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Solid insulation drying of 110 kV paper-oil instrument transformers

Gerards Gavrilovs[1], Sandra Vītoliņa[2]
[1]High Voltage Network (Riga, Latvia), [2]Riga Technical University (Riga, Latvia)
gerards.gavrilovs@latvenergo.lv, sandra.vitolina@rtu.lv

Abstract - **Influence of moisture on the instrument transformers' paper-oil insulation and its further maintenance is described in this paper. Improved insulation drying method using vacuum and temperature regulation with definite regulation algorithm of parameters is proposed and analyzed by comparing it with conventional drying method.**

I. INTRODUCTION

Insulating media consists of paper wrapped around the conductors in the coils plus mineral oil and pressboard to isolate the coils from ground. From the moment an instrument transformer is placed in service, both the solid and liquid insulation begin a slow but irreversible process of degradation.

Paper and pressboard are composed primarily of cellulose, which is a naturally occurring polymer. As the cellulose molecule degrades, the polymer chain ruptures and the average number of repeating units in each cellulose molecule decreases. With this reduction in the degree of polymerization of cellulose, there is a decrease in the mechanical strength of the cellulose as well as a change in brittleness and color.

Cellulose has a great affinity for holding water. Water that is held in the paper can migrate into the oil as the temperature of the system increases or the reverse as the temperature of the system decreases.

Moisture can be in the insulation when it is delivered from the factory. If the instrument transformer is opened for inspection, the isolation can absorb moisture from the atmosphere. Moisture is also formed by the degradation of insulation as the instrument transformer ages. Even if the instrument transformer was perfectly sealed, the moisture concentration of the paper would continue to increase. The rate of generation of water is determined primarily by the oxygen content of the oil and the temperature of the system. Increases in each of these factors increase the rate of water generation and with this the exploitation life is decreasing too.

Mostly the purchase of new instrument transformers is economic unprofitable, which leads to a conclusion, that effective maintenance of instrument transformers must be ensured. Well timed solid insulation drying of instrument transformers is one of the maintenance techniques ensuring increase of unit's lifetime.

II. BASIC PRINCIPLES OF INSULATION DRYING

Drying is a mass transfer process resulting in the removal of water moisture or moisture from another solvent, by evaporation from a solid, semi-solid or liquid to end in a solid state. To achieve this, there must be a source of heat, and a sink of the vapor thus produced [1].

In the most common case, a gas stream, e.g., air, applies the heat by convection and carries away the vapor as humidity. Other possibilities are vacuum drying, where heat is supplied by contact conduction or radiation (or microwaves-oven) while the produced vapor is removed by the vacuum system. Another indirect technique is drum drying, where a heated surface is used to provide the energy and aspirators draw the vapor outside the room.

Drying of solids can be brought about by storing the solid over a drying agent such as phosphorus pentoxide (P2O5) or silica gel, storing in a drying oven/vacuum-drying oven, heating under a high vacuum or in a drying pistol, or to remove trace amounts of water, simply storing the solid in a glove box that has a dry atmosphere.

The one of many winding insulation drying methods is realized with using drying process in the oven by vacuum pump. In this case the instrument transformer is disjointed and its winding is put in electrical oven. The electrical oven must be heated to an initial temperature of 70÷80 °C as well as degassing process must be done before putting the winding of instrument transformer inside. Also following environmental conditions must be assured: air temperature not less 20 °C and relative air humidity less than 75 %, when disjointing of the instrument transformer is performed.

Absorption water is especially popular degassing product in the artificial vacuum system due to absorption materials in the vacuum chamber. Degassing water can condense. The vacuum chamber system should be clean from organic substance to minimize degassing process.

Windings insulation drying process can be considered in two stages:

1. Vaporization of moisture from the surface of solid isolation;
2. Followed by moisture displacement inside solid isolation.

Vaporization of moisture happens if there is the pressure difference between steam pressure P_S with isolation surface S and environment steam partial pressure P_0. Thus instrument transformer winding drying process occurs if following convention is true: $P_S > P_0$, since if $P_S \leq P_0$ degassing process is negative [2]. Increasing temperature T and decreasing environment pressure leads to decrease of environment partial pressure P_0 and air relative humidity.

There are two types of moisture displacement inside solid insulation:

1. Moisture conduction result i_U which can be described by (1) – all types of moisture displacement in direction of moisture increasing by constant volume (such as diffusion, capillary displacement proportional to moisture gradient etc.);
2. Moisture thermoconduction i_T – moisture displacement in warm stream direction which is determined with temperature decreasing (2).

$$i_U = - k\gamma_0\Delta U; \quad (1)$$

$$i_T = - k\gamma_0\delta\Delta t; \quad (2)$$

$$i = - k\gamma_0(\Delta U + \delta\Delta t), \quad (3)$$

where k – moisture conduction rate;
γ_0 – H_2O density;
δ – moisture thermoconduction rate of material;
ΔU – moisture gradient;
Δt – thermoconduction gradient.

If ΔU and Δt are with opposite direction, then total moisture stream i as shown in (3) is equivalent to the difference of two items: i_U and i_T. So this is the drying process, where one of the moisture conduction types disturbs another. That means, if the winding of instrument transformer is heated with exterior source at low vacuum, it can bring to ingress of moisture inside solid insulation.

III. COMPARISON OF TWO DRYING METHODS FOR INSTRUMENT TRANSFORMER'S WINDINGS

There are many methods of solid material drying [1]. There are two common methods of instrument transformer winding drying process are described in this paper. The winding putted in the special oven and dried by following methods:

a. Exterior heating method with constant value of temperature and vacuum;
b. Exterior heating method with temperature and vacuum regulation.

In succession get a look each method:

A. Exterior heating method with constant value of temperature and vacuum

This is a conventional instrument transformer's insulation drying method [3] that was with good results practically used in HC "High Voltage Network" till 2005. This method is described here on the base of example for current transformer windings, because they have thicker layers of solid insulation and are more demonstrative for analysis of absorption rate.

Parameters characterizing the moisture level of current transformer are measured before drying and measuring results fixed for further comparison. Mostly drying is applied to current transformers with dielectric loss angle tangent $tg\delta \geq 2.5$ %. The winding of current transformer is dried at constant temperature about $75 \div 90$ °C and constant maximum as possible vacuum. The winding is measured each 8 hours: the measurements of dielectric loss and resistance of solid insulation (absorption rate) are performed. The typical curve of dielectric loss angle changes during drying process, using exterior heating method with constant value of temperature and vacuum, is shown in Fig. 1. The moment of dielectric loss angle improvement is visible and mostly as the result we have solid insulation with dielectric loss angle $tg\delta \leq 1.0\%$. The improvement of dielectric loss angle $tg\delta$ value depends on solid insulation weight and moisture extent, but normally it is gradually downward curve.

As mentioned before, the value of solid insulation resistance R60 is measured also. Fig.2 shows insulation resistance's value changes during drying process, using exterior heating method with constant value of temperature and vacuum. It is visible, that improvement of solid insulation resistance value is reached approximately the in 3rd day of drying. The drying process, is completed if there are no changes in the resistance value curve during last 6 hours.

Above 65 % of all checked instrument transformers have the same curves after drying process. Drying process using exterior heating method with constant temperature and vacuum continues comparatively long time (≈ 72 hours) [3].

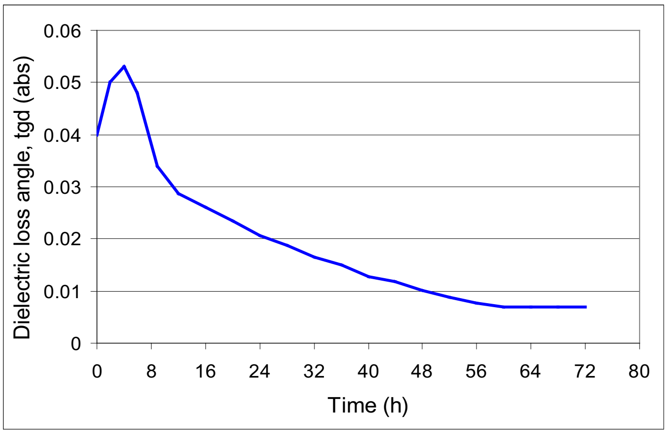

Fig. 1. Changes of insulation dielectric loss angle tg δ during drying process, using exterior heating method with constant value of temperature and vacuum

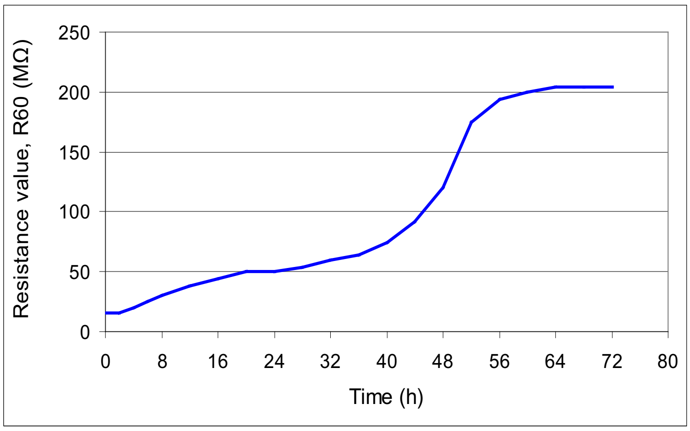

Fig. 2. Changes of solid isolation resistance value during drying process, using exterior heating method with const value of temperature and vacuum

If the curves gained during drying process matches typical ones it means that drying process was well done.

B. Exterior heating method with temperature and vacuum regulation

Previous insulation drying method practically showed good results but it was time-consuming work. Therefore "High Voltage Network" maintenance staff had an aim to decrease this time and made several experiments using the same drying process equipments. As a result accelerated drying method was developed in which value of temperature and vacuum must be regulated during drying process.

During accelerated drying process the vacuum must be ensured at maximum value in several time intervals, for maintenance time economizing. The temperature value of exterior heater is also adjusted and depends on quantity of solid insulation and construction of winding. The temperature of exterior heater oscillates from 80 °C to 140 °C. The main steps of this method are shown in Fig. 3, and each step is described in Table 1.

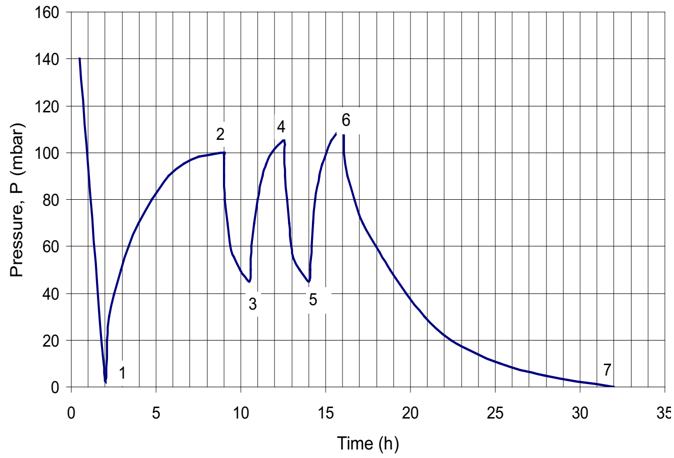

Fig. 3. Vacuum regulation algorithm

TABLE I
DESCRIPTION OF DRYING PROCESS

Interval	Description
Till 1	The oven is under vacuum at least 2 hours
1 - 2	Interval continues 7 hours. Winding is heated till 80 – 90 °C. Vacuum 100 mbar. The first step of accelerated method starts at point 2.
2 - 3	Pressure of vacuum is decreased till approximately 45 mbar in 1.5 hours.
3 - 4	Interval continues 2 hours. Temperature increases 100 – 110 °C and vacuum pressure is increased till 100 – 105 mbar.
4 - 5	Interval continues 1.5 hours. Vacuum pressure is the same as in interval 2 – 3 respectively 45 mbar. Temperature level is as described in interval 3 - 4.
5 - 6	Interval continues 2.0 hours. Vacuum pressure is again increased till 100 – 110 mbar and temperature is increased to 120 °C and higher.
6 - 7	Temperature value is 120 °C. Till point 7 the value of vacuum must reach maximum. This time can differ; it depends on moisture grade of solid insulation.

Several aspects of this method must be regarded:

– If vacuum pressure is 0.1÷1 mmHg and temperature is equal or higher than 200 °C disintegration of paper can start;
– Hydrolyzes disintegration process can start at 150 °C, if moisture is located in paper.

The curve of dielectric loss angle tgδ changes, using exterior heating method with temperature and vacuum regulation, is shown on Fig. 4. Above 65 % of all checked instrument transformers after drying process have the same curve.

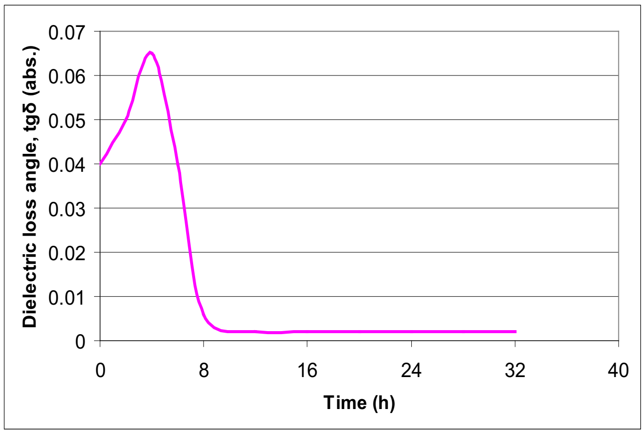

Fig. 4. Changes of insulation dielectric loss angle tgδ during drying process, using exterior heating method with temperature and vacuum regulation

After 16 – 32 hours time interval the heating process can be stopped and the control measurements can be done. Practical experience allows concluding that instrument transformers with solid insulation weight till 100 kg with dielectric loss $tg\delta \geq 2.5\%$ and moisture grade $R_m > 3.5\%$ before drying after accelerated heating process have following parameters: $tg\delta = 0.2 \div 0.35\%$, $R_m \approx 0.5\%$. It has to be mentioned that the value of tgδ must be fixed at f = 50 Hz .

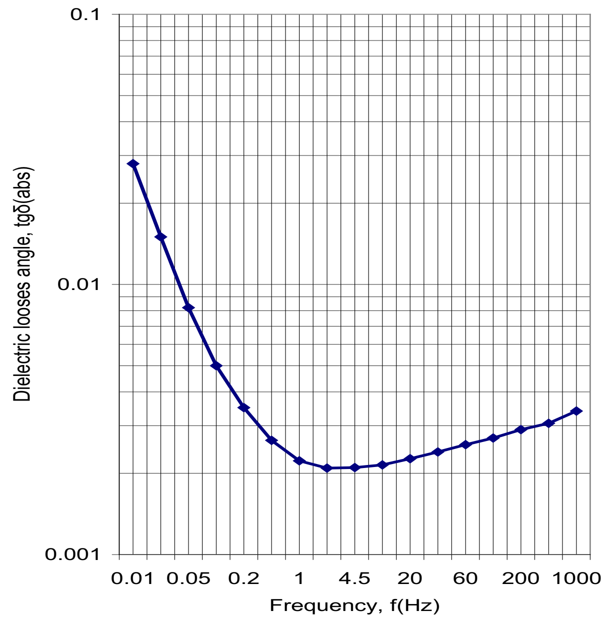

Fig. 5. Dielectric loss angle curve as function of frequency obtained by electronic measuring device

Usually tgδ is measured with Shering bridge and determining capacitance, but recently many laboratories mostly use an electronic dielectric loss measuring devices with wide frequency measuring diapason, which helps to reduce the influence of network frequency to dielectric loss tgδ measurements. An example of determining tgδ at different frequencies is shown in Fig. 5.

Fig. 6 shows insulation resistance's value changes during drying process, using exterior heating method with temperature and vacuum regulation. This curve indicates effectiveness of this method. It is obvious that after approximately 8 hours of drying the resistance value of solid insulation achieves the maximum. So it means that the drying process continues 6 hours and after that can be stopped.

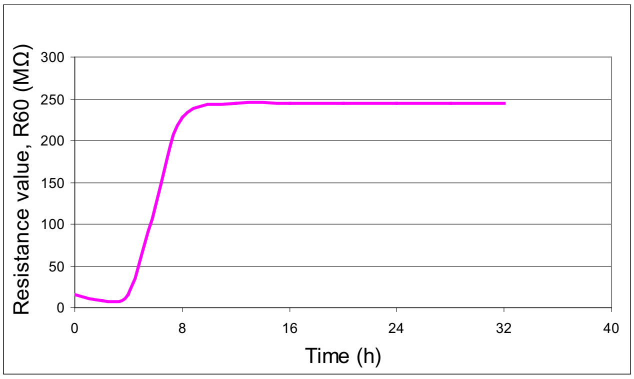

Fig. 6. Changes of solid insulation resistance value during drying process, using exterior heating method with temperature and vacuum regulation

C. Comparative assessment of two drying processes

The accordant curves of both above mentioned drying methods are compared in Fig. 7 and Fig. 8.

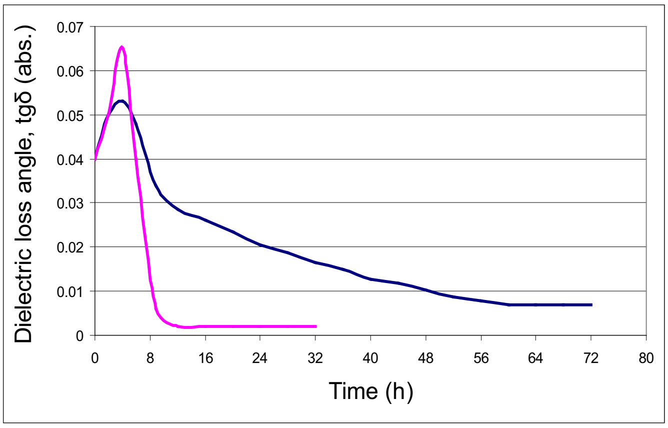

Fig. 7. Comparison of dielectric loss angle tgδ curves of both drying methods

Both figures (Fig. 7 and Fig. 8) shows that drying process, using exterior heating method with temperature and vacuum regulation, is at least two times faster than drying process, using exterior heating method with constant value of temperature and vacuum. Furthermore the drying quality is better for the drying process, using exterior heating method with temperature and vacuum regulation, since it ensures superior insulation parameters (higher insulation resistance and smaller tgδ) afterwards.

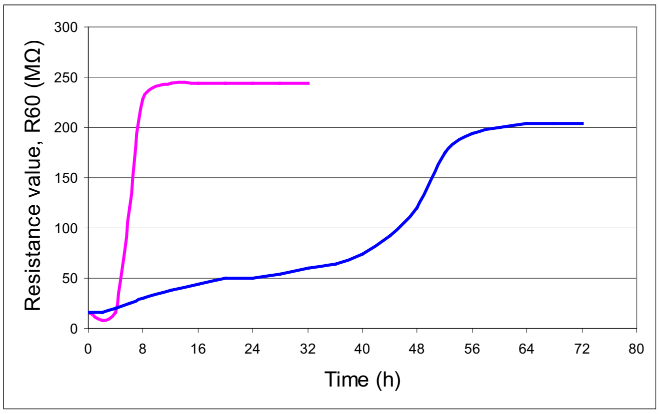

Fig. 8. Comparison of solid insulation resistance values of both drying methods

IV. CONCLUSIONS

Stated material allows concluding that proposed insulation drying method using temperature and vacuum regulation:

1. Considerably reduces drying time (at least 4 times), thereby exploiting fully the same drying equipment;
2. Ensures superior insulation parameters (insulation resistance and tgδ) afterwards in comparison with conventional drying method with constant value of vacuum and temperature.

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