Application of the Dielectric Spectroscopy Method for Assessing Quality of HV Capacitors[1]

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Abstract – The dielectric spectroscopy method is an excellence instrument for the diagnostics of high voltage insulation and assessing quality of HV equipment such as transformers, cables, capacitors, etc. This method allows the state of HV insulation to be estimated by using the dielectric response over the frequency range. The possibility of assessing the insulation quality of HV capacitors is shown in this paper. It was found that the dielectric spectroscopy method allows us to estimate not only the HV insulation quality but also a moisture presence in composite insulation.

1. Introduction

Application of solid polymeric dielectrics as HV insulation in the power engineering and electrical engineering results in a necessity of development of new effective methods of diagnostics of their prebreakdown state under the electric field. Diagnostics of the insulation state of HV capacitors both after producing and during exploitation period is very important problem as damage of insulation of HV capacitor can result in the destroy of unique HV equipment.

Traditional measurements of loss factor tanδ or overall conductivity γ at the fixed frequency can not give synonymous appreciation of the insulation quality as these methods allow the integral value of tanδ and ρ of composite insulation to be measured. As a consequence, alternative non-destructive methods are of considerable interest for assessing the state of composite insulation.

In particular, the dielectric spectroscopy method (DSM) in frequency domain is widely used for assessing quality of the oil-paper insulation of power transformers [1–3]. A sinusoidal signal is applied to the high voltage bushing and the frequency response measured at the other terminal. The insulation system of HV equipment frequently is a composite of some dielectric media. It is important to realize that each has its own dielectric response and, when putting them together, the total response will not only reflect properties of each material, but also the way they are combined.

This method allows both the moisture content in oil-paper insulation and the degree of ageing of insulation of HV power transformers and HV power cables to be estimated [4–6]. Besides, the given method can be used for the quality assessment of novel composite polymeric materials [7, 8].

The study of possibility of DSM application for assessing quality of HV capacitors was the main aim of this work.

2. Experimental procedure and samples

The measurements of real part ε′ (or C) of the complex permittivity and tanδ (or imaginary part ε″ of the complex permittivity) of paper samples were carried out under AC voltage 3 V at temperatures 20–100 °C in the frequency range from 10^{-2} Hz to 1 MHz by using the Solartron Instrument (Impedance/Gain-Phase Analyzer Solartron 1260 + Dielectric Interface Solartron 1296) [9]. The experimental setup is shown in Fig. 1.

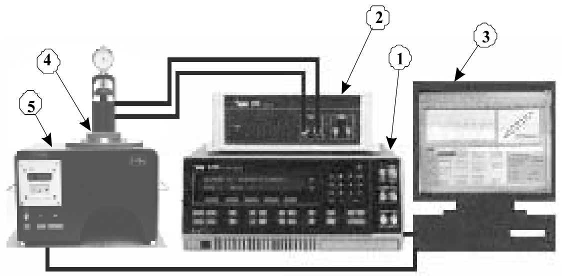

Fig. 1. Experimental setup: 1 – frequency response analyzer Solartron 1260; 2 – dielectric interface Solartron 1296; 3 – computer; 4 – test cell with a sample; and 5 – temperature controller

Measurements of C and tanδ or ε″ for capacitors were carried out in the frequency range from 10^{-1} Hz to 10^4 Hz by using the same measuring instrument.

Samples of paper 75 × 75 mm with thickness of 100 μm were used in this study. On both surfaces of samples graphite electrodes 25 mm in diameter were made. All samples were conditioned in vacuum at 100 °C for 4 h before the measurements. Three groups of samples were prepared: A, dry paper; B, dry paper impregnated with hydrocarbon oil; and C, humidified paper-oil insulation.

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Others studied objects were HV impulse capacitors HCEI 50-0.25 and HCEI 50-0.1. Figure 2 shows a general view of impulse capacitor HCEI 50-0.25.

Fig. 2. High voltage capacitor HCEI 50-0.25

Insulation on these capacitors was made as a combination of paper and PET films of thickness 10 μm impregnated by castor oil.

3. Experimental results and discussion

The experimental results of the study of frequency dependencies of the overall admittance for three groups of samples are shown in Fig. 3.

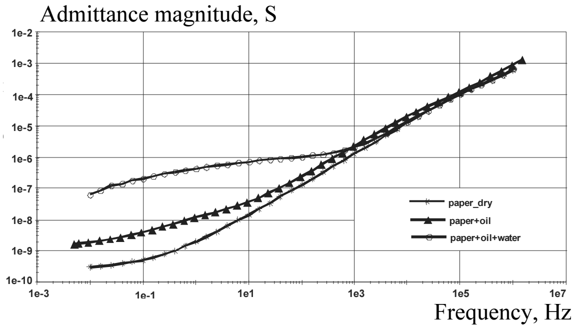
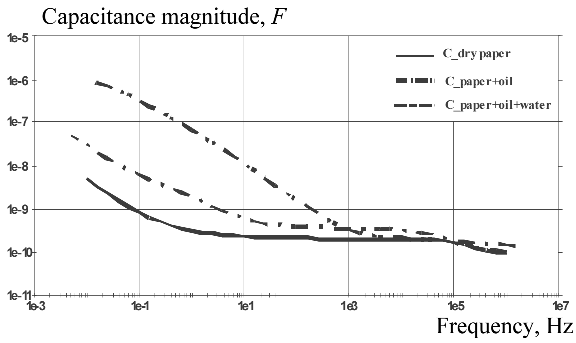


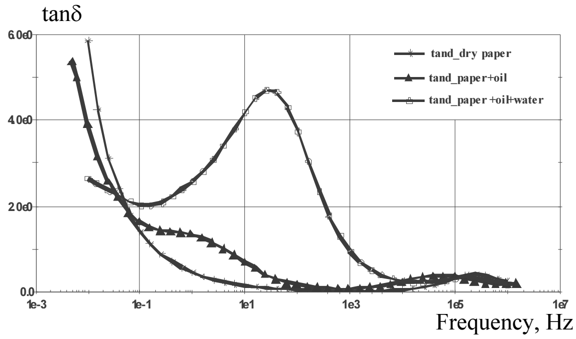
Fig. 3. Frequency dependencies of admittance for dry paper, oil impregnated paper and wet paper

It can be seen that the value of admittance are practically unchangeable for all samples with decrease in the frequency approximately up to 10^3 Hz. For the frequencies lower than 10^3 Hz the admittance value is increased significantly for the oil-impregnated and especially for wet paper samples (B and C groups) compared to that for the dry paper (group A). For example, the values of the admittance at 60 Hz for the samples of B and C groups are increased by a factor of 1.9 and 11, while at 10^{-1} Hz by a factor of 7.5 and 400 compared to that for the dry non-impregnated paper respectively (Fig. 3). It is conditioned by that in B and C groups an additional dielectric loss related with the polarization of molecules of oil and water are observed. This results in the increase in dielectric loss due to the current increase through oil-paper insulation.

However not only the admittance value but also parameters of the dielectric relaxation spectra depend on the experimental conditions of oil-paper insulation. Figure 4 shows typical dielectric relaxation spectra for three groups of samples.



a



b

Fig. 4. Frequency dependencies of capacitance (*a*) and tanδ (*b*) for dry paper, oil impregnated paper and wet paper

It is obvious that the value of tanδ is practically invariable in the high-frequency range for all groups of samples. The frequency dependencies of tanδ for B and C groups in the low-frequency range are shifted towards the lower frequency (< 10^{-1} Hz) compared to that for the dry paper. The most significant changes of tanδ are observed in the medium frequency range. Characteristic tanδ relaxation peaks corresponding to the oil and water are observed at 1 and 30 Hz respectively. These dielectric losses will give the significant contribution into the total dielectric loss of oil-paper insulation.

Figures 5 show frequency dependencies of tanδ for samples: 3 layers of polyethylene terephthalate (PET) film + 3 layers of paper. The thickness both of PET film and paper was 10 μm. Total thickness of samples was equal to the insulation thickness in the capacitor sections. Samples were no dried before measurements. Two cases were considered. First, when a PET layer of sample was turned to the measuring electrode of measuring instrument (1). Second, when the opposite paper layer of sample was turned to the measuring electrode (2).

It can be seen that the difference between two curves in Fig. 5 is negligible in the high frequency range, while the value of tanδ in the low frequency range is sharply increased for the second case. Relaxation tanδ peak for both cases is observed at ~ 2–3 Hz. The difference between two dependencies in the low-frequency range in Fig. 5 may be related with various moisture contents in paper and PET and with dissociation of H_2O molecules during measurements.

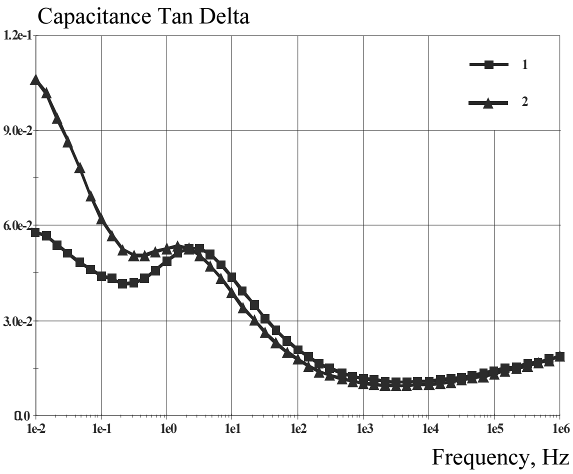


Fig. 5. Dielectric relaxation spectra for paper/PET samples

Frequency dependencies of the imaginary part of complex permittivity $\varepsilon'' = \varepsilon' \cdot \tan\delta$ for HV capacitors are represented in Fig. 6.

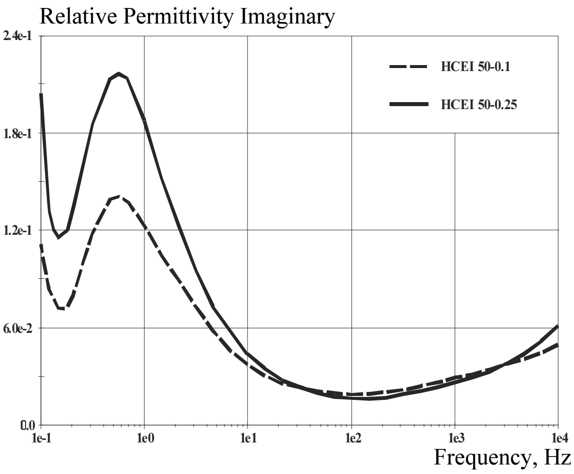


Fig. 6. Dielectric relaxation spectra for HV capacitors at 20 °C

It can be seen that characteristic relaxation peaks of the imaginary part of the complex permittivity ε″ are observed at ~ 0.5–0.6 Hz in the dielectric relaxation spectra of both capacitors. The maximum value of ε″ for capacitor HCEI 50-0.25 at F ≈ 0.5–0.6 Hz is increased by ~ 65% compared with a capacitor HCEI 50-0.1. Difference between two capacitances in the high frequency range is negligible. Minimum dielectric losses for both capacitors are observed at ~ 80 Hz.

It should be noted here the dielectric loss maximum is not related with paper, PET or castor oil. This maximum may be conditioned by the combined water in spite of the capacitor insulation drying.

The comparison of Figs. 5 and 6 shows that the relaxation maximum of tanδ is shifted from 0.5–0.6 to 2–3 Hz for capacitors and for PET/paper samples respectively. This may be related with availability of water both on the surface and inside the paper in PET/paper samples.

Figure 7 shows frequency dependencies of tanδ for two capacitors HCEI 50-0.1. One of them was made by the ordinary technology. Impregnation of capacitor sections with castor oil were carried out after drying in vacuum at the temperature ~ 105 °C. Other capacitor was not dried before the impregnation with castor oil.

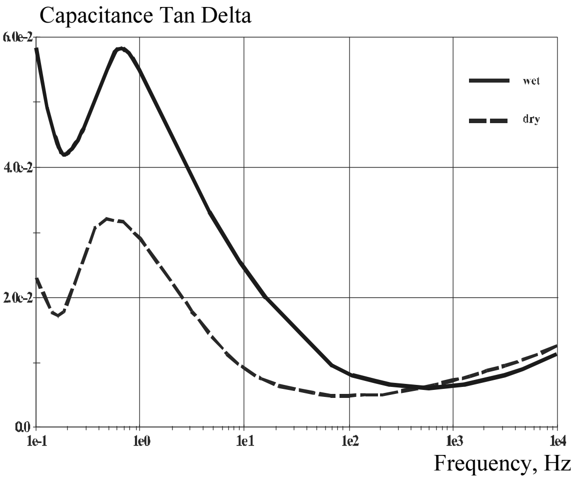


Fig. 7. Dielectric relaxation spectra for a capacitor HCEI 50-0.1 at 20 °C

It is obvious that the value of tanδ for the latter capacitor is increased by ~ 70–75% compared with dried one. Besides, the presence of moisture in the insulation of the second capacitor results in the shift of the dielectric relaxation spectrum towards the higher frequency compared to that for the first capacitor. The shift of the dependency $\tan\delta = f(F)$ can be estimated by the shift of the tanδ minimum. In this case, the frequency corresponding to the tanδ minimum for the second capacitor is increased by a factor of ~ 7 compared to that for the first capacitor (see Fig. 7).

However, main differences between both capacitors are observed in the low-frequency range and assessing the moisture content in paper/PET insulation by the value of tanδ at fixed frequency (for example, at 1000 Hz) is impossible. In this case the values of tanδ for both HV capacitors are practically close to each other.

Thus, the comparison of relations in Fig. 7 allows us to find difference between two dielectric relaxation spectra for dry and wet insulation of HV capacitors. This fact can be used for non-destructive assessing quality of HV capacitors after producing.

By using preliminary study results, a novel non-destructive method of the dielectric strength definition of HV equipment insulation was proposed. The method is based on measurement of parameters of dielectric relaxation spectra and calculation of the breakdown strength by using the low voltage characteristics of insulation system without high voltage application [10]. However for the verification of this method for impulse HV capacitors an additional study is needed. Knowledge of the dielectric properties of the insulation components is needed for this purpose. Nevertheless, at present the dielectric spectroscopy method may be applied for the quality assessment of insulation of HV capacitors as a non-destructive method.

4. Conclusion

It was shown that the dielectric spectroscopy in frequency domain can be applied to diagnostics of HV capacitors and assessing the quality of HV insulation without high voltage application. The dielectric spectroscopy method allows the presence of moisture in the capacitor insulation to be detected.

References

[1] U. Gäfvert, L. Adeen, M. Tapper et al., *in Proc. Int. Conf. Prop. App. Diel. Mater.*, 2000, p. 1.

[2] U. Gäfvert, *in Proc. IEEE Int. Conf. Solid Diel.*, 2004, pp. 1–10.

[3] S.M. Gubanski, P. Boss, G. Csepes et al., IEEE Elect. Ins. Mag. **19**, 12 (2003).

[4] D. Linhjell, L. Lundgaard, and U. Gäfvert, IEEE Trans. Diel. Elect. Ins. **14**, 156 (2007).

[5] Y. Du, M. Zahn, B.C. Lesieutre et al., IEEE Elect. Ins. Mag. **15**, 11 (1999).

[6] U. Gäfvert and P. Werelius, *in Proc. 9th Int. Symp. High Volt. Eng.*, 1995, p. 5662.

[7] O.S. Gefle, S.M. Lebedev, S.N. Tkachenko, Bull. Tomsk Polytech. Univ., **309**, 114 (2006).

[8] S.M. Lebedev, O.S. Gefle, Y.P. Pokholkov et al., *in Proc. 15th Int. Symp. High Volt. Eng.*, 2007, p. 477.

[9] *Solartron Analytical. Impedance/Gain-Phase Analyzer and Dielectric Interface. Operating manual,* http://www.solartronanalytical.com, 2001.

[10] O.S. Gefle, S.M. Lebedev, S.N. Tkachenko et al., *in Proc. Int. Conf. Solid Diel.*, 2007, pp. 651–653.