept under 1 % in all experiments.

The Dielectric Response Analyser “Dirana” manufactured by Omicron was used to perform dissipation factor measurements. The measurements were performed with a peak voltage of 200 V and frequencies from 1 kHz to 1 mHz.

3 EXPERIMENTAL RESULTS

Using the experimental setup described in last section, repetitive square waveform high voltage pulses have been applied to the test object. To encounter the statistical variations of different specimens, at least five experiments with the same pulse parameters have been performed. Figure 3 shows the measuring results of dissipation factor on a paper sample in new condition and 5 paper samples after subjecting to electrical stress with the same parameters of the applied voltage pulses. As shown in Figure 3, there is no significant variation between the results of measurements on different samples, which were subjected to the repetitive square pulses with the same parameters and duration.

3.1 Impact of the aging time

The results of dissipation factor measurement versus frequency as a function of aging time are shown in Figure 4.

Figure 3: Typical measurement result variations with the same parameters of the applied voltage

Figure 4: Dissipation factor vs. frequency for oil impregnated paper samples aged with repetitive high voltage pulses as function of aging time with the same pulse parameters
To investigate the influence of the aging time of the samples, three different experiments have been performed on the oil impregnated paper film samples. The repetitive pulses with the same parameters were applied to the paper samples for different times. The amplitude of the applied voltage pulses was 2800 V, the rise time of the voltage pulses 0.9 μs, the pulse width 125 μs and repetition rate of the voltage pulses 1000 pulses per second.

3.2 Impact of rise time of the applied voltage pulses

Figure 5 shows the dissipation factors versus frequency for different specimens aged with high voltage pulses with different rise times, keeping all other parameters the same, compared to the virgin samples. The amplitude of the applied voltage pulses was about 2800 V, the repetition rate was about 1000 pulses per second and the pulse width was 125 μs.

As it can be seen, in case of more steep voltage pulses, the changes in the dissipation factor become more significant. Especially in the frequency range of 0.1 Hz to 10 Hz, the dissipation factor of the aged samples is at least one order of magnitude higher than that of virgin ones. These results are in good accordance to the earlier experimental results of [4].

Figure 5: Dissipation factor vs. frequency for oil impregnated paper samples aged with repetitive high voltage pulses with different rise times

3.3 Impact of repetition rate of the applied voltage pulses

The changes in dissipation factor of samples aged with high voltage pulses with different repetition rates are depicted in Figure 6 as a function of measured frequencies. The amplitude of the applied voltage pulses was about 2800 V, the pulse width was about 125 μs and the rise time of the voltage pulses was 1.2 μs.

The higher the repetition rate, the changes in dissipation factor are more significant. It is interesting to note that the repetition rate itself is an important parameter and not the number of pulses.

Figure 6: Dissipation factor vs. frequency for oil impregnated paper samples aged with repetitive high voltage pulses with different repetition rates

4 DISCUSSION

The measured changes in dissipation factor shown in Figures 4, 5 and 6, may be explained as follows. During the aging of the samples, as described in detail in [8], the insulation material is heated up locally and this may trigger some thermal stimulating processes, which are responsible for generation of trapped charges within the insulation material. These are detected macroscopically as space charges within the insulation material.

Oscillation of the trapped charges under application of alternating voltage to the samples during the dissipation factor measurements cause some losses, which are interpreted as an increase in dissipation factor of the insulation material. To better explain this phenomenon, consider a charge \( q \) with an equivalent mass \( m \), which is subjected to an alternating electrical field \( E_0 \cos(\omega t) \). Its motion equation may be expressed as:

\[
\frac{d^2 x}{dt^2} + k \frac{dx}{dt} = qE_0 \cos(\omega t)
\]

where \( k \) is a coefficient to encounters the losses during the motion of the charged particle. Solving equation (1), the trajectory of the charged particle after its initial transients can be derived:

\[
x(t) = \frac{qE_0}{m^2 \omega^2 + k^2} \left( -m \cos(\omega t) + k \sin(\omega t) \right)
\]

and the mean energy dissipated by the oscillation of the charged particle is calculated:

\[
\bar{W}_{\text{loss}} = \frac{k \cdot q^2 \cdot E_0^2}{2(m^2 \omega^2 + k^2)}
\]

In other words, the phenomenon involved in aging of the oil impregnated paper samples seems to be sensitive to the time between two successive pulses.
proportional to $\frac{\Phi}{\omega}$. So it is possible to explain the changes in dissipation factor due to the oscillating motion of charged particles. It is interesting to note that the absolute amount of changes would be higher in case of lower measurement frequencies. This is in accordance to the measurements reported.

Considering equation (2), it can be seen that the maximum displacement of the charged particle becomes larger for lower frequencies. So it can be expected that in case of very low frequencies applied to the specimen for long times, the charged particles come out of the insulating material. This would result in different dissipation factor measurements, if for the same sample the measurement is repeated. Furthermore, an increase in the applied electrical field would accelerate this process and therefore it is expected that the changes between successive measurements on one sample would be more significant if much higher measurement voltages are used to perform the dissipation loss measurements.

Figures 7 shows the successive measurement results on one aged sample with two different applied voltages. Comparing different curves in Figure 7, a decrease of dissipation factor is observed. The reduction in changes of the measured dissipation loss is more pronounced in the second measurement compared to the first one.

![Figure 7: Successive Dissipation factor vs. frequency measurements of an aged sample with an applied measurement voltage of 200 V](image)

5 CONCLUSION

In this paper, degradation of oil impregnated paper samples under application of repetitive high voltage pulses has been investigated. For this purpose, 50 μm oil impregnated paper samples have been subjected to the voltage pulses with different rise times, repetition rates and for different time periods. The dissipation loss measurements on the aged specimens indicated a significant change especially in the frequency ranges of 0.1 Hz to 100 Hz. Using a simplified model, it has been shown that such changes in dissipation factor can be interpreted as the impact of presence of generated space charges within the aged insulated materials.

6 ACKNOWLEDGMENTS

The first author would like to acknowledge the financial support of the Alexander von Humboldt foundation.

7 REFERENCES


