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Determination of the Power Transformer Efficiency Monitoring the Electrical Insulation Parameters

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Abstract

The paper presents the monitoring methods for the insulating state of power transformers. For a transformer with oil-paper insulation system the ageing curves was obtained using the criterion of insulating resistance, and the correction coefficients for directly obtained the real insulation resistance. All these measurements are realized on the same transformer with S = 250 MVA power and 400/110/20 kV voltages. Using graphical method, the lifetime of insulation, respectively, of transformer is possible to be quickly obtained.

1. Introduction

The continuous diversification of working conditions of the power transformers and the increasing of the solicitations of the power electric equipments needs an exactly acknowledgement of materials characteristics and their evolution in time. On the other side the customers won't to estimate their life time.
In power transformers the most sensitive component at electrical and thermal solicitation is the insulation system. The paper insulating power transformers represent actually the majority in the system having a relative high life time cycle. Monitoring the state of the insulation systems of the transformers represents an important method for the unscheduled and undesired shutdown of them.
The paper-oil system was studied for about a century ago and many international symposiums (CIGRE, INSUCON etc.) and reviews has the objective of «diagnosis of the insulation state ».
The high price of the transformer, the impossibility of local repair on the place, the high price of reparation, all are restrictions exceeded by adequate monitoring methods.
These methods are:

Gases analyzing method analyzes the gases dissolution in oil for the identification of insulation aging process. With the increasing of temperature the composition of gases is modified in the increasing sense and is possible to be putted in evidence analyzing the dissolute gases in oil.

Prophylactic measuring method permits the detection of insulation state and even to establish a prognostic of degradation of insulation. Measured parameters are: insulation resistance, insulation loosing factor, insulation capacity, dielectric rigidity and the loosing factor for transformer oil, neutralization index of the oil. These are specific criteria for the insulation degradation, noted with *p*. Analyzing the aging diagrams $p=f(t)$, it is possible to estimate the life time of insulation and so of the transformer.

2. Insulation Resistance Measurement

For the transformer, the insulation resistance is determined measuring the resistance in d.c. current between every coil and the tank and between two coils.
Depending on the humidity degree of the insulation, the values R_{60} measured after 60 seconds and R_{15} measured after 15 seconds are different. The ratio between these two values is called absorption coefficient.
For dry insulation the current decreases quickly for a maximum value giving high values for the absorption coefficient.
For wet insulation the current decrease is not quickly resulting small values for the absorption coefficient.
Generally the insulation resistance R_{60} and the absorption coefficient k_{abs} are parameters appreciating the insulation state of the insulation system.
One other degradation criteria is the insulation resistance at 20˚C, noted R_{20}. This value could be obtained using a correction factor k_{cor}:

$$R_{20} = k_{cor} \cdot R_T , \quad (1)$$

where R_T is the insulation resistance measured at *T* temperature [8].
So, the insulation life time τ, defined as that time interval in which the degradation criteria *p* (in this case R_{20}), achieves the limit value p_{lim}, called end of life criteria, under this value the insulation is not reliable.

3. Experimental determinations

Keywords: *mobile robot, Kalman filter*

Measurements of insulation resistance R_{60} was effectuated for a three phases transformer, in oil, forced cooled with S = 250 MVA and voltages 400/110/20 kV.
For a period of 15 years it was measured:

- Insulation resistances between phases coils of 400 kV and 110 kV and 20 kV coils connected together to the earth (noted *R*21);
- Insulation resistances between 110 kV coils and phases coils 400 and 20 kV connected together to the earth (noted *R*22);
- Insulation resistances between 20 kV coils and phases coils 400 and 110 kV connected together to the earth (noted *R*23).

Studying insulation resistance according with time and temperature was established the function $Rij_{20}(T,t)$. For establishing the correction coefficient k_{cor} was effectuated supplementary measurement of *R*21 for different temperatures *T*, for two days (the transformer being disconnected from the network. The results are presented in fig.1.

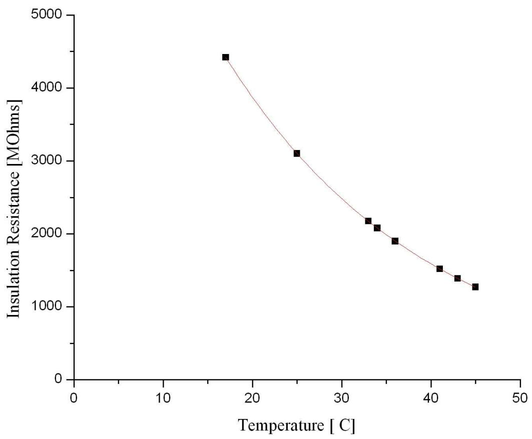
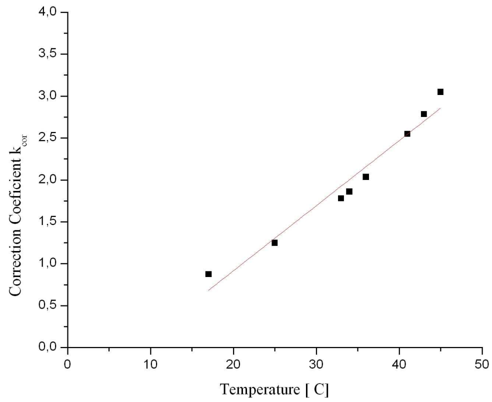


Fig.1. The *R*21 variation by temperature

This characteristic *R*21(*T*) has an exponential form as result by experimental data analysis:

$$R_2 = a + b\exp\left(-\frac{T}{c}\right); \qquad (2)$$

where values for *a, b, c* constants are:
a [MΩ] = -32,36759; *b* [MΩ] = 9391,7788; *c* [ºC] = 22,77439,
and the correlation coefficient is 0,999.
The value of *R*21 at 20˚C obtained with (2) is $R21_{20}$ = 3869,703 MΩ. The variation of k_{cor} correction coefficients by temperature is presented in fig.2.



Mathematical dependence is given by (4) equation:

$$k_{cor} = \exp\left(a + b\,T\right), \qquad (4)$$

where
a and *b* constants has values: *a* =-0,88957 and *b* $[(^\circ C)^{-1}]$ = 0,04447.
Insulation resistance array reported to the reference temperature $Rij_{20}(T,t)$ is obtained with (1) and (4) relations. In fig. 2-4 are presented the dependencies of insulation resistance reported to the temperature depending to the exploitation period, called aging curves.

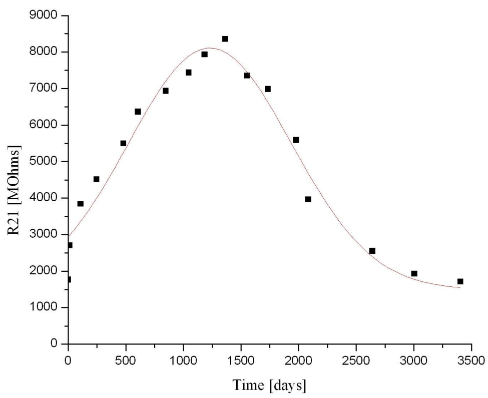


Fig.3. Insulation aging curve using *R*21 criteria

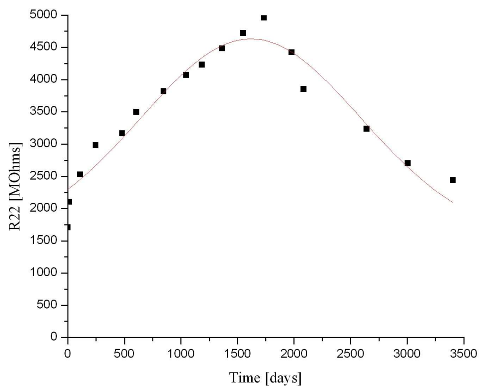


Fig.4. Insulation aging curve using *R*22 criteria

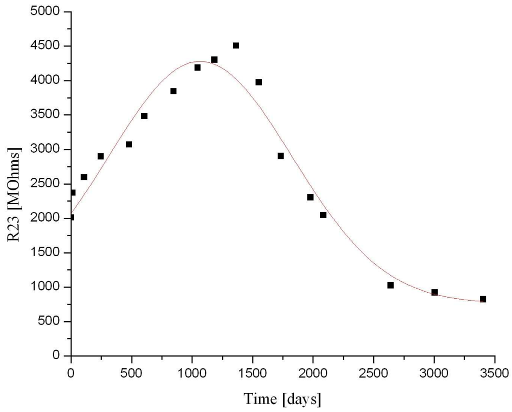


Fig.5. Insulation aging curve using *R*23 criteria

From 2 - 4 figures it is observed that:

- Insulation resistances of the three windings are different, because of different ways of leaking currents;
- All curves has a maximum, due to a drying process after the transformer putting in operation;
- Aging curves have a settle after a time period.

Because in the aging period these curves have the same form result the aging time is practically constant, and permits the estimation of insulation life time.

4. Insulation life time estimation

The end of life criteria for the insulation resistance of power transformer [8], are:

$$R_{cr}21 = 1000\ \text{M}\Omega$$
$$R_{cr}22 = 600\ \text{M}\Omega$$
$$R_{cr}23 = 300\ \text{M}\Omega.$$

The life time it is easy to be determined by graphical method at aging time curves intersection (fig. 2 –4) with a strait line $R= R_{cr}$, where R_{cr} represent the value of the end of the corresponding life criteria. Results are presented in table 1.

Table 1: Transformer insulation life time

Resistance	*R*21	*R*22	*R*23
R_{cr} [MΩ]	1000	600	300
Life time [days]	6350	7288	10635
Life time [years]	17,397	19,967	29,136

5. Conclusions

From table result the maximum life time periods for the insulation are for medium voltage 20 kV (*R*23 criteria) and the smallest for insulations working at 400 kV (*R*21 criteria). It seems to be normal because the solicitations are higher for 400 kV.

For the table result the life time for windings insulations are reduced. The reason is that the principal materials of the transformer insulation are the paper and oil, very hygroscopic materials. For the oil 20 ppm of water assure [8] a good dielectric rigidity of the oil. For more than 20 ppm of water the losing factor increase abruptly and the risk of thermal breakdown is imminent.

For the paper the losing factor increases abruptly if the water content is over 100 ppm. The aging time increase proportionally with water content.

Results that by drying the insulation is possible to increase the time life reserve. Drying degree of a transformer is good when the water content in oil is over 30 ppm and water content in paper is under 0,3%.

Applying the renewal techniques (drying, degasification, filtering) was obtained significant increasing of insulation characteristics (insulation resistance, windings losing factor), especially for 110 kV windings.

A special case is that of reserve transformers presenting a high degree of insulation aging, because of the atmospheric humidity exposition.

For transformers in reserve the water content is:

- in oil: 34 ppm (in summer), 17 ppm (in winter);
- in paper 12,5% (in summer), 12,5% (in winter).

These values are disquieting because the dielectric rigidity of windings insulation is reduced at less than 1/3 from initial value. Important is to have a good silicagel equipment.

For studied transformer after a drying opperation the water extracted from winding insulation was 4,96 liters and from solid insulation 20,86 liters.

In these conditions the total values of water contents is smallest [1]:

- in oil: 3,1 ppm (in summer), 0,8 ppm (in winter);
- in paper 1,2% (in summer), 0,6% (in winter).

The profilactic transformer insulation tests have to be executed only after the complete disconnection of transformer and after the receive of all necessary advises and the planning of operation.

So, these tests are effectuated even not all prescribed conditions are respected and the measurements are not alwais correct. (good wheather, athmosferic temperature higher than 10ºC, etc).

Generally, these presented monitoring methods needs also efficient techniques for maintenance and fixing, the purpose being the increasing of transformer working efficiency.

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