Execution stage No.3: Tests on experimental models of insulation systems

Introduction

When present in transformer, moisture leads to a decrease of the electrical and mechanical performances of its insulation. Generally, each time the moisture content is doubled, insulation lifetime is halved and paper thermal failure rate is proportional with its moisture content.

In order to be able to control the moisture content from transformer insulation, several methods are used namely:

- Paper insulation moisture estimation using equilibrium diagrams
- Dielectric response evaluation to obtain information on moisture content.

The classical method consists in oil specimen sampling from the energised transformer, moisture content determination using Karl-Fischer titration and paper-oil moisture determination using equilibrium diagrams.

Since this procedure contained error sources like:

- Oil specimen infestation with environment moisture during sampling and transportation
- Absence of a steady equilibrium inside the transformer, depending on environmental temperature and loading degree
- Non-uniform temperature distribution along transformer coils
- Water dissolving capacity changes with transformer ageing meaning an increase of water solubility

Other solutions were looked for.

A new approach for equilibrium curve method improvement with a view to moisture evaluation consists in using oil moisture related to saturation level (%) instead of moisture weight to oil weight ratio (ppm).

Relative oil moisture has the advantage of containing ageing influence and is easier and more accurately to be measured in comparison with moisture as weight in ppm.

The method can be applied for on-line transformer moisture monitoring by implementing some sensors for relative moisture and temperature measurement. Taking into account that instruments for relative moisture and temperature measurement are available on the market, researches are necessary to improve the knowledge on moisture equilibrium in paper-oil insulation system and to expand equilibrium diagrams also to the ageing conditions of this system.

Taking into account that transformer thermal equilibrium state is rather rare the researches undertaken within the project frame were focused to an analysis of insulation dielectric response so that to estimate moisture content in transformer solid insulation.

The dielectric response of transformer insulation system depends on three main factors:

- Trafoboard and paper quality
- Oil quality
- Geometric configuration of system components

For a correct evaluation of the results it is necessary to know the above mentioned parameter variation depending on temperature and moisture.

Therefore, for the modelling necessary to evaluate correctly the moisture from transformer insulating systems it is necessary to have exact data from oil impregnated trafoboard/ paper specimens.

The aim of this paper is to present data about the dielectric response in a wide frequency range for new and artificially aged specimens.

Experiments by coulometric and by spectrometric methods on the same insulation system

The frequency answers of the paper specimens with a thickness of 60μm and of transformerboard specimens with a thickness of 1,5mm were investigated. Both cellulosic insulations are made by Weidmann AG, Switzerland.

The oil used was type NYNAS Nytro Taurus, Sweden.

In order to obtain a controlled moisture and number of oil particles, an oil regeneration installation using molecular filters for moisture absorption and paper filters for particle retention was designed.

The oil used to achieve the test specimens was brought to a moisture of 3ppm.

The dielectric answer in frequency range was performed with IDA 200 Insulation Diagnostics System manufactured by Programma Electric Inc. din SUA.

Karl Fischer coulometric titration technique was used to determine the moisture content in oil, oil impregnated paper and oil impregnated transformerboard. The equipment used was Karl Fischer CA 21 Titrator, Mitsubishi – Japan.

Moisture influence

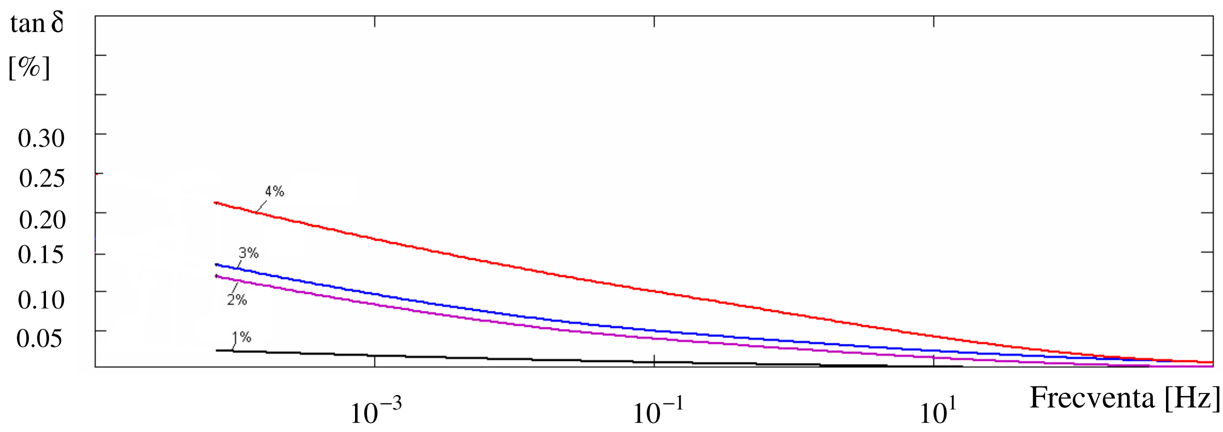

Fig.1. Mean dielectric response of transformerboard – oil insulation system with different moistures
Measuring temperature 50^{o}C

Temperature influence

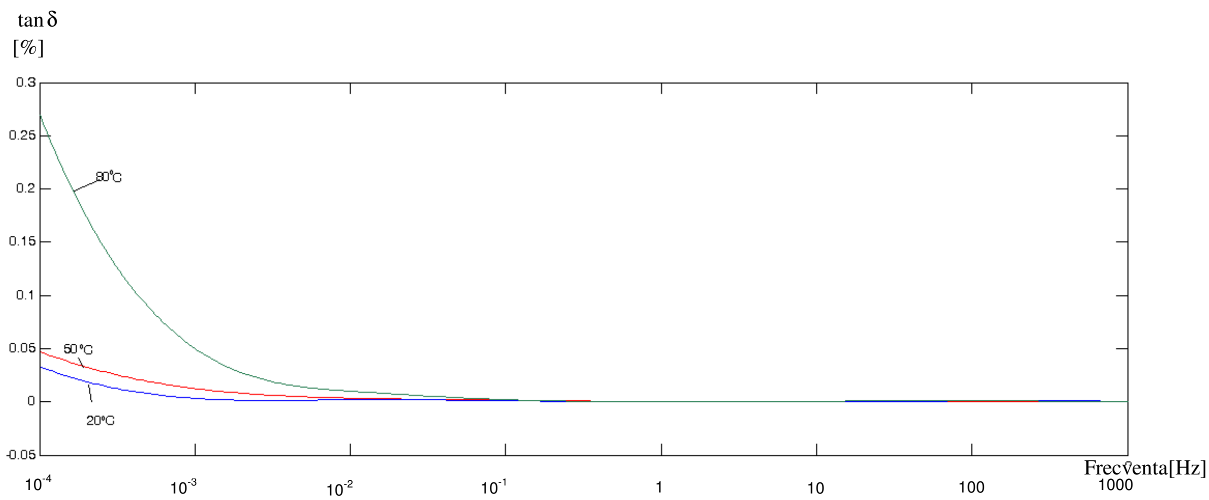

Fig.2. Dielectric response versus temperature for a transformerboard specimen impregnated with oil with a moisture of 1%
The measurement was performed at a temperature 50^{o}C

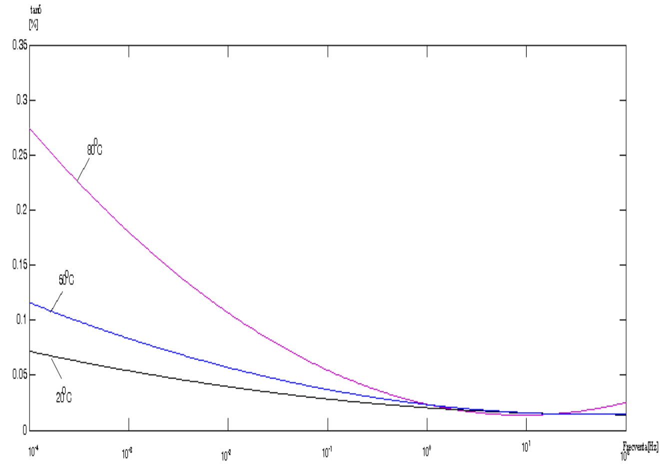

Fig.3 Dielectric answer versus temperature for a test specimen with a moisture of 2%

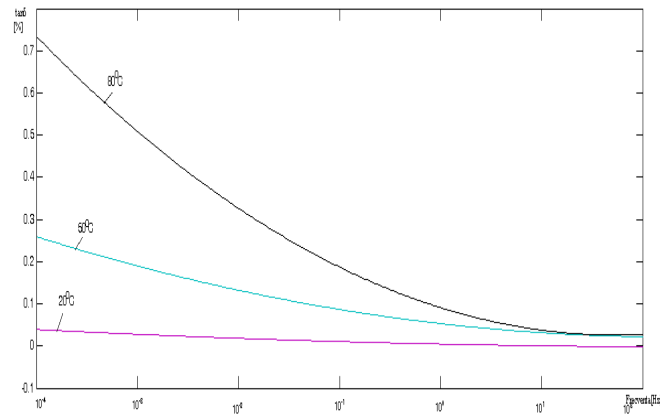

Fig.4 Dielectric answer versus temperature for a test specimen with a moisture of 1%

The measurement was performed at a temperature of 50°C

Thermal ageing for insulation models with linear response.

Following the conclusion that the frequency response of paper oil insulation is approximated by the response of transformerboard insulation system the measurements were directed to artificially aged transformerboard specimens.

14 oil impregnated transformerboard specimens, with a moisture of 0.5% checked by Karl Fischer titration method on one specimen, were prepared.

These specimens were distributed in 3 groups namely: 6 specimens at a temperature of 135°C, 4 specimens at a temperature of 110°C and 4 specimens at a temperature of 90°C.

The specimens were placed in steel sealed vessels filled with oil with a moisture content of 3ppm. Each of these vessels were placed in an oven programmed to maintain the above mentioned temperatures.

Dielectric loss factor measurements were performed with Megger Delta 2000 bridge at 50Hz according to the following program:

Specimens aged at a temperature of 135°C: 25, 50, 100, 150, 200 and 250 days.

Specimens aged at a temperature of 110°C: 100, 150, 200 and 250 days.

Specimens aged at a temperature of 90°C: 100, 150, 200 and 250 days.

Measurement results are presented in Fig.6.

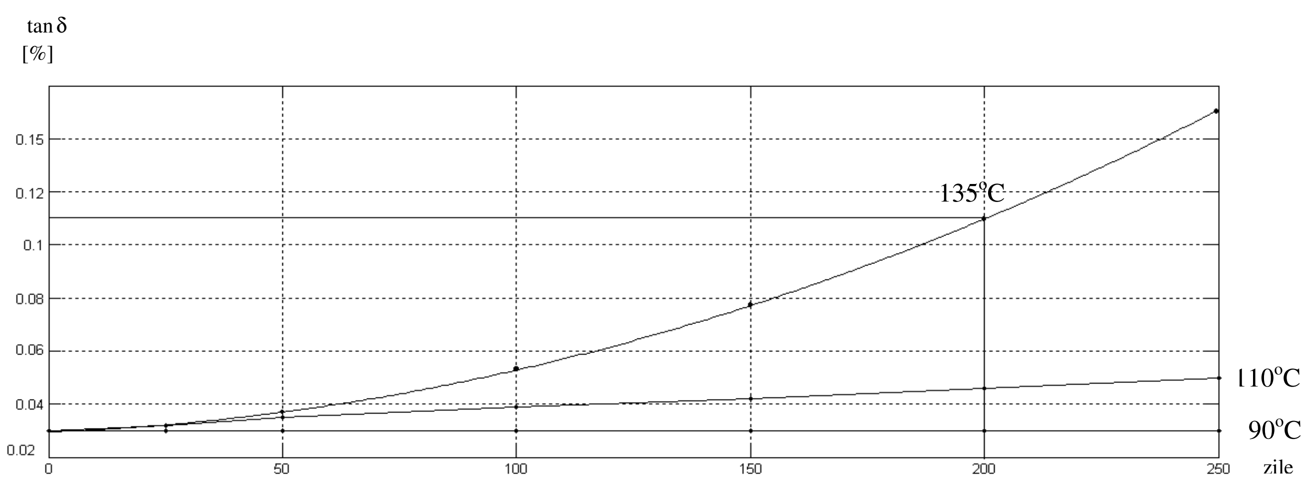

Fig.6. Loss factor dependence upon the ageing.
Measurement performed at a temperature of 50°C

The dielectric frequency response of a specimen identical with the 14 previously described ones, aged at a temperature of 90°C was measured and the result was measured with the response on a non thermally aged specimen.

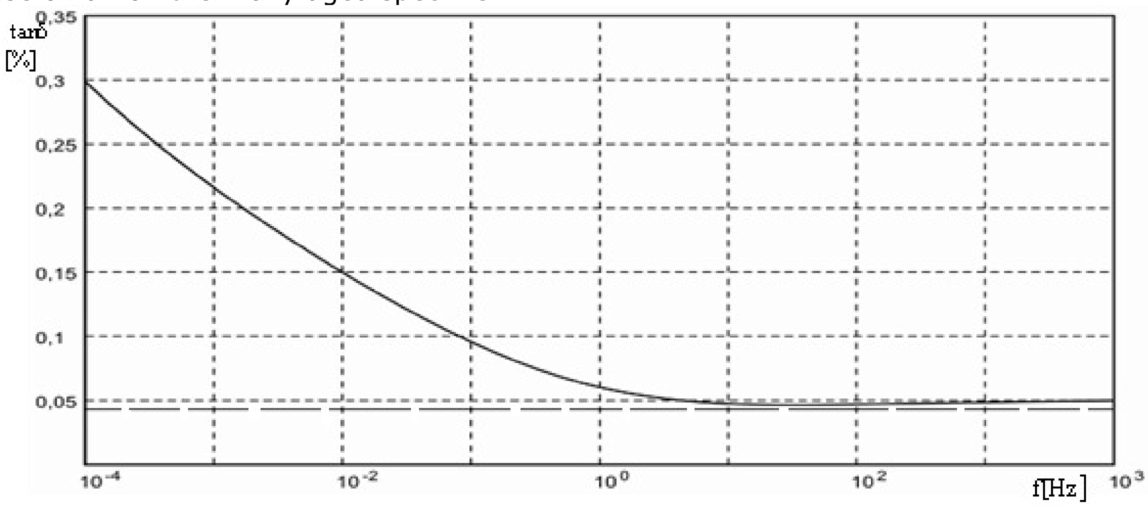

Fig. 7.Comparison of the frequency response of transformerboard-oil system for aged and non-aged cases; —— insulating system aged for 250 days at a temperature of 90°C --- non-aged insulating system; Systems moisture: 0,5%; Measuring temperature:50°C

The ageing process causes an increase of the loss factor in the frequency range 0,1mHz – 100Hz. The value of the dielectric losses in percentages at a frequency of 50Hz is comparable with the one measured with Megger bridge leading to the conclusion that insulation condition assessment according to tan delta magnitude at a frequency of 50Hz does not take into consideration the thermal ageing process.

Conclusions

The measurements performed in this study enabled us to obtain curves of dielectric response for transformerboard and oil impregnated paper for different moisture degrees in the frequency range $10^{-4}...10^{3}$Hz.

Moisture presence is rendered evident by the frequency response curves of the dielectric in the low frequencies range.

The frequency response of transformerboard insulation is similar to the paper one.

Temperature and ageing may be identified as transformer insulation depreciating factors due to a change of the frequency response in the low frequency range in comparison with the response of a new insulation at a temperature of 20 °C.

In order to obtain the standard curves resulted from the performed tests, the analytical relations for the real and imaginary part of the permittivity of transformerboard-oil insulation system will be drawn up.

In order to obtain the virtual model of a transformer insulation, it is necessary to measure the polarisation-depolarisation currents and based on the analytical relation describing them to determine the concentrated parameters of the equivalent electric network (ohmic resistance owed to insulating system conductivity, insulating system capacity and branches R_iC_i representing dielectric polarisation versus time for transformer insulating system.

Polarisation current conversion in loss factor tan δ is made using the analytical relation of the currents.

The virtual model of transformer insulation is necessary to correct the standard curves with each transformer geometry contribution. The last one will be evaluated from measured curve of the polarisation current.

This approach represents the innovative part of the project with a view to applying the dielectric spectroscopy for moisture assessment in power transformers.

Transformer insulation moisture assessment has applicability in the maintenance process of the transformers in operation and may represent a new solution applied in the drying process at transformer manufacturing factories.