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Aspects regarding the Calculation of the Dielectric Loss Angle Tangent between the Windings of a Rated 40 MVA Transformer

The paper aims to identify how to determine the dielectric loss angle tangent of the electric transformers from the transformer stations. Autors of the paper managed a case study on the dielectric established between high respectively medium voltage windings of an electrical rated 40 MVA transformer.

***Keywords**: dielectrics, dielectric losses, dielectric measurements, insulation resistance*

1. Introduction

It is known that by dielectrics exposure to electric field action a process of converting electrical power into heat occurs. This power is called power loss in the dielectric or dielectric loss and has two components [1-2]:

- a component that is due to the electrical conductivity of the dielectric and it is proportional to the square of the current of electrically conductive i_{cond} and in substance it represents the power losses by the Joule effect. This component appears in both DC and AC electric fields.
- the second component of power loss occurs only on variable electric field. It represents in essence the losses due to friction between the dielectric particles that occurs as they reposition in the direct sense of the polarization field.

It must be noted that visible power losses are determined by relaxation polarizations. Polarization of electrons and ions are practically without losses [1-2].

The paper has considered the fact that, starting from simple to complex, it is possible to formulate a general way of determining the losses in the dielectric capacity established between the active conductors of electrical cable lines (where the calculating of the dielectric cables losses is required in the design phase) and the losses in the capacities dielectric established between the windings of the power transformers and their tank. The calculation of percentage losses in the dielectric capacities established between the windings of the power transformers and their tank is one of the tests with a major impact on their reliability and failure prevention schemes. To determine the power losses in the dielectrics specific to any electrical capacity it is required to know the phase shift angle δ, which, if it is considered as argument for the trigonometric function, „tg", it is obtained the so-called tg(δ) "tangent of the dielectric loss angle". As will be seen in the detailed presentation of how to determine the losses in the dielectric of the condensers, the value of the of phase shift angle influences directly the value of the power losses.

2. The determination of the dielectric loss angle tangent between the windings of a 40 MVA rated transformer

The power transformers operating in distribution and transmission grids have the insulation systems made of cellulose paper and mineral oil. The mineral oil represents 70–80% of the insulation system weight which means, for example, about 80.000 liters in the case of a 150 MVA transformer [3].

The insulation fluid in power transformers performs two main functions: insulating and cooling. The highly refined mineral oils (transformer oils), typically used as insulating fluids, have low thermal conductivity and thus perform low cooling efficiency [4].

It was shown that the heat transfer in electromagnetic devices can be substantially improved by using magnetic fluids consisting of magnetic nanoparticles suspended in transformer oils [4].

A magnetic nanofluid, so-called ferrofluid is a stabilized colloidal material which contains nanoparticles within a carrier fluid. A ferrofluid has three main constituents: ferromagnetic particles such as magnetite and composite ferrite, a surfactant such as oleic acid, citric acid, and tetramethylammonium hydroxide, to keep the magnetic nanoparticles from clumping and a base liquid such as water or oil. The surfactant coats the ferromagnetic particles, each of which has a diameter of about 10 nm. This prevents coagulation and keeps the particles evenly dispersed throughout the base liquid. Its dispersibility remains further stable when the magnetic field is applied adequately [4-7].

The nanoparticles accumulate over time on the electro-insulating oil in the transformer tank and can be detected by means of chromatographic analysis and indirectly, by a higher value of the loss angle tangent in the dielectric. Large power transformers and reactors play a fundamental role in the production, transmission, distribution and industrial use of electric energy. Failures in transformers often have social, economic and especially environmental consequences, due to possible fire and/or explosion resulting in the introduction of pollutants in all the environment compartments. Mineral oil, the most common insulating liquid used for transformer impregnation, belongs to the class of dangerous waste [7-10].

Since large power transformers are the most expensive and strategically important components of any power generator and transmission system, their reliability is crucially important for the energy system operation. Most serious failures of a large power transformer are due to the insulation breakdown.

The partial discharge (PD) which damages insulation because of the gradual erosion is the major source of the insulation failure. Techniques for locating a PD source are of the major importance in both the maintenance and repair of a transformer .In the previous projects, the discharge between the winding of the transformer and the ground has been analyzed [8–10].

The paper presents a case study on how to determine the loss angle tangent tg(δ) in the dielectric between the high and low voltage windings respectively metallic tank (connected to the grounding ring) for an 40 MVA rated transformer. Own service transformer block whose nominal apparent power of 40 MVA converts electrical energy produced by the synchronous generator of 388 MVA at a voltage level of 24 kV, to a step voltage of 6 kV for supply their own services, entering in the configuration of technological flow scheme of a group of 330 MW electric power (388 MVA). Current regulations define maximum allowable limits that must followed in operating transformers in electric transformer stations, to prevent dangerous operating regimes, which can result in power swings in the power grid and material loss by damaging transformers power. In the case of power plants producing electricity, these losses are higher due to the fact that units are disconnect from the power grid for long periods necessary for the repair or replacement of defective transformer [11-16].

Based on these considerations, it can be concluded that a continuous monitoring of insulation resistance, ohmic resistance and dielectric loss tangent angle is required. These values must be recorded continuously in a data base and their variation against time must be monitored in order to prevent faults and increase the life of the transformer. The results of insulation resistance, ohmic resistance and dielectric loss angle tangent measurements can be recorded on a yearly basis, by drawing a variation plot which represents their variation in time. Determination of dielectric loss angle tangent determination of dielectric loss angle tangent is an operation in a set of prophylactic checks that aim to prevent faults in power transformers generated by changes of the capacitance between the transformer windings and transformer tank [11-16].

For power transformers and autotransformers with high powers, the measurement of the loss angle tangent in the dielectric of the winding to during the commissioning will be carried out at two temperature values: 50°C ± 5° C and $T_{factory}$ ± 5°C or at room temperature, if this is higher than $T_{factory}$ ± 5°C ($T_{factory}$ - the temperature at which insulation parameters were measured in the factory, value indicated by the factory test report) [16]. The loss tangent measurements for the two windings of the 40 MVA power transformer consists of the following measurements:

- high-voltage winding to low-voltage windings, which is connected to the earthing ring HV- (LV+Ground)

- low-voltage winding to high-voltage winding, which is connected to earth belt LV - (HV + Ground)

The values of the loss angle tangent determined for the two windings are presented in Table 1:

Table 1. The Measured Dielectric Loss Angle Tangent

Parameter	Determined variant connection winding	The measured value [%]	Factory temperature[^oC]	Measured temperature [^oC]
$tg(\delta_m)$	HV-(LV+ground)	1,06	22	25
$tg(\delta_m)$	LV–(HV+ground)	1,42	22	25

The value of the dielectric loss angle tangent of the two windings of the power transformer, according to the regulations in force it must be recalculated based on a correction factor that is determined by the temperature variation Δt of the temperature at which measurements were made in the factory and the temperature at which the measurements were carried out. Correction coefficient values of the dielectric loss tangent of the angle of winding of the transformer are measured and shown in Table 2 [16]:

Table 2. The correction coefficient values according to temperature

Δt	1	2	3	4	5	10	15	20	25
k	1,03	1,06	1,09	1,12	1,15	1,25	1,51	1,75	2

Based on the measured values and taking into account the correction coefficient that accounts for temperature variation the recalculated value of the dielectric loss angle tangent is determined using the expression [16]:

$$tg(\delta_r) = \frac{tg(\delta_m)}{k} \quad (1)$$

From table 2 is apparent that the change in temperature is given by:

$\Delta t = 25^0 - 22^0 = 3^0C$

Based on this value we choose in Table 2 correction coefficient of dielectric loss tangent as being equal to 1.09.Recalculated value of the dielectric loss angle tangent of the two windings associated to power transformer will become:

For HV version- (LV + ground): $tg(\delta_r) = \frac{1.06}{1.09} = 0.9724\%$

For LV version– (HV + ground): $tg(\delta_r) = \frac{1.42}{1.09} = 1.303\%$

Table 3 presents the values of loss angle tangent in the dielectric of the windings of power transformer recalculated at the measured temperature value.

Table 3. Values of dielectric loss angle tangent recalculated

Parameter	Connection variant of the winding	Recalculated value[%]	Factory temperature [°C]	Measured temperature [°C]
$tg(\delta_r)$	HV –LV+ground	0,9724	22	25
$tg(\delta_r)$	LV - HV+ground	1,303	22	25

To determine the allowable limit of the dielectric loss tangent of the transformer windings at a temperature of 25ºC, we perform interpolation with the permissible limit values shown in Table 4 for rated voltage of 24 kV related to the 40 MVA power transformer.

Table 4. Values for tg(δ)

The rated voltage of the windings U_n[kV]	The value tg(δ) for a temperature of 20ºC	The value tg(δ) for a temperature of 50ºC
< 10	4 %	11 %
10-60	2,5 %	7 %
110-220	2,5 %	7 %
400	1,5 %	2,5 %

For electrical transformers in service, the maximum allowed values of loss angle tangent in the dielectric at the winding insulation temperatures of 20ºC or 50ºC are shown in Table 4 [16]. As it can be seen from Table 4, the nominal voltage of the transformer falls within the range of 10-60 kV.

By interpolation of 20ºC, 25ºC and 50ºC temperatures correlated with the corresponding values tg(δ) 2.5% and 7% yield allowed limit value transformer tg(δ) analyzed as 3.75%. It follows that the recalculated values for the dielectric loss tangent of the angle of the two windings (0.9724% and 1.303%) is well below the maximum allowable operating (3.75%, corresponding to point A on the tg(δ) curve).

From Figure 3 the following can be observed:

- Point *A* on tg(δ) is the locus of the intersection between measured value of the temperature (25°C) and the recalculated value of dielectric loss angle tangent (3.75%);
- The recalculated tg(δ) value in the variant LV–(HV+ground) is represented in the point A' situated on the curve 2 which is the locus of the intersection between the measured temperature (25°C) and the recalculated value of the dielectric loss angle tangent 1.303%;
- The recalculated value of $tg(\delta_r)$ in the variant HV-(LV+ground) is represented in point A'' situated on curve 3, which is the locus of the intersection between measured value of the temperature (25°C) and the recalculated value of the dielectric loss angle tangent (0.9724%). It appears that the recalculated

values for the dielectric loss tangent of the angle of the two windings (0.9724 % and 1.303 %) is well below the maximum allowable operating.

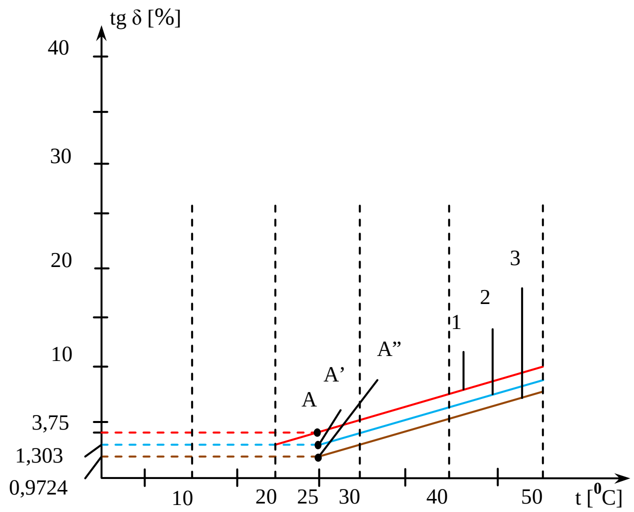

Figure 3. Curve tg(δ) in the power transformer dielectric

Measurement of dielectric loss tangent in the two windings tg(δ) is performed at an relative humidity ambient less than 80% [16].

The measurement is performed after checking with the megohmeter insulation resistance and the absorption coefficient, also this measurement is performed before the sample is tested with increased voltage [16].

3. Conclusion

Dielectrics that have relatively low value losses of the tangent of the angle δ tg(δ) are characterized by relatively low power losses and dielectrics that have relatively large value losses of the angle δ tg(δ) are characterized by relatively high power losses.

The maximum values for the power losses in dielectrics due to their frequency of oscillation achieved by dielectric particles, which depends on temperature.

The value of dielectric loss tangent winding transformers depends on the correction coefficient determined by the temperature variation of the temperature at which the measurement was performed and the factory temperature.

The recalculated values of dielectric loss tangent of the angle of the two windings (0.9724% and 1.303%) is well below the maximum allowable operating conditions (3.75%).

It can be noticed from Figure 3 that tg(δ) decreases proportionally with the increase of the voltage (for HV winding tg(δ) = 0.9724% and for LV winding tg(δ) =1.303%).

Determination of the dielectric loss tangent winding power transformers is a preventive check with major impact on operational reliability and failure prevention schemes for this type of transformers.

In this sense requires a planned inspection of these transformers, followed by preparation of the test papers to record the values obtained for each due date in order to monitorize the progress during winding insulation level, which depends directly by the dielectric established between windings.

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