ФІЗИКА І ХІМІЯ ТВЕРДОГО ТІЛА
Т. 7, № 3 (2006) С. 572-576

PHYSICS AND CHEMISTRY OF SOLID STATE
V. 7, № 3 (2006) P. 572-576

PACS 77.22.ej, 77.22.gm

ISSN 1729-4428

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The Influence of Temperature and Dampness on the Value of the Main Time Constant of Paper-Oil Insulation Determined by Using Deby's Model

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The paper presents research results of paper-oil insulation samples obtained through the measurement of the electric polarization current. The research tests were carried out in a home-made laboratory system, which made it possible to regulate and control the temperature and humidity of mineral insulation oil. The samples of the electrotechnical paper differed in the degree of aging. Based on the measurements of the polarization current the value of the main time constant of the insulation under study and values R & C of the substitute diagram were determined by using the Deby's model. The analysis of the influence of temperature, humidity and the degree of aging of the paper-oil insulation samples on the values determined from the model was carried out..

Keywords: dielectric polarization, paper-oil insulation system, mineral insulation oil, power transformer, dielectric relaxation, electrotechnical paper aging.

Стаття поступила до редакції 11.10.2005; прийнята до друку 15.05.2006.

Introduction

Throughout a few recent years the research-developmental work carried out in numerous scientific institutions in the world has significantly improved the knowledge on the phenomenon of electrical polarization in dielectrics [1, 2, 3]. As a result of this research the apparatus developed [4, 5], which has been successfully introduced onto the market and adopted for the research on paper-oil insulation of transformers and power cables. Presently, various methods of the evaluation of insulation condition are used (PDC – polarization and depolarization current, RVM – recovery voltage method, LFDS – low frequency domain spectroscopy). Modern PDC or RVM meters are used mainly for determining the degree of electrotechnical paper dampness of power transformer insulation [6, 7]. For example, a RVM 5461 meter by the firm Tettex Instruments provides as the main measurement parameters the content of water in percentages in paper (percentage of water weight in relation to paper weight) and critical temperature, at which the time constant of the insulation under study is about 200 ms. Moreover, in this meter as well as in meters by other manufacturers, the parameters that are analyzed are as follows: maximum value of recovery voltage, the time of obtaining this value, and the speed of increase of the voltage registered. However, the attempts to use the RVM or PDC meters for the evaluation of the aging degree of paper-oil insulation encountered considerable difficulties in interpreting the measurement results obtained. A simultaneous influence of temperature, dampness and aging processes on the runs registered caused significant and difficult to explain changes of the above—mentioned parameters. The issue of a specific separation between the influence of dampness and aging still remains open. At present, many research institutes in the world conduct research work to improve the level of knowledge in this scope [6].

According to the author, the lack of a more thorough analysis of the runs of polarization and depolarization current, and recovery voltage can cause the above-described situation [8]. Therefore a bigger number of parameters should be defined and their behavior during the simulated phenomena should be analyzed using a mathematical model, and we should go back to laboratory research on small objects, which imitate an actual paper-oil insulation of a transformer relatively well. Obviously, the last stage of the research work should be comparing the laboratory results with the measurements on real objects. This paper presents the influence of temperature and dampness on a time constant determined by using the analysis of the polarization current run and Deby's mathematical model.

I. Measuring set-up

A properly prepared sample of paper-oil insulation was used as the research object. The measuring set-up and the shapes and sizes of the electrodes are shown in Figure 1 and Figure 2. The sample of paper-oil insulation was made by cutting one sheet of electroinsulation transformer paper and pouring carefully fresh mineral insulation oil over it. The process of pouring oil was carried out in such a way as to prevent the occurrence of air bubbles inside the insulation. First, the sample underwent drying and after being poured with oil, it was seasoned. The measurements of temperature and dampness of oil were taken with an HMP228 transducer by the firm Vaisala, which was scaled for transformer oils in ppm units. The polarization current was measured with a resistivity meter BM 25 by the firm Megger, connected with a PC for data archivization. Temperature control in the system was ensured by a circulating oil pump with a water heater. The level of dampness of the insulation sample under study was changing with temperature, however, the apparatus made it possible to determine only the dampness of oil. Therefore, for each consecutive temperature the fact of establishing a new water balance between paper and oil was taken into consideration, thus the measurement taking of polarization current was delayed deliberately.

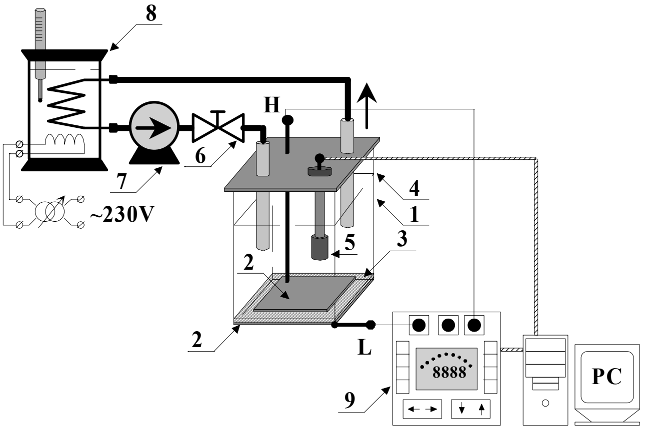


Fig. 1. Measuring set-up for the measurements of polarization current and paper-oil insulation
1 – container, 2 – electrodes, 3 – electroinsulation paper, 4 – insulation oil level, 5 – czujnik temperature and dampness sensor, 6 – valve, 7 – pump, 8 – water heater, 9 – resistivity meter BM 25

In this setup three samples of transformer electroinsulation paper saturated with mineral insulation oil of an unknown origin were tested, which differed significantly in their degree of aging. It was decided to mark the samples in the following way:

I – fresh paper, dried;
II – paper from a transformer after a failure;
III – artificially thermo-aged paper.

Sample II was obtained during the repair works of the transformer after the interwinding fault of the upper voltage. The markings of the transformer manufacturer were as follows: TAOC 100/15 Elta Lodz; 100 kVA/89. Sample III was aged for in the temperature of 110ºC for 50 h with the access of air.

II. Mathematical model

When a dielectric is exposed to the activity of the external electrical field it is subject to the phenomenon of polarization. However, the very polarization is extremely difficult to observe. It is tested through registration of the changes of current flowing through a dielectric. Current density J(t) is the sum of conductivity current connected with a finite conductivity of a material and current resulting from the shift of bounded charges:

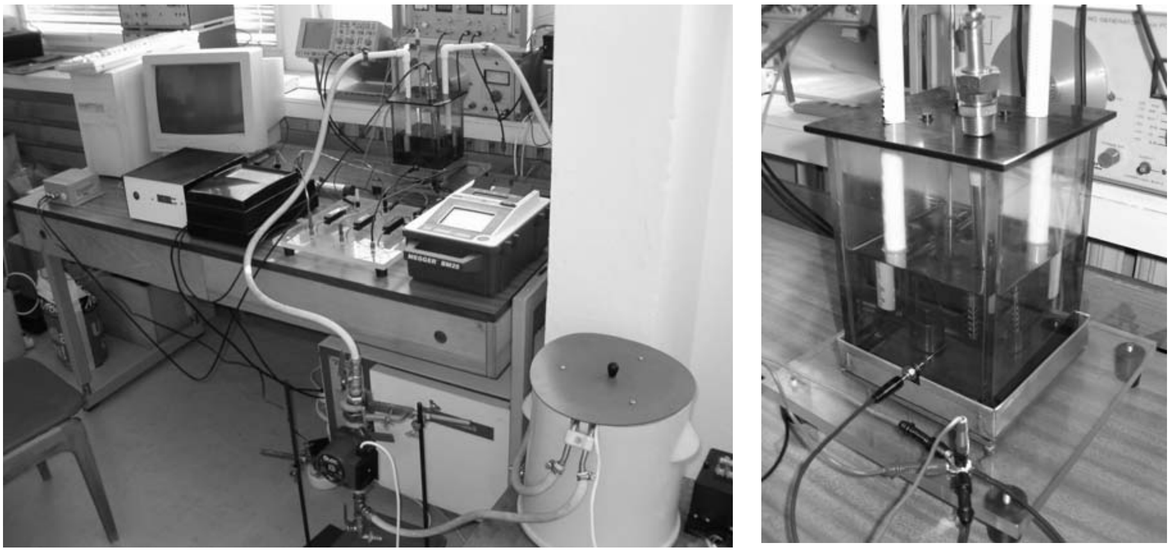
$$J(t) = \sigma E(t) + \frac{dD}{dt} \tag{1}$$

where: σ – conductivity, E(t) – external electrical field, D – electrical induction.

If a dielectric is exposed to the activity of a constant electrical field for time t_C, polarization current $I_p(t)$ will assume the form:

$$I_P(t) = E(\sigma + \varepsilon_0 f(t)) \tag{2}$$

where: ε_0 – electrical permeability of vacuum, f(t) – dielectric response function.



a) b)

Fig. 2. Overall view of the measuring setup (a) and a close-up of the vessel with the sample under study (b)

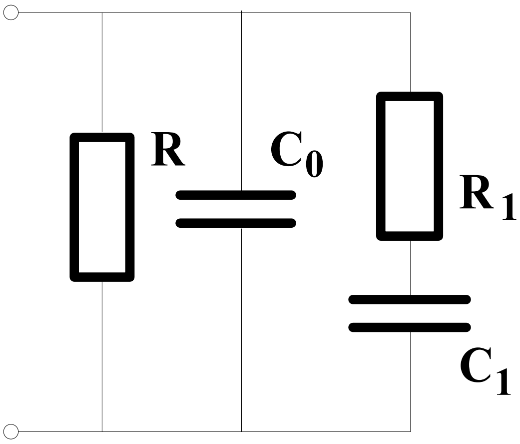


Fig. 3. Substitute scheme of the insulation under study R – skew resistance of insulation, C_0 – geometric capacity of an object, R_1 i C_1 – elements simulating a time constant of insulation

Response function f(t) can be calculated based on a substitute scheme of the insulation under study, which is shown in Fig. 3:

$$f(t) = A_1 e^{-\frac{t}{\tau_P}} \tag{3}$$

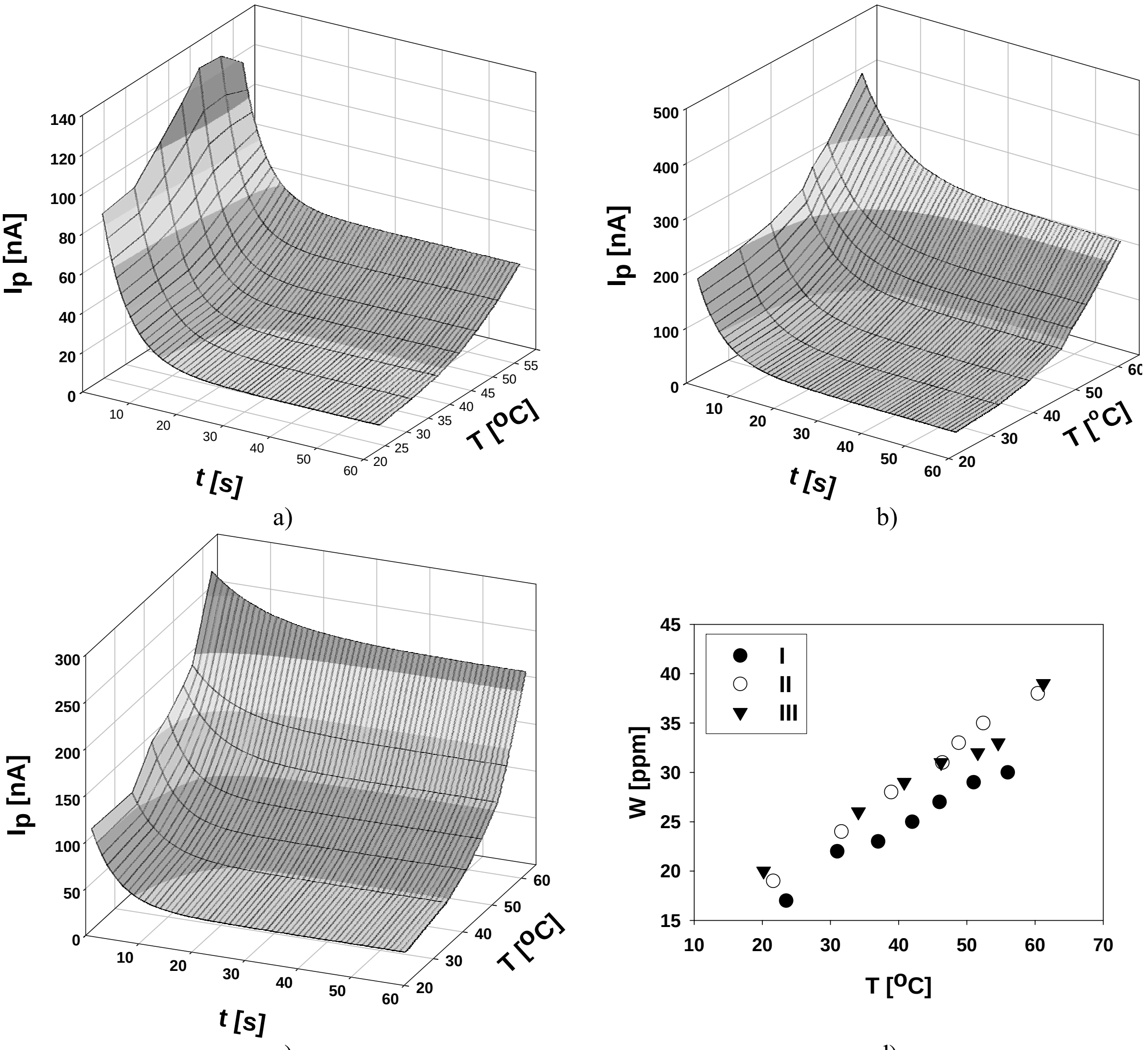
$$A_1 = \frac{1}{C_0 R_1}(1 - e^{-\frac{t_C}{\tau_P}}) \tag{4}$$

where: τ_P – time constant of insulation $\tau_P = R_1 C_1$.

Time constant can be also determined based on the measurements of polarization current properly approximating the registered function run $y(x) = A \cdot e^{B \cdot x} + C$.

III. Research results

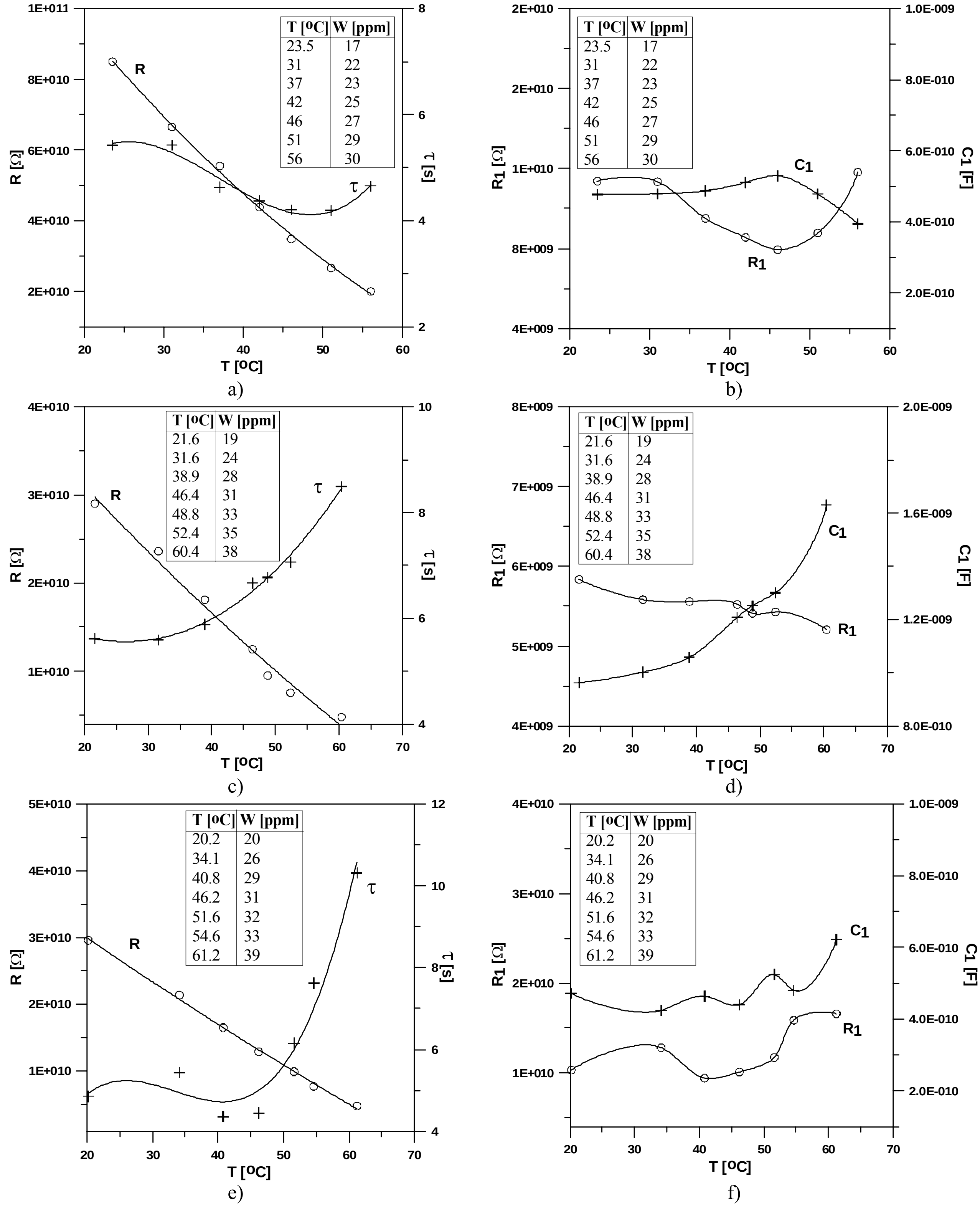
Fig. 4 presents collective characteristics of the influence of temperature of paper-oil insulation of the polarization current registered. There should be noted a constant and significant increase of the established value of polarization current with the increasing temperature of the measurement. This phenomenon is due to the



a) b)

c) d)

Fig. 4. Influence of temperature and dampness on polarization current (4a, 4b,4c) and changes of oil dampness caused by rising temperature of the insulation under study (4d)
a) sample I, b) sample II, c) sample III



T [°C]	W [ppm]
23.5	17
31	22
37	23
42	25
46	27
51	29
56	30

a)

T [°C]	W [ppm]
23.5	17
31	22
37	23
42	25
46	27
51	29
56	30

b)

T [°C]	W [ppm]
21.6	19
31.6	24
38.9	28
46.4	31
48.8	33
52.4	35
60.4	38

c)

T [°C]	W [ppm]
21.6	19
31.6	24
38.9	28
46.4	31
48.8	33
52.4	35
60.4	38

d)

T [°C]	W [ppm]
20.2	20
34.1	26
40.8	29
46.2	31
51.6	32
54.6	33
61.2	39

e)

T [°C]	W [ppm]
20.2	20
34.1	26
40.8	29
46.2	31
51.6	32
54.6	33
61.2	39

f)

Fig. 5. Resistance and a time constant (5a, 5c, 5e) and elements R_1 and C_1 (5b, 5d, 5f) of paper-oil insulation a, b) sample I; c, d) sample II; e, f) sample III

decreasing skew resistance of insulation, the almost linear drop of which is shown in Fig. 5a, 5c and 5e.

Figure 4d shows how the dampness of oil changed with rising temperature during testing the consecutive samples of oil-paper insulation. Significant changes of the degree of oil dampness in the heating circuit should be observed, which proves the significance of the stabilization of conditions that make it possible to keep the water balance between paper and oil during the tests of this type of insulation.

Fig. 5a – 5f show the changes of time constant τ and elements R_1 and C_1, which were determined using a mathematical model from polarization current runs. The initial decrease of the time constant is caused mainly by increasing temperature, i.e. lowering value R_1 at an almost constant C_1 (Fig. 5b). For temperatures above

45ºC the time constant increases, which is caused by transformer paper drying, i.e. migration of water from paper to oil (repeated increase of R_1 and a quite significant decrease of C_1 – Fig. 5b). Such situation is typical for fresh insulation (sample I), when dampness in cellulose is entirely of the external origin, and not, for example, the result of aging reactions.

An entirely different behavior of the main time constant τ was observed in the case of testing the polarization current of the aged samples II and III. In an almost whole range of rising temperature of insulation, the time constant also rises, except for insignificant fluctuations for 30 – 50ºC of sample III (Fig. 5e). It should be also noted that the resistance of the insulation from both the paper aged through operation and aged artificially is at a similar level and behaves similarly in the temperature function (Figs 5c and 5e). The increase of the main time constant τ is caused by a rising value C_1 at an almost unchanged value R_1 (Figs 5d and 5f). It should be also observed that value R_1 of the insulation from the most aged paper (sample II) is considerably lower than value R_1 for the other samples. Moreover, the more aged the paper is, the bigger influence of element C_1, not R_1, on value τ in the temperature function (dampness) is. This observation proves the usefulness of determining the values of elements R_1 and C_1, which simulate the main time constant τ of paper-oil insulation to evaluate the degree of its aging.

Conclusion

According to the author, the temperature of a measurement influences significantly the value of time constant τ of paper-oil insulation. While estimating the state of dampness or aging of transformer insulation based on the measurements taken with PDC or RVM meters, this influence should be taken into account, the proof of which are tests already carried out on a simple sample of such insulation. Determining the changes of the values of elements R_1 and C_1 of a substitute scheme can prove to be very useful. Only a correct interpretation of τ changes in correlation with R_1 and C_1 and other parameters of the PDC and RVM methods should lead to a correct diagnostics of paper-oil insulation of transformers and power cables.

Taking the dominant role of value C_1 in the main time constant τ together with the degree of aging of paper-oil insulation obviously requires confirmation by further research work (increasing the number of samples, precise control of the degree of paper dampness, extending the time scale of artificial thermo-aging, etc.). The research schedule for fulfilling the above-discussed aims will constitute a part of the author's further research tasks in the nearest future.

Stefan Wolny – Dr. Ing.

[1] T.K. Saha, Z.T. Yao. Experience with return voltage measurements for assessing insulation conditions in service – aged transformers // *IEEE Trans. Power Delivery*, **18**(1), pp. 128-35 (January 2003).

[2] Y.C. Kuang, G. Chen. Recovery voltage measurement on oil – paper insulation with simple geometry and controlled environment // *8th ICSD Conf.*, Toulose, (July 2004).

[3] T.K. Saha. Deriving an Equivalent Circuit of Transformers Insulation for Understanding the Dielectric Response Measurements // *IEEE Trans. Power Delivery*, **20**(1), pp. 149-157 (January 2005).

[4] G.M. Urbani, R.S. Brooks. Using the recovery voltage method to evaluate ageing in oil–paper insulation // *IEEE Intern. Conf. Conduction Breakdown in Solid Dielectr.*, Vasteras, Sweden, pp. 93-97 (1998).

[5] W.S. Zaengl. Dielectric spectroscopy in time and frequency domain for HV power equipment (transformers, cables etc.) // *12th Internat. Symposium on HV Engineering – ISH*, Bangalore, India (2001).

[6] T.K. Saha. Review of modern diagnostic techniques for assessing insulation condition in aged transformers // *IEEE Trans. on Dielectr. And Electrical Insulation*, **10**(5), pp. 903-917 (October 2003).

[7] J.-J. Alff, V. Der Houhanessian, W.S. Zaengl, A.J. Kachler, A Novel. Compact Instrument for the Measurement and Evaluation of Relaxation Currents conceived for On-Site Diagnosis of Electric Power Apparatus // 2000 *IEEE International Symposium on Electrical Insulation*, Anaheim, CA, USA, (April 2000).

[8] S. Wolny. Parameter changes of the return potential phenomenon in paper-oil insulation // *APTADM'2004 International Conference*, Wroclaw, Poland, (September 2004).

Штефан Вольний

Вплив температури и вологості на значення головної константи часу паперово-масляної ізоляції, визначеної при використанні моделі Дебайя

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В статті приведені результати дослідження зразків паперово-масляної ізоляції, визначені за методом вимірювання струму електричної поляризації. Дослідження були проведені в системі власної конструкції, де була можливість регулювання і контролю температури і вологості мінерального ізоляційного масла. Зразки електротехнічного паперу відрізнялися один від другого ступінню старіння. На основі вимірювання струму поляризації при застосуванні моделі Дебая визначено значення головної константи часу досліджуваної ізоляції і значення R и C в схемі заміщення. Проведено аналіз впливу температури, вологості и ступеня старіння зразків паперово-масляної ізоляції на відповідні значення із моделі.