The Influence of Aging on Results of Dielectric Spectroscopy on Impregnated Pressboard

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Abstract: Several parameters such as oil condition, temperature and aging state of insulation can influence the results of dielectric spectroscopy and should be considered for an accurate and reliable interpretation of the results of this method. In this paper the results of dielectric spectroscopy in time and frequency on some pressboard samples, which were thermally aged in laboratory, are presented. The measurements were done at different condition: after aging, impregnated with new oil, and in elevated water content. The aging of oil can influence the results of dielectric spectroscopy especially in mid frequency range of FDS results and short time range of PDC results. The aging of pressboard can influence FDS results in low frequency range and the PDC results in long time range. For pressboard with high moisture concentration, aging of pressboard may influence the results of dielectric spectroscopy lighter than dry pressboard.

INTRODUCTION

Moisture is an important factor in aging of cellulosic insulation and is tried to remained below 1% in power transformers [1]. The direct measurement of moisture in solid insulation of transformers is often sophisticated and is not usually possible. The determination of moisture with the help of equilibrium curves through the moisture of oil is theoretically possible [2], but in praxis there are limitations and difficulties for existence of an equilibrium condition [3].

Nowadays dielectric spectroscopy methods are used to determine the moisture in solid insulation of power transformers [4]-[6]. Recovery Voltage Measurement (RVM) [7], Polarization and Depolarization Current (PDC) [8] and Thermally Stimulated Depolarization Current (TSD) [9] are the dielectric spectroscopy in time. Measurement of real and imaginary part of capacitance versus frequency is known as Frequency Domain Spectroscopy (FDS) [10].

There are many parameters which influence the results of dielectric spectroscopy of insulation systems. Temperature, moisture content of insulation, insulation condition (such as aging, curing, origin, etc), charging voltage (electric field) and geometry are the major factors which influence the dielectric response methods. To obtain a reliable interpretation of dielectric methods, the behavior of the dielectric response versus all parameters must be known.

EXPERIMENTAL SETUP

Laboratory Aging

The oil belongs to commercial grade insulating oil designed as mineral oil. Some pressboard was dried at 100°C and vacuum condition below 1 mbar for 2 days and than impregnated with the new oil, which was prepared and degassed under vacuum condition too.

Thermal aging was carried out at 135 °C in glass container in presence of air for 135h, 500h and 2000h. As catalyst 2.5 grams per liter of Cu and Fe and 0.5 grams per liter of Zn and Al each are added. The weight ratio of oil: pressboard: Cu: Fe: Al: Zn in the experiment was 100: 8: 0.3: 0.3: 0.06: 0.06. Fig. 1 shows schematically the aging vessel.

Measurement Setup

Fig. 2 shows the electrode system, which consists of chromium plates to reduce the influence of electrode material on dielectric measurements.
A setup was equipped with precision high voltage source and picoammeter, which are controlled by a personal computer for polarization and depolarization current (PDC) measurements. An integrated instrument “IDA 200” was used for frequency domain spectroscopy (FDS) [11].

All measurements were carried out at room temperature. As a compromise between accuracy and linearity test voltages of 200 V for PDC measurements and 140 V (RMS value) for FDS measurements were selected.

RESULTS

Measurements after Aging

Fig. 3 shows the effect of aging on FDS results of impregnated pressboards, which were measured at room temperature after the aging process. The water content of the samples is similar, due to similar condition in aging process (135°C) and similar handling after aging process. The PDC were immediately measured after FDS measurements. Fig. 4 shows the PDC results. It is clear that for comparison of FDS and PDC results, the low frequency part of FDS may be compared with PDC results. The same behavior is observed in FDS and PDC results.

![Fig. 3: Effect of aging on FDS results of impregnated pressboards](image)

The loss factor and capacitance of pressboard samples increase during aging process. It can be seen from PDC results that the conduction of pressboard increases during aging process. The depolarization current of aged samples is higher than the depolarization current of un-aged sample. When the conduction current is higher than the relaxation current, the polarization current has higher value than depolarization current and it seems that the polarization current and depolarization current are not equal. The time when the polarization current start to converge to conduction current (separation of polarization and depolarization current) in Fig. 4 is approximately constant. The dc conductivity of new oil, 135h aged oil and 500h aged oil were $2.4\times10^{-13}$, $4.0\times10^{-12}$ and $6.5\times10^{-12}$ S/m respectively. The conductivity of the oil was measured at room temperature by 400 V/mm after 1 min charging period.

Fig. 3 shows that the oil conductivity may change the loss factor at the mid frequency of FDS more than at other frequency. The influence of the oil conductivity on the PDC results is in the short time range (Fig. 4).

![Fig. 4: Effect of aging on PDC results of impregnated pressboards](image)

Influence of Oil

Fig. 5 shows the results of FDS for an oil sample, measured at room temperature. The imaginary part of capacitance ($C''$) is linear with slope of 1 in loglog-scale, therefore the conduction mechanism does not change remarkably in the frequency range ($R_p=C''\omega$, in which $R_p$ is parallel resistor in the dielectric model of oil and $\omega$ is angular frequency).

![Fig. 5: FDS of an oil sample at room temperature and at different field strength](image)

Below a frequency which is determined by transit time (the time an ion needs to cross the whole gap between electrodes) [12], an increase of capacitance is observed. If an insulating liquid is charged longer than the transit...
time, space charges are build up near the surface of electrodes. A tin oxide layer on the surface of electrode, make built up of ions near surface of electrode possible too [13]. The FDS results of impregnated pressboard were obtained by 70 V/mm, therefore the aged oil can influence the FDS results in form of capacitance increase at low frequency. Through capillary characteristics of pressboard and moving possibility of oil into pressboard the conductivity of oil can influence the conductivity of pressboard too.

**Pressboard Aging**

To eliminate the influence of oil on dielectric response of aged pressboard, the pressboards were impregnated again together with new oil under 1 mbar vacuum and 90°C for 100h. If the water equilibrium between pressboard and oil does not change with aging state of pressboard, it can be assumed that the water content of pressboards are similar. The same values of capacitance at high frequency show that the water content of pressboard can not have different values too. Fig. 6 shows the FDS results of the pressboards. The water content of pressboards was determined from master curve of the FDS instrument about 0.7%. The oil influence can be recognized through comparison of Fig. 3 and Fig. 6. Fig. 7 shows PDC results of the same samples.

![Fig. 6: Effect of aging of pressboard on FDS results](new oil, dry condition)

With assumption of same water content for the pressboards, Fig. 6 shows that the aging of pressboard influence the low frequency of dielectric response methods. The aging of the pressboards causes increase of DC conductivity and higher value for PDC and FDS results. However comparing the 2000h aged sample from Fig. 6 and 500h aged sample from Fig. 3 with new sample in both cases the influence of aging only pressboard is smaller than the influence of aging the complete insulation system.

![Fig. 7: Effect of aging of pressboard on PDC results](new oil, dry condition)

To obtain pressboards with higher water content, the dry impregnated pressboards (0.7%) and water were put in a sealed oven. A thermal cycling was applied to the samples, to increase moisture content. During each cycle the samples were heated from ambient temperature to 90°C and were remained 6h and cooled down afterwards to ambient temperature and were remained 6h. During heating and at 90°C the water solubility of oil increase and water migrate from ambient to oil, and during cooling and at room temperature water solubility of oil decrease and absorption of pressboard increase and water migrate from the oil to the pressboard. The different water absorption and desorption time constant of pressboard causes the increase of moisture in each cycle. The dynamic of moisture migration is similar to an exponential form, therefore a cycle duration 6h was selected. The water content of the pressboard was determined from dielectric spectroscopy data. After thermal cycling the temperature was hold at 70°C for about 200h to achieve a new equilibrium condition between the pressboards.

![Fig. 8: Effect of aging of pressboard (un-aged, aged 500h and aged 2000h) on FDS results](new oil, wet condition)

Fig. 8 and Fig. 9 show the FDS and PDC results of different aged pressboard with 1.6% water content.
It seems that the influence of pressboard aging on the result of dielectric spectroscopy in the case high water content is not significant. Fig. 9 shows that the DC conductivity of samples increases with increase of water content. The separation time of polarization current from depolarization current is for wet samples shorter than for dry samples.

CONCLUSION

Dielectric spectroscopy of impregnated pressboard provides very useful data from insulation system. The influence of oil condition, aging of oil-paper insulation system, aging of pressboard and water content of pressboard can change the results of dielectric spectroscopy.

The experience shows that the aging of pressboard influence the results of FDS in low frequency range and the aging of oil influence at the mid frequency range. The oil condition influences the PDC data in short time range, and aging state of pressboard influences the long time range data of PDC. Therefore separation of aging of oil or pressboard by the dielectric spectroscopy may be possible. The dielectric response of pressboard with high water content not changed remarkable with the aging state of pressboard.

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