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Analysis of humidity influence in a transformer model

***Abstract**. To prevent failure states of transformers, we perform different types of measurements. They shall illustrate a momentary state of the measured equipment and if necessary to draw attention in advance to changes of parameters, which have specific relationship to no-failure operation of the equipment. Water presence in oil transformer causes deterioration of its insulation and finally thermal defect of solid insulation*

***Streszczenie.** W artykule przedstawiono analizę wpływu wilgoci w transformatorach olejowych na przyspieszenie starzenia się materiałów izolacyjnych. Na podstawie analizy przewidzieć można potencjalne uszkodzenia i sposoby ich eliminacji poprzez zmianę parametrów transformatora. (**Badania i analiza wpływu wilgotności na podstawie modelu transformatora**)*

Keywords: Humidity, transformer, insulation resistance, dissipation factor
Słowa kluczowe: wilgotność, transformator, rezystancja izolacji, współczynnik rozproszenia.

Introduction

State of new insulation in operation mostly deteriorates due to surface contamination of insulators and insulation, their moistening and ageing. If no measures are taken in time so as to avoid this degradation, the situation usually results in damage of insulator and consequently in stop of electrical device. State of insulation of important electrical devices, such as transmission transformer which bring huge economic cost due to each stop in operation, needs to be checked regularly.

Water presence in oil transformer causes deterioration of its insulation and finally thermal defect of solid insulation. Dielectric warming can be so high that the temperature increase is out of control and transformer becomes dangerous for its surrounding.

Analysis of humidity by measuring of insulation resistance

The oldest and easiest method of inspecting the state of insulators is by means of insulation resistance measuring. Main disadvantage of this method is that insulation resistance does not only depend on state of insulation but also on its type and dimensions. Therefore, insulation resistance method can be used to evaluate the state of insulation of electric device only on the basis of previous experience with the same insulation on the same device. Moreover, this method enables to identify even small insulation degradation, if it passes through insulation layer e.g. oil – paper, but it can not identify whether the degradation is on the side of oil or paper.

The method is based on the following principle: change in insulator state causes change in time dependence of a current flowing through the insulator by direct voltage [1]. Current flowing through insulator consists of time-decreasing absorption element and stabilized element. More water content is there in insulation, more apparent increase of stabilized element of a current is observed comparing to absorption element. Absorption element of a current has a low effect on characteristics of time dependency in relation to current as well as resistance, and flattens with increasing humidity (Fig.1).

Utilizing this knowledge for evaluation of insulation state does not require determining full time dependence of a current. It is enough to determine value of a current (resistance) in two different moments from the time of connection to direct voltage. Ratio of these two values defines the state of insulation and is called polarizing index. Since it is a non-dimensional parameter, it does not depend on dimension of insulation. In USA polarizing index is measured after 1 and 10 minutes, in EU after 15 and 60 seconds.

Example of insulation resistance meter is in the Fig.2. It employs American and European norm of insulation resistance and polarizing index measurement.

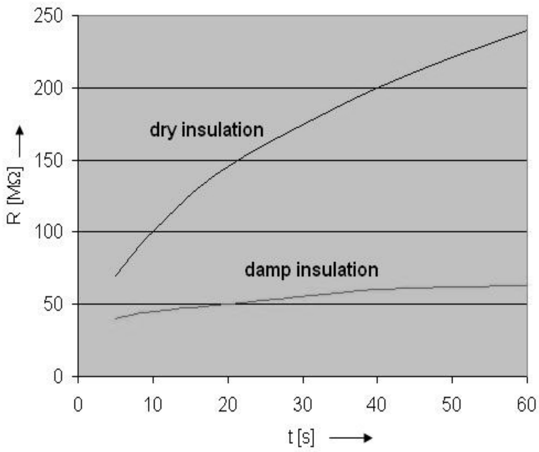

Fig.1 time dependence of the insulation resistance

So as to better illustrate change in values of polarizing index, it needs to be expressed by both elements of current – absorption element i_a and stabilized element i_∞

$$p_i = \frac{R_{60}}{R_{15}} = \frac{i_{a15} + i_\infty}{i_{a60} + i_\infty} \quad (1)$$

Humid and contaminated insulation is determined by i_∞, therefore numerator and denominator are very close values and their ration tends to 1. On the other hand, dry and clean insulation which is in good condition has stabilized current very low and time dependent element i_a is dominant. Thus, fraction value is noticeably higher than 1.

Fig.2 5 kV insulation resistance meter Megger MIT510 [7]

Absorption coefficient of new transformers before usage in operation should reach at least 1,3, usually value varies from 1,7 to 1,8.

The next advancement of the measurement of polarization index against isolation resistance is small temperature dependence. So we don't need temperature stabilization during whole measurement. Of course, during single measurement the temperature cannot be changed.

Humidity analysis by measurement of dissipation factor and capacity

The measurements of dissipation factor and capacities of transformer windings are used for additional determination of insulation quality as whole or only of some parts of transformer. The value of dissipation factor indicates presence of polar and ion compounds in oil and it also determinate the aging of oil. The degree of oil humidity can be measured by temperature dependence of tgδ [1].

The next method for determination of the degree of oil humidity (to 10 kHz – Fig.3) is a frequency dependence on the capacity of a transformer. In wet isolation, the absorption current is negligible to leakage current, which is independent on frequency. The stage of insulation can be determined as the ratio of capacities at two different frequencies. Frequencies 2 and 50 Hz are used in the case of transformer of class A. Values of the ratio: C_2/C_{50} before the dehydration are in the range between 1,3 and 2,3 and after the dehydration are around 1,2.

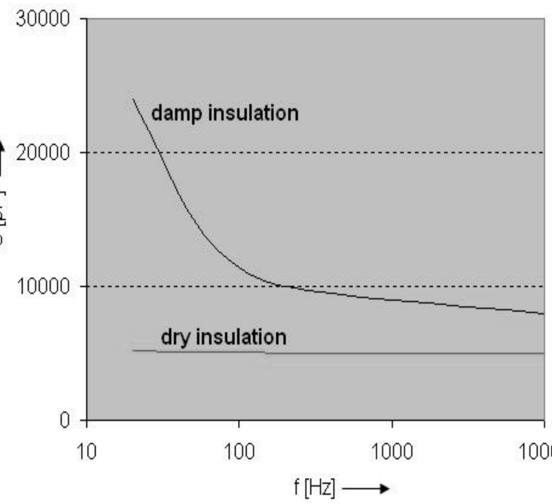

Fig.3 Frequency dependences of capacity at dry and damp insulation

The method on the determination of oil humidity was the measurement the value of capacity at various temperatures. The capacity is also the function of the absorption processes, which are characterized by their time constants, and distribution of absorption charges. This method is base on the determination of the ratio $\frac{C_{75}-C_{20}}{C_{20}}$, where C_{20} and C_{75} (or C_{80}) are capacities at 20 and 75 °C (or 80 °C). For some disadvantages of experiment this method was substitute by previous method base on the determination of the ratio C_2/C_{50}.

Description of experimental measurement

Experimental measurement on test transformer 60 VA, 220/52 V immersed in tank with transformer oil ITO 100 is provided as an example of safety and reliability inspection of transformer based on insulation humidity (Fig.4).

State of insulation was measured step by step - with no water content in oil and after water was added in amount of 0,05%; 0,15% and 0,25% of transformer tank volume filled with oil. The aim of experiment was to verify relation between increase in oil humidity and capacity-frequency characteristics (see Fig. 3).

Fig.4 Test transformer 60 VA, 220/52 V - immersed in tank with transformer oil and heating apparatus

In the second step, we measured frequency dependence of capacities at different temperatures in oil: 25, 35, 45, 55, 65 and 75 °C. The experimental measured values showed the connection between the increase of temperature and the change of frequency development of capacity (see measured values Fig.7).

We were measured capacities as function of oil temperature, applied frequency (to 10 kHz) and oil humidity (water content in oil). The results were compared with the value of insulation resistance. The measurements were automatic using RLC meter and computer.

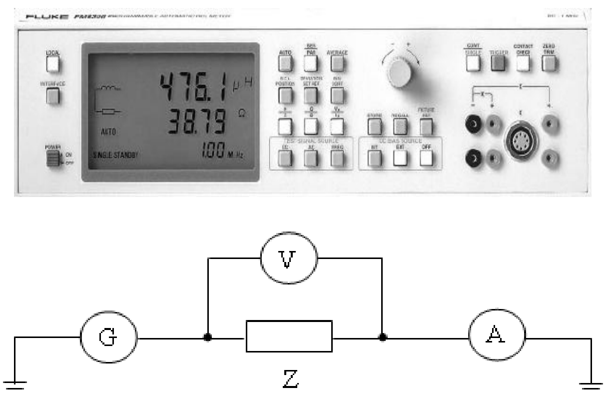

Fig.5 RLC meter [5] and setup of experiment

Computer program set the values of voltage and its frequencies for RLC meter and then it read electrical parameters of selected transformer, which were determined by RLC meter. All measured values were plotted using Excel.

Automatic RLC meter Fluke was used to measure dependence of capacity on frequency (Fig.5). Measuring principle of RLC meter is based on measuring selected voltage and current values of measured impedance between transformer's Z_X, see Fig.5.

Results of measurements

Based on measurements, we proved correctness, reliability and high sensitivity of the method for determining humidity in transformer. After water was added in amount of 0,05% of transformer tank volume filled with oil, we already experienced significant change in curve upwards (increase in humidity – Fig.6).

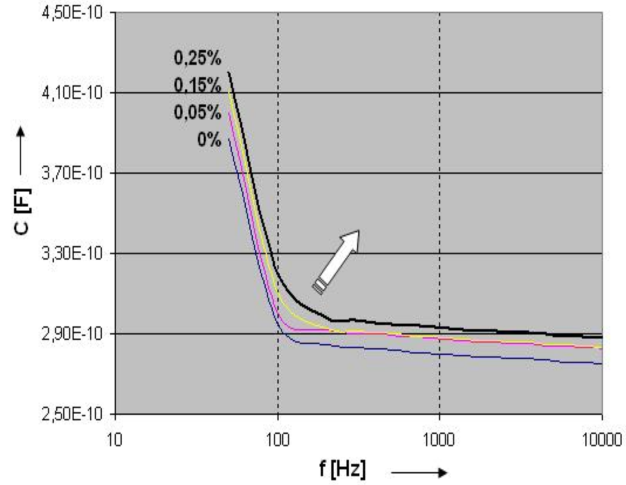

Fig.6 Frequency developments of capacity as function of water contents in oil: 0; 0,05; 0,15 and 0,25 % (curve increase with water content)

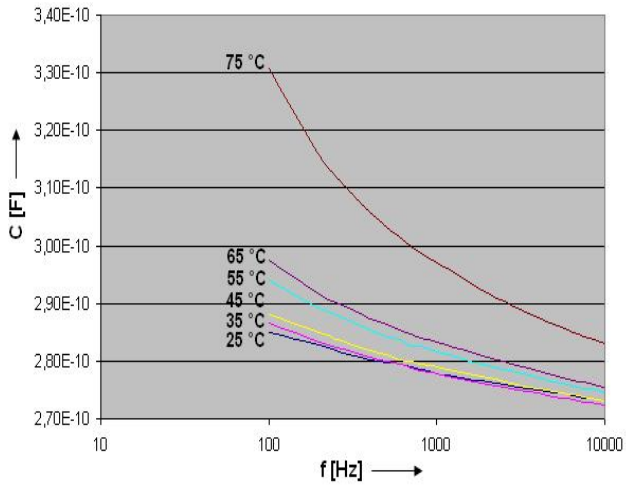

Fig.7 Frequency developments of capacity as function of oil temperature

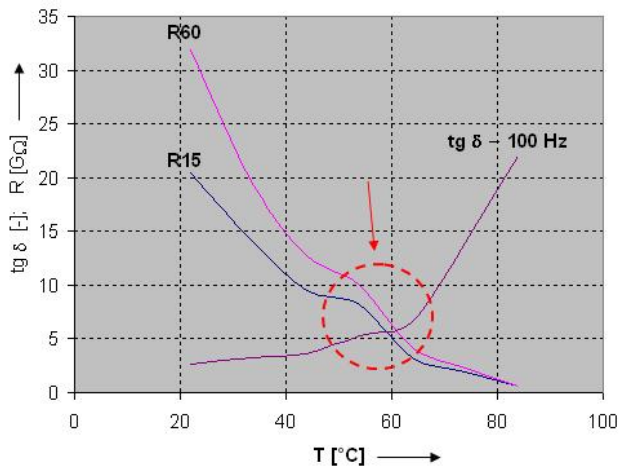

Fig.8 The temperature dependence of dissipation factor tg(δ), R15 and R60.

In the second step of measurements (see Fig.7) it is different frequency dependence of capacities at temperatures in oil: 25, 35, 45, 55, 65 and 75 °C. The experimental measured values we verified the connection between the increase of temperature and the change of frequency development of capacity, i.e. the capacity is also the function of the absorption processes, which are characterized by their time constants, and distribution of absorption charges.

In the last step we measured temperature dependence of the dissipation factor tg(δ) at 100 Hz (Fig.8). The ranges of temperatures were determined by normal stages of the transformer (20°C to 75°C) and the temperature 85°C (transformer thermal overload, the polarization index is close to 1). The dissipation factor increases with temperature and at the temperature around 50 ºC there is a visible step. These results were compared with the values of insulating resistances at 15 s and 60 s (R15 a R60 - Fig.8). The insulating resistances R15 and R60 decrease with temperature and at temperature over 75ºC resistance values are very similar. In the range of temperatures 40 – 60ºC there can be seen steps on the waveforms - represented by a dash circle.

Resultant similarities between insulation resistances and dissipation factor show that we verified the connection between both these methods.

Conclusion

On the base of measurements, we proved correctness and high sensitivity of both methods for determination of oil moisture in the transformer, i.e. the frequency monitoring of capacity to 10 kHz.

These methods can be utilized to determine insulation state during short term layoff of transformer and thus increase its reliability and safety.

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