CHECKING OF POLARIZED AND DEPOLARIZED CURRENTS FOR THE ELECTRICAL EQUIPMENTS, IN ORDER TO DETERMINATE THE STATE OF INSULATION AND ITS HUMIDITY CONTENT

Gabriel Tanasescu

S.C.SIMTECH INTERNATIONAL SRL, BUCHAREST, ROMANIA
romex@fx.ro

INTRODUCTION

During the evaluation of the electrical power transformers and of other high voltage electrical equipments, a very important part is the diagnosis of the insulation. During the last years, the dialectical measurements based on the evolution of the discharging currents become more and more used to determinate the state of insulation materials or insulation systems.

For a better checking of the insulation state of an equipment, it will be present below the measurement of discharging currents (polarization – depolarization). Based on the obtained results, we can determinate the aging grade and the humidity contain, achieving a complete evaluation for the state of the insulation. This method can be applied for electrical transformers, electrical equipments, energy cables, etc.

THE INSULATING SYSTEM OF THE POWER TRANSFORMERS

During functioning the transformer is submitted at high stress. The stress can be thermal, electric and mechanic producing a big distortion of the state of the paper-oil insulation system. As a consequence, the quality of the insulation decrease. Local break downs can destroy the coils forming hot points. We must use this phenomena to obtain necessary information for our measurements.

2.1. Solid insulation

The celluloses base materials have 2 functions :

a) to increase the dielectric stability of the insulation respect an oil layer with same thickness ;

b) to maintain a certain distance between surfaces with different electric potentials.

The solid insulation (paper, cardboard, transformer board) used normally in transformers is based on celluloses.

The deterioration of the paper is induced mainly by oxidation. Under the action of the oxygen, the macromolecules of the celluloses depolymerize with a decrease in length and very bad mechanical properties. In the same time, the oxygen favorite the chemical reaction of the cellulosing with water, increasing the polarization and reducing the dielectric properties.

The moisture induce a decrease of the mechanical characteristics mainly traction resistance, elongation characteristics, etc. The moisture effect is more important for impure corps or if the water contain soluble impurities.

2.2. The liquid insulation

The oil act as insulating element and in the same time transfer the heat to the cooling battery. During function, the transformer oil is aging loosing its dielectric qualities and some of its physical chemical properties.

The oil characteristics are influenced by the content of water manifested in two forms :free water (emulsion or suspension) and solution (composition water) with electrostatic connection between the two forms. We observed that the water as solution has no big influence on the dielectric rigidity ; by the other hand, the free water from the oil induce a big decreasing of the dielectric properties. Under electrical load, the oil molecules dissociate, creating products insoluble in oil . These products (the pitches) do not modify the essential properties for the oil, but deposit on the coils and on the walls ; consequently, the cooling process of the transformer is damaged.

DIAGNOSTIC AND MONITORING METHODS FOR THE POWER TRANSFORMERS INSULATION

The state of oil-paper insulation and the moisture content can damaged the electrical , mechanical and chemical properties of the insulation. So, electrical, mechanical and chemical method can be used to analyze the state of the transformers insulation

3.1.Chemical diagnosis

- Dissolved gasses anylsis(DGA) ;
- Polymerization degree (DP) ;
- Gel permeation cromatographie (GPC) ;
- High performance liquid cromatographie (HPLC) ;

3.2. Mechanical methods

- Measuring of the breaking resistance at traction of the paper .

3.3. Electrical methods

- Checking of the tg δ ;
- Checking of dielectric rigidity at industrial frequency and impulse;
- Checking and measure of partial discharge (PD) ;
- Method of dielectric response :

1. Measuring of polarized/depolarized current (PDC) ;
2. Return voltage measurement (RVM) ;
3. Frequency dielectric spectroscopie (FDS) .

BASIS OF THE DIELECTRIC RESPONSE [7÷16]

The dielectrics are materials which polarize as effects of an external electric fields, through mechanical effects (piezoelectricity) or thermal effects (pyroelectricity)

As per their polar molecules (with permanent electric moment) or unpolarized, the dielectric material can be polar or unpolar.

If a dielectric is situated in an electric field **E**, this one polarized. The polarization can be temporary or permanent if depends or not on the electric field. The temporary electrical polarization law give us the connection between temporary polarization $\mathbf{P_t}$ and **E**

$$\mathbf{P}_t = \varepsilon_0 \chi_e \mathbf{E} \qquad (4.1)$$

where χ_e , named electrical susceptibility is a non dimensional material size, scalare for isotropic corpses and II grade tensor for the unisotropic ones.

Combining the temporary electric polarization law with the connection electric field law ::

$$\mathbf{D} = \varepsilon_0\mathbf{E} + \mathbf{P}_t + \mathbf{P}_p \qquad (4.2)$$

where $\mathbf{D}$ = electric induction and $\mathbf{P}_p$ = temporary polarization:

$$\mathbf{D} = \varepsilon\mathbf{E} + \mathbf{P}_p \qquad (4.3)$$

$$\varepsilon = \varepsilon_0\varepsilon_r\ ,\ \varepsilon_r = 1 + \chi_e$$

where ε = absolute permittivity of the material and ε_r relative permittivity.

The polar materials have the relative permittivity bigger then unpolar ones and the polar liquids have ε_r bigger then the polar solids.

The electrical polarization for dielectrics can be produced through various mechanisms, establishing the following basic classes for electrical polarization.:

1. Electronic polarization as a result of deformation of the electronic barrier of the atoms (ions) induced by the force of the external electrical fields (actives). A relative movement appears nucleus respect electron, creating an electric moment:

$$\mathbf{p} = \alpha_e\mathbf{E} \qquad (4.4)$$

where α_e = the electronic polarization.

2. Ionic polarization as a deformation, the same as the electronic one. The corpses submitted to ionic polarization have also an electronic polarization, but the ionic one is dominating;

3. Trend polarization is acting in the corpses of polar molecules (with permanent electric moment), rotating it into the external electric field.

4. The non homogeneous polarization is an equivalent electric polarity created in the non homogeneous corpses ;the separation surfaces of their homogeneous parts are electrically charging in contact with an external electrical field.

Not all dielectric materials have all the above polarization mechanisms. Various mechanisms are characterized by specific time constants which can be different. The temperature influence also the system.

MEASURING OF THE POLARIZATION/DEPOLARIZATION CURRENTS

Measuring of the polarization/depolarization currents is a method to investigate the slow polarization process of the dielectric materials during the time.

With an unload test object, giving a voltage so definite :

:

$$U(t) = \begin{Bmatrix} 0 & t < t_o \\ U_c & t_o \le t \le t_c \\ 0 & t > t_c \end{Bmatrix} \qquad (4.5)$$

For $t_o \le t \le t_c$ appear a polarization current with three components. One is the conductivity of the test object, the second one can not be registered practically because of the variation of the current amplitude and the third one appears due to various polarization processes. The polarization current can be written :

$$i_{pol}(t) = \left(\frac{\sigma}{\varepsilon_0} + \varepsilon_\infty\delta(t) + f(t)\right)C_0U_c \text{ pentru } \quad t_o \le t \le t_c \qquad (4.6)$$

where C_o is the geometrical capacity of the test object and $\delta(t)$ is the impulse function with origin at $t=t_0$. Immediately after polarization the depolarization current can be measured disconnecting the power source and breaking down the test object (fig. 4.2). Accordingly with the superposition principle and neglecting the second term from the equation (4.6) we will have for $t \geq (t_0 + T_c)$:

$$i_{depol} = -C_0 U_c \left[f(t) - f(t+T_c) \right] \tag{4.7}$$

This current have an opposite polarity. The second term from the equation (4.7) can be neglected if Tc is big. So, the depolarization current become direct proportional with the feedback function f(t).

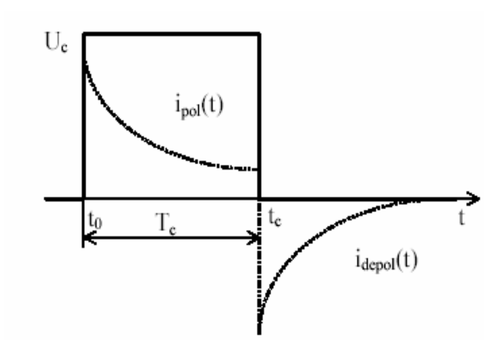

Fig.4.2. The principle of measuring the depolarization current

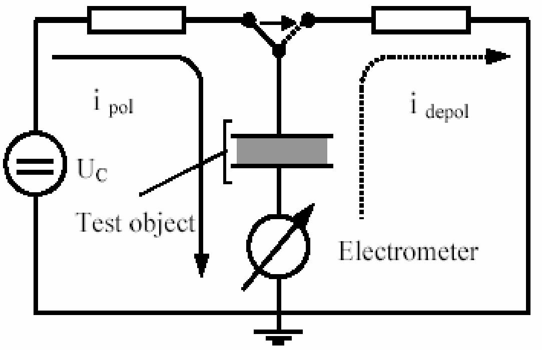

Fig.4.3. How measure the polarization or depolarization current

Practically, the polarization and depolarization current are measured through the technique sketched at fig 4.3.

RESULTS

The polarization / depolarization current for the transformer T (40 MVA, 110/6 kV, Y_0d-11, with start up in 1979) are presented in fig .5.1-5.2. The measurements were done in the same meteorological conditions (clear sky, reduced humidity, trafo temperature above 25°C, ambient temperature about 20 °C), at 1000 V.

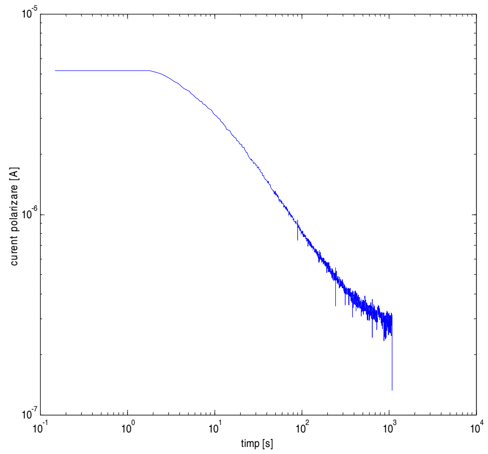

Fig.5.1. Polarisation current T

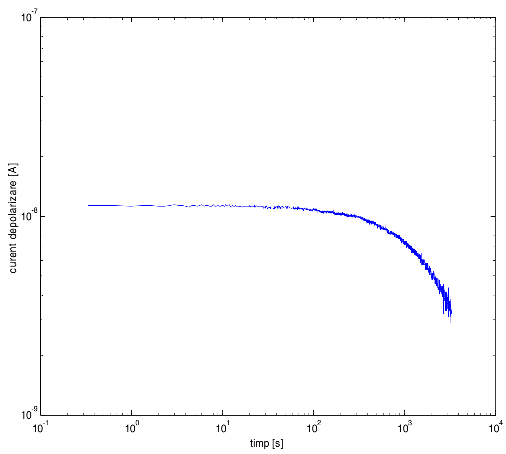

Fig.5.2. Depolarization current T

The initial exponential form of the polarization / depolarization currents is due to its dependence of the exponential time created by the insulation system (oil channels, supports, insulating cylinders, etc.); during the first seconds the properties of the oil can influence the results. During the measurements, the geometry of the insulation, the oil properties and the aging products are very important. The moisture content and the conductivity of the solid insulation are an important part respect the obtained results and concerning the form and the amplitude of the currents after a bigger period of time.

The influence of the oil conductivity under the initial value of the polarization currents can be used to estimate the oil conductivity without taking a test quantity of oil to measure straight on it. In the same way can be estimated the conductivity of the paper, using the polarization / depolarization current values obtained at the end of measurements.

For the polarization current a smaller initial value means a better quality of the oil. As we can observe from the results obtained at T_2 oil conductivity : $160x10^{-13}$ S/m and the solid insulation conductivity $650x10^{-14}$ S/m we have a big initial value for the polarization current. The same results are obtained from the oil moisture content (17.83 ppm) and from the solid insulation (3.4%). Anyway, the straight form of the current curve induce the conclusion of the damaging of the oil quality and the high moisture content from the solid insulation – as we can see in fig. 5.1-5.2 and from the final results

The conduction current is the difference between the polarization and depolarization current, normally with reference at the water content. If the initial values of the polarization and depolarization current are very near or even equal, means that the oil have less humidity then the transformers for which the polarization and depolarization currents are not equal or very near.

From the curve of the depolarization current we can extract the feedback function for each transformer. A software was developed to determinate the feedback function. Considering also some geometrical characteristics of the insulation of the transformers, we can establish the oil and paper conductivity, the moisture content from the paper, the insulation resistance, the polarization index, the variation of C tan delta (fig.5.3, 5.4). measuring between 1 second and over 1000 seconds, we can determinate the evolution of the real component of the C tan delta, function of frequency. The moisture content in the solid insulation influence the tan delta at low and very low frequencies much more then at an industrial frequency.

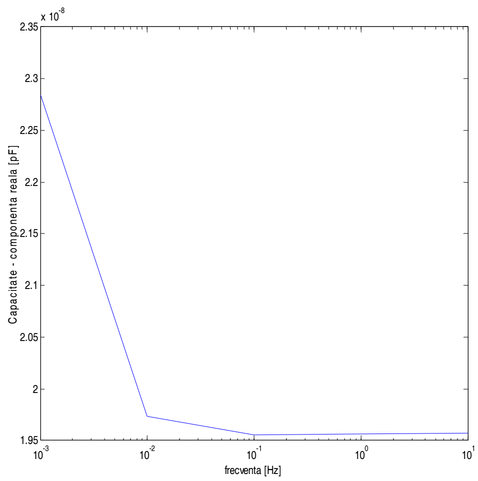

Fig.5.3. Variation of capacity with frequency

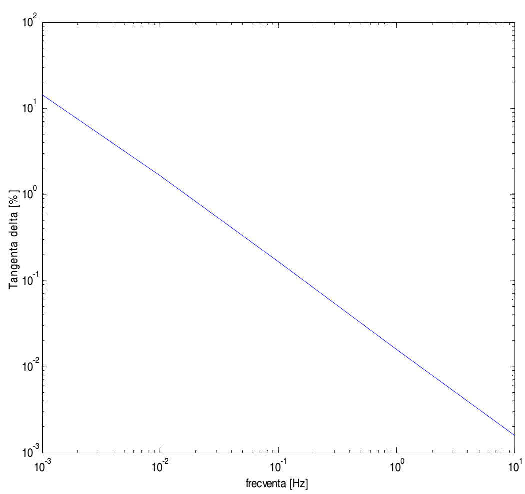

Fig.5.4. Variation of tan delta with frequency

The most important characteristic near the all parameters we can measure,- is that we can give also a diagnosis with a high precision for the complex insulation state of the electrical power transformers

This technique is useful for power electrical transformers and also for other equipments as : instrument transformers, bushings, cables, electrical machines, etc. The importance of this technique is to check the evolution of the equipments state even if the meteorologic conditions are unfavorable (clear sky- high humidity, rain). The final results of this diagnosis are not influenced by the weather.

BIBLIOGRAPHY

1. Cioc I., Vlad I., Calota G. : Transformatorul electric, Ed. Scrisul Romanesc, Craiova, 1989.

2. P.J. Burton et al. : Recent Developments by CEGB to Improve the Prediction and Monitoring of Transformer Performance, CIGRE Paper, No. 12-09, 1984.

3. Boggs, S.A. :PD – Overview and Signal Generation (PI), IEEE Electrical Insulation Magazin, no. 4, 1992 .

4. Kreuger, F.H. :Partial discharge detection high voltage equipement, ISBN 0-408-02063-6-BUTTERWORTH and CO-Ltd. 1989 .

5. Konig, D. and Narayana, R. : Partial Discharges in Electrical Power Apparatus, ISBN 3-8007-1760-3, Berlin, Offenbach, VDE, Verlag, 1993.

6. Kreuger, F.H. :Industrial High Voltage, Delf University 1991, vol. I.

7. Ifrim A., Notingher P. :Materiale electrotehnice, EDP, Bucuresti, 1992.

8. T.K. Saha, M. Darveniza, : The Application of Interfacial Polarization Spectra for Assessing Insulation Condition in Aged Power Transformer, *International Conference on Large High Voltage Electric Systems,* CIGRE'98, Vol. 2, August 1998, pp. 7.

9. T.K. Saha, M. Darveniza, " Ageing of Transformers Insulation: A Study by Interfacial Polarization Spectra Measurements," *Australian Universities Power Engineering Conference, Institution of Engineering Australia: Electric Energy Conference,* Sydney, Australia, September 1997, pp. 61-66.

10. T.V. Oommen, "Moisture Equilibrium in Paper-Oil Insulation Systems," *Preceedings of Electrical / / Electronic Insulation Conference*, Chicago, IL Oct 3-6, 1983, pp.162-166.

11. T.K. Saha, *Assessment of the Extent of Degradation of Electrical Insulation in Aged Power Transformers* , Phd Thesis, Department of Electrical Engineering and Computer Science, University of Queensland, 1993.

12. J. Fabre and A. Pichon,"Deteriorating Process and Products of Paper in Oil.Applications to Transformers *International Conference on Large High Voltage Electric System (CIGRE*), Paris, France, Paper 137, 1960.

13. Z.T. Yao, *Condition Assessment of Power Transformers by Interfacial Polarization Spectra Measurement,* Master Thesis, Department of Electrical Engineering and Computer Science, University of Queensland, 1999.

14. A. K. Jonscher, "*Dielectric Polarisation/depolarisation in Solids*", Chelsea Dielectric Press, 1984.

15. Der Houhanessian, Vahe and Zaengl, W.S.: Time Domain Measurements of Dielectric Response in Oil-Paper Insulation Systems, 1996, IEEE Int. Symp. on Electr. Insulation, IEEE Publication 96CH3597-2, pp.47-52.

16. T. Leibfried, A.J. Kachler, W.S. Zaengl, V. Der Houhanesian, A. Kuchler, B. Breitenbauch : Ageing and moisture moisture analysis of power transformer insulation systems, CIGRE 2002, Paper 12-101, Paris, August 2002 ;

17. A. Helgeson : Analysis of Dielectric Response Measurement Methods and Dielectric Properties of Resin-Rich Insulation During Processing, PhD thesis, Royal Institute of Technolofy (KTH), Stockholm, Sweden, ISSN 1100-1593, 2000 ;

18. W. S. Zaengl : Dielectric spectroscopy in time and frequency domains or HV power equipment (Transformers, cables, etc.), 12th International Symposium on High Voltage Engineering – ISH2001, Bangalore, India 20-24 August 2001