The Effect of Insulation Oil on the Electrical and Dielectric Properties of Epoxy Resin

M. M. Saei Shirazi, H. Borsi, E. Gockenbach
Schering-Institut
Leibniz Universität Hannover
Hannover, Germany
m.saei@si.uni-hannover.de

Abstract— It is well known that thermal and electrical stresses have a strong influence on the degradation of insulation, but the effect of insulation oil is not yet well analysed. There are different electrical apparatus operating with insulation oil as cooling system and epoxy resin as the insulation system. So it is very important to be cleared, how the oil will affect the electrical and dielectric properties of the solid insulation material. On this account thermal stress was applied to a number of cast-resin samples with the presence of insulation oil and its effect was evaluated via partial discharge inception voltage, loss factor, capacitance and breakdown voltage measurements. Starting point of the investigations for this study was the question of how far the insulation oil at higher temperatures affects the electrical and dielectric properties of the epoxy resin. To evaluate this influence, several samples were produced considering a special geometry, so that the possibility of diffusion of oil in epoxy resin can be increased. Then after different ageing periods, breakdown voltage, partial discharge inception voltage and loss factor of the specimens were measured as key parameters.

Keywords-component; Insulation Oil; Epoxy Resin

I. INTRODUCTION

Cast resin materials are distinguished by easy working properties, excellent electrical and dielectric properties and good resistance against thermal and chemical stresses. For that reason this solid insulating material is widely used in electrical applications like switchgears, bushings, rotating machines or transformers. By variation of the moulding material components, the properties of the insulating material can be adapted to the application requirements [1].

With regard to the possible range of applications, it is important to know the dielectric behaviour of a cast resin, particularly since essential material properties like the breakdown voltage or the partial discharge characteristic are strongly influenced by quantities like the dielectric loss factor, the relative permittivity or the volume d. c. resistivity [2].

As there are different electrical apparatus working with oil as cooling system especially electrical machines, it is to evaluate their electrical and dielectric properties during ageing process.

The working life of electrical machines is primarily affected by the insulation system quality. The working life of electrical insulating system is commonly determined, estimated and predicted in terms of accelerated laboratory ageing of studied insulating materials. Accelerated ageing could be applied as single factor ageing like thermal or electrical ageing or multiple factor ageing. During the multiple factor ageing, all factors take effect together in the same time.

Degradation of an insulation system occurs during the accelerated ageing. The degradation is related to the physical and chemical changes within material structure. These changes are consequently detectable with physical or chemical test methods (see Fig. 1). Partial discharge testing belongs to one of the high applicable test method of insulating materials within electrical machines. This non-invasive or non-destructive test method allows determining the degradation ratio or homogeneity of insulation [3].

To evaluate the insulation material after ageing more precisely, breakdown voltage and loss factor were also measured.

Measurements of the electrical properties of epoxy resin systems, in particular the loss factor, are an effective way of investigating curing processes. The change of dissipation factor during curing has been studied by a number of researchers [4]. In this research, the samples were aged for a long time and in spite of ageing, lower loss factor was recorded. So the post curement can be a reason for this improvement, what will be discussed more in the next session.

II. TEST CONDITIONS

A. Used Insulation Materials

To study the matter, high temperature mono component epoxy resin as solid insulation material and high temperature insulation oil as impregnation liquid were considered.

The mentioned epoxy resin would be used in medium voltage electro motors and they would be cooled down by insulation oil. The epoxy resin was cured during 12 hours with 165 °C. Thermal class of this resin is 220 °C and glass transition temperature 145 °C.

The samples were produced under vacuum without any mixing during vacuum, so that some cavities remain in the samples. The existence of the cavities was confirmed by partial discharge measurement. In the next steps, the behaviour of
partial discharge will be shown related to the cavities during ageing of the samples in oil.

**III. SETUP FOR MEASUREMENTS**

**A. Setup for partial discharge inception voltage measurement**

PD Measurements were performed with the PD measuring system of the company ICM Diagnostix Power Systems GmbH. Before each PD measurement, the measurement system was calibrated with a calibrator CAL1A with a charge of 10 pC.

**B. Setup for Breakdown Voltage Measurement**

Increasing rate of voltage for this test was considered 2 kV/s.

Both tests (partial discharge and breakdown) were done under insulation oil to avoid flashover on the surface of the test samples.

**B. Electrode Configurations**

To increase the probability of the diffusion of the oil in the epoxy resin, the sphere-sphere electrode configuration with a distance of 1 mm between both electrodes was considered. In addition, the geometry of the specimen was so designed, that the oil can go through the insulation material between the electrodes easier (Fig. 2).

**C. Ageing Process**

To consider a normal application of both insulation oil and epoxy resin, the samples were divided into several groups and each group included 5 samples. Then the samples were aged with 180 °C and 200 °C and 220 °C for total 4000 hours. The measurements of partial discharge, breakdown voltage and loss factor were done after 1000, 2000 and finally 4000 hours for each group.
C. Setup for Loss Factor Measurement

This measurement was done considering 200 V, 50 Hz in a completely shielded measurement system by an Omicron measurement device.

IV. RESULTS

A. Partial Discharge Inception Voltage under Homogeneous Field

All the measurements were done at room temperature. To apply no temperature changing stress to the samples, they were cooled down after each period very slowly.

The results of the measurements of partial discharge inception voltage after ageing the samples with 180 °C and 200 °C show an increase of inception voltage in comparison with non stressed and shorter time stressed samples. Considering 200 °C some samples were broken after 1000 hours. The samples aged with 220 °C were all damaged.

B. Breakdown Voltage

As shown in Fig. 6, it seems that up to 1000 hours the samples have not yet been influenced by oil, but by temperature. So after 1000 up to 4000 hours, it can be assumed that the oil has been influenced the solid insulation material and tried to neutralize the effect of ageing relatively. Consequently, after 4000 hours thermal stress on the samples, the results of breakdown voltage measurement in Fig. 6 and 7 show an improvement in breakdown voltage, in spite of a long ageing period with high temperatures.

As already mentioned, the samples aged with 220 °C were all damaged.

C. Loss Factor and Capacity

This parameter was influenced by the ageing process up to 1000 hours with 180 °C as shown in Fig. 8. Considering 200 °C, the results show a decrease up to 1000 hours and then an increase of loss factor up to the loss factor value of the non-aged samples.

Assuming the diffusion of the oil in epoxy resin results an increasing of capacitance of the samples with 180 °C gently. The capacitance is proportional to the permittivity and on the other side; permittivity is proportional to the loss factor. So the capacitance should be logically reduced according to the above discussion. But as shown in Fig. 10 and 11, it has been gently increased. The reason is that during diffusion, insulation oil was penetrated into the epoxy resin and made charge-careers move easier in the direction of electrodes. On the other side, as the cavities were filled with the insulation oil, loss factor was decreased.
Furthermore, the diffusion of the oil plays a bigger role for decreasing loss factor in comparison to the charge-careers which can now move easier in the electrical field and consequently increase the loss factor. So the loss factor will be reduced, because the cavities are now relatively full of oil and do not let the polarization happen easily. The mentioned interpretation is more or less valid for aged samples with 180 °C.

There are also some explanations for this improvement as shown below:
- This behaviour may be also caused by the fact that the samples have some inorganic fillers with molecular water. So during ageing the samples, the molecular water evaporates and will improve the electrical and dielectric parameters.
- It can be also possible that empty spaces will be replaced by oil.
- It is also possible that there are some short polymeric chains in epoxy resin, so that during ageing the mentioned chains would go out of the sample.
- Another possibility for these improvements is, that the epoxy resin would be post cured during ageing.
- It can be also possible, that ionic impurities in the samples go out of it and may result in better electrical and dielectric properties.
- In addition the cavities can become smaller or omitted during the ageing process because of molecular changes of the solid insulation material during ageing.

REFERENCES