Evaluation of the Influence of Nano Fillers on the Electrical and Dielectric Properties of Epoxy Resin

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Abstract—Nano fillers have been found in recent years in several areas of technology and can cause electrical, mechanical and chemical improvements. In this study, host material, namely bisphenol-A epoxy resin as indoor application, and related micro filler are the same for all produced samples. Al2O3 has been considered as nano fillers. Nano fillers were mixed with the host material using ultrasound device and high speed mixer simultaneously. An even distribution of the nano fillers was validated by means of transmission electron microcopy.

The investigations were carried out under homogeneous (plane-plane) and inhomogeneous (rod-plane) electric field configuration. The influences of the amount of the nano fillers up to 10% part by weight (pbw) and the temperature from 23 °C to 180 °C on the partial discharge (PD) inception voltage and breakdown voltage of the specimens are investigated.

Keywords-component; nano filler; nanocomposite; high voltage insulation system

I. INTRODUCTION

Nanotechnology is emerging as one of the 21st century technologies. It is a general term covering a wide range of many fields. It deals with characteristics in nanometer size and/or microscopic regions on materials and functional devices [1]. Epoxy resin often suffers lower dielectric breakdown strength if micro-fillers are loaded. It might be possible to raise the once lowered breakdown strength if nano fillers are added [2].

This study reports about the influence of nano fillers Al2O3 with different percentages including 0%, 1%, 3%, 5%, and 10% part by weight (pbw) in combination with the conventional micro fillers on the electrical and dielectric properties of bisphenol-A epoxy resin. In addition, Al2O3, TiO2, ZnO nano fillers are the most famous ones which would be used for researches [3]. Using electron microscope observation, it was shown that the area surrounded by dispersed micro-scale silica fillers was also filled with the nano-scale fillers. Nano fillers can fill the cavities between micro fillers and as a result can protect insulation material against partial discharge (PD). Furthermore, the estimate of spacing between the fillers and the filler/epoxy resin interface area shows a more densely packed structure of the filler mixture composite than the conventional filled epoxy resin. The morphological feature of the filler mixture composite improves its insulation breakdown strength.

As partial discharges are very dangerous for solid insulation materials, nano fillers can fill the cavities which are difficult for micro fillers and this results an optimal partial discharge behavior of the insulation and consequently will prolong its life [5, 6]. Nano fillers can also reduce the negative effect of the electrical treeing within the insulation material [7].

The two key parameters partial discharge inception voltage and breakdown voltage were evaluated under homogeneous and inhomogeneous fields.

Regarding to the importance of mixing nano fillers with the host material homogeneously and in nano scale, high speed mixer and ultrasonic were used simultaneously for a definite time. Then the homogeneous distribution of them was checked by means of transmission electron microcopy.

II. TEST CONDITION

Although the samples were produced under vacuum, it is difficult to omit cavities during the production completely. In this condition, nano particles can operate against PD, when the nano particles are mixed correctly. So mixing nano particles with the host material homogeneously is the most important point in order to reach good results.

A. Host Material

Indoor epoxy resin system including CY228 as resin, HY918 as hardener, DY062 as accelerator and 65% Quarz Millisol W12 as micro filler was used as the host material for all the samples.

B. Nano Filler

Unmodified Al2O3 was selected as nano fillers, because this is the conventional nano filler and also economic. The samples were produced considering maximum 10% pbw,
because the final costs of the product with more than 10% pbw are uneconomic and the viscosity of the whole material after the mixing is too high and casting would be difficult consequently. The mentioned percentages by weight are valid for the end product and not only for resin or hardener

The average particle size of the Al2O3 is 40 nm. The different sizes of particles influence mixing and casting process. As smaller the size of nano filler, easier is the mixing and casting.

C. Electrode Configurations

The expriments were done under homogeneous and inhomogeneous field considering two different electrode configurations. To create homogeneous field Rogowski-Rogowski and to create strong inhomogeneous field needle-plate electrode configurations were considered.

To evaluate the electrical resistivity of the insulation material, it is necessary to do the measurement under both mentioned field. IEC 60455-2 discusses about this matter and a related standard recommends the determination of the breakdown voltage by brass electrodes with Rogowski profile and 1 mm distance between both electrodes. The used electrodes have a nominal diameter between 24 mm and 27 mm as shown in Fig. 2.

D. Mixing Nano Fillers with Resin, Hardener, Micro Fillers and Accelerator

The nano fillers were firstly mixed with resin as the base material. After all the nano particles were poured in the resin, both materials were mixed for 15 minutes by high speed mixer and ultra device simultaneously to make the most optimal mixing. Principally, nano particles should be distributed homogeneously and in nano scale. Otherwise they play the role of micro fillers and will not let evaluate their influence on the based material. To prevent unwanted heating of the material, the temperature of the material was kept approximately constant by using a water cooling system.

The above mentioned mixing behavior was used till 5% pbw. For 10% pbw it was not possible to mix all the nano fillers with resin. So 60% of the nano fillers were mixed with resin and the rest with hardener, instead.

It is much better to mix the nano particles with resin instead of hardener, because the hardener is very sensitive to humidity. So mixing nano fillers with hardener would influence the electrical and dielectric parameters of the test samples.

The materials were mixed with hardener, micro fillers and accelerator under vacuum and controlled temperature in several steps for 45 minutes. Finally the mixed material was casted into the molds with needle and Rogowski electrodes and cured for 4 hours at 80 °C and 8 hours at 140°C in an oven. To reduce the internal mechanical forces, the forms were cooled down for 8 hours.

To let the molecules of the samples relax, the measurements were done 4 weeks after the curing process.

If the nano fillers were distributed homogeneously and in nano scale, a proper sample of each material was prepared and an even distribution of the nano fillers was validated by means of transmission electron microscopy.
The results show that the nano particles were well distributed in the whole volume.

Fig. 4 shows the micro and nano fillers separately and also a combination of them in the host material, so that the green points show the distribution of nano particles and the red areas the distribution of micro fillers. Due to REM technique a separation of nano and micro filler is possible. As explained, it is obvious that the spaces between micro fillers are mostly filled by nano particles.

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.

Increasing rate of voltage for this test was considered 500 V/s till the discharges appeared. Partial discharges were recorded during 60 seconds after appearing the first discharges.

B. Setup for Breakdown Voltage Measurement

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

Both tests were done under insulation oil to avoid flashover on the surface of the test samples.

IV. RESULTS

A. Partial Discharge Inception Voltage under Homogeneous Field

The measurements of PD inception voltage under homogeneous filed were limited up to 30 kV, because the samples were needed for the determination of breakdown voltage too. As shown in Fig. 5, the PD inception voltage of the samples with 1% and 10% is around the PD inception voltage of the samples with 0%. But it remains stable with 3% and especially 5% up to 150°C in comparison with the other percentages. Furthermore, glass transition temperature (Tg) of the host material is between 110°C till 120°C. So for the other percentages the situation is normal up to Tg. Consequently by 25% above Tg of the host material, addition of 3% and 5% nano fillers did work properly. This improvement can have two reasons. The first one is an increase in the Tg of the samples with 3% and 5% nano filler. The second one is a much better adhesion force between the electrodes and the epoxy resin, when nano fillers were used. Up to 150°C, although the kinetic energy of the molecules is high, the effect of the nano fillers reduces the effect of the molecules with high kinetic energy.

Above 150°C, the molecules get much more kinetic energy, so that PD starts by low voltages. As explained, at 1% pbw nano filler no improvement was seen in the values of PD inception voltage. The reason can be insufficient inter phases in the material. With 10% just vice versa so that the quantity of the nano particles are so high that inter phases are strongly reduced, because the fillers were located side by side in colony form in the host material.

![Figure 5. PD inception voltage under homogeneous field](image-url)
B. Partial Discharge Inception Voltage under Inhomogeneous Field

Under inhomogeneous field the results introduced in Fig.6 show approximately a stable behavior with 0%, 1%, 3% and 5% pbw nano filler at higher temperatures. But considering 10% pbw nano filler results a small increase of PD inception voltage up to Tg.

C. Breakdown Voltage under Homogeneous Field

Adding micro fillers can increase the electrical resistivity of insulation materials. According to the following results, it seems that nano fillers can not improve the breakdown voltage of the samples considerably.

D. Breakdown Voltage under Inhomogeneous Field

Under inhomogeneous field, there is no improvement in break down voltage and all the curves follow the curve of 0% nano filler.

V. CONCLUSION

• The PD inception voltage can be held till 150°C or 30°C above Tg as good as at room temperature under homogeneous field using 3% and 5% pbw Al2O3 nano filler.

REFERENCES


