

LIFETIME ESTIMATION OF COMPOSITE INSULATIONS BY ABSORPTION/RESORPTION CURRENTS METHOD

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In this paper, an analysis of degradation processes influence on the increase of polar products and charge carriers concentration, and the values and forms of absorption/resorption currents curves are presented. Based on their values, the polarization index and conductivity factor are determined and lifetime duration curves are drawn. Finally, it is shown that the obtained lifetime values are very close to the ones determined using the mass loss method, and the possibility of the absorption/resorption (A/R) currents use to estimate lifetime values for composite insulations of high power electrical machines is also discussed.

1. INTRODUCTION

During electrical machines operation, the insulation systems are exposed to normal permanent (thermal, electrical, mechanical, environmental, etc.) and accidental (overvoltage, overcurrent, etc.) stresses. These stresses initiate and maintain degradation processes (oxidation, molecule fracture, micro-cracks, insulation loosening, etc.), which lead to the worsening of mechanical and electrical insulation characteristics (increase of charge carriers and polar radicals concentration, etc.) and consequently to the insulation systems breakdown and electrical machines premature take out [1]. Therefore, the knowledge regarding the condition of the insulation systems and their lifetime estimation has become a present-day problem.

Different macroscopic models and methods were developed in order to calculate insulation lifetime, taking into consideration only one stress factor (unifactor models) or more stress factors, which act simultaneously or consecutively (multifactor models). For the unifactor models, the stress is usually electrical (reverse power model [2], exponential model [3], etc.) or thermal (Montsinger [4], Dakin [5], Paloniemi [6] models, etc.).

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Multifactor models usually consider the simultaneous actions of electric field and heat (Simoni [7], Ramu [8], Fallou [9], Montanari [10] models, etc.), but there are also models that use more stress factors (Crine [11], Ifrim [1], etc.).

Physical models are based on the description of the predominant degradation mechanisms, associated to a certain stress factor (field emission [12], electrical trees [13], Dissado, Montanari [14], Notingher [15] models, etc.).

In the thermodynamic models, it is considered that the thermally activated degradation reactions are responsible for materials ageing (electrokinetic endurance model [16], space charge model [17], etc.). Probabilistic models are represented by certain expressions which contain the probability, duration of failure and the stresses which determine that failure [18].

The most frequently used methods are global (based on the measurement of the insulation resistance, loss factor, partial discharge level, gas analysis, etc.) and sometimes require expensive equipment [19–25]. Recently, there are attempts to analyze the ageing of electrical equipment insulation systems based on absorption/resorption (A/R) currents measurement [26–29].

When a step voltage U_0 is applied to a plate-plate capacitor (with electrodes of surface A and the dielectric of thickness g , electrical conductivity σ and permittivity ϵ), an absorption current $i_1(t)$ appears (Fig. 1):

$$i_1(t) = i_i(t) + i_p(t) + i_{sc}(t) + i_c(t), \quad (1)$$

where $i_i(t)$ is the charging current of the capacitor with vacuum dielectric, $i_p(t)$ is the polarization current, $i_{sc}(t)$ is the space charge current and $i_c(t)$ is the conduction current [1].

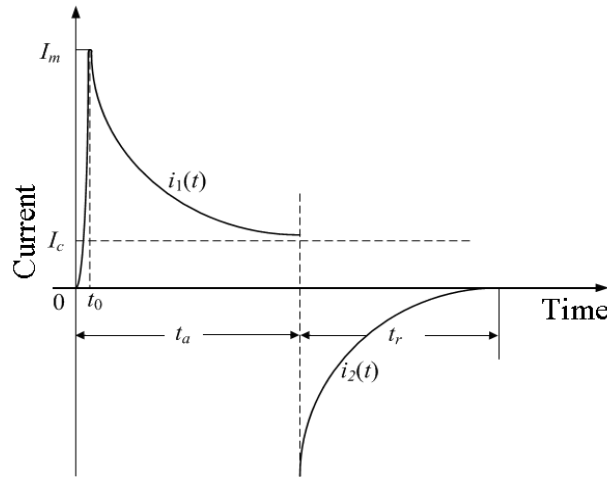


Fig. 1 – Time variation of the current in a capacitor dielectric for a step applied voltage U_0 ($i_1(t)$), and after the supply disconnection and electrode short-circuit ($i_2(t)$).

The current $i_i(t) = \varepsilon_0 A \partial E / \partial t$ is due to the charging of vacuum dielectric condenser ($\varepsilon = \varepsilon_0$) and decreases to zero very quickly. By consequence, for usual measurements, the start of the curve $i_i(t)$ is not recorded (Fig. 1).

The component $i_p(t)$ is given by the dielectric polarization phenomena that consist in very small motions of a large number of attached charges. When the applied voltage is reduced to zero, these charges return to their initial positions.

The $i_{sc}(t)$ current corresponds to the movement of the existing space charge in the dielectric volume. This charge is generated by the technological process (molecules' fractures etc.), degradation processes during work service (thermal, electrical, mechanical, etc.), charge injection at the surfaces of the metallic electrodes with small curvature radii, protuberances, etc. In a certain time depending on dielectric properties, the currents $i_p(t)$ and $i_{sc}(t)$ become zero.

The conduction current $i_c(t) = I_c = A \cdot \sigma \cdot U_0 / g$ (Fig. 1) is given by the convection of electrons, ions and molecular ions. The concentration of each charge type depends on the chemical nature and physical structure of the dielectric and gives an electronic or ionic preponderant conduction [1, 26].

When the voltage supply is turned off ($U_0 = 0$) and the capacitor electrodes are connected in short-circuit, the capacitor discharge begins and the dielectric is passed by a transitory current $i_2(t)$:

$$i_2(t) = i_d(t) + i_{dp}(t) + i'_{sc}(t), \quad (2)$$

where $i_d(t)$ is the discharge current of the vacuum dielectric capacitor, $i_{dp}(t)$ – the depolarization current and $i'_{sc}(t)$ – the current that corresponds to the dielectric space charge.

Taking into account that $U_0 < 1$ kV and the applied time is not very large (minutes or hours), in the case of usual insulation systems, important transformations (notable chemical degradations) that can modify the electrical dipoles' concentration do not appear, resulting: $i_p(t) = i_{dp}(t)$. The i_{sc} component corresponds to the detrapping and drifting of charge carriers mainly found in small hole traps. Some of them reattach to other defects, while other reach the electrodes; thus, $i'_{sc}(t) < i_{sc}(t)$.

For polar insulation systems (hydrophilic) or with high porosity (and which had already absorbed water) and for those highly degraded, $i_d(t)$ current values are bigger compared to I_c , and its canceling is realized in a large time interval. The existence of polar products (water, degradation products, etc.) and space charges can be shown by the polarization index k_p values [20, 22]:

$$k_p = \frac{I_{60}}{I_{600}}, \quad (3)$$

where I_{60} is the current $i_1(t)$ measured after 60 seconds and I_{600} – the value of $i_1(t)$ measured after 600 seconds from the applied voltage U_0 start.

Generally, it is considered that the insulation condition is great when $k_p > 4$, while those highly degraded have $k_p < 1.5$.

Insulation systems degradation can be highlighted by the modification of the conductivity factor k_c [27]:

$$k_c = \frac{i_1(30) - i_2(30)}{i_1(60) - i_2(60)}, \quad (4)$$

where $i_{1,2}(30, 60)$ are the currents $i_{1,2}(t)$ measured after 30 and 60 seconds from the U_0 start (i_1), respectively from the voltage stop and electrodes' short-circuiting (i_2).

The conductivity factor values depend on the *report* between the space charge and conduction current values. For small values of I_c (compared to i_{sc}), $k_c > 4$, while for very big I_c values, $k_c \rightarrow 1$.

For dry composite insulation systems, the space charge current cannot be neglected compared to the polarization current. Moreover, the values of $i_{sc}(t)$ can substantially increase as a result of the degradation process and the direct measurement or determination of $i_{sc}(t)$ allows the estimation of the ageing state of insulation systems [20, 27–31]. In this way, the increase of the maximum value of $i_1(t)$ shows the increase of the charge concentration, respectively the degradation of the insulation system. A large value of the time constant τ shows the increase of the permittivity, respectively the increase of the electrical dipoles concentration as a consequence of the molecules' fractures and/or water contamination.

In previous papers [20, 26, 27], the A/R currents from different types of samples were presented. In this paper, the variations of the relative mass loss Δm_r , the polarization index k_p and the conductivity factor k_c with the thermal ageing time of the different samples (made from materials used for stator winding insulations of medium power rotating machines) are analyzed. The estimated lifetime values are also presented, using the above-mentioned diagnostic factors (Δm_r , k_c and k_p).

2. EXPERIMENTS

2.1. SAMPLES AND EXPERIMENTAL SETUP

For the experimental study, two types of samples – named A and B – were used.

The A samples are tape CALMICAGLAS (ISOVOLTA) plates that contain glass texture, mica paper and epoxy resins, having the dimensions of $100 \text{ mm} \times 100 \text{ mm} \times 1.5 \text{ mm}$. Using steel plates of $650 \text{ mm} \times 110 \text{ mm} \times 2.5 \text{ mm}$, seven layers of tape with 0.18 mm in thickness were rolled up (with $\frac{1}{2}$ superposition). The plates were pressed at $p = 3 \text{ bar}$ and $T = 160^\circ \text{C}$ for $t_p = 2.5 \text{ hours}$. The values of T , p and t_p correspond to those used in technological processes of large power electrical machines manufactured by GENA ELECTRIC Ltd. From these plates were made samples of $100 \times 100 \text{ mm}^2$, which have been processed to obtain a

requested thickness of 1.5 mm and a fine surface. Adherent semiconductor electrodes were stuck to the surfaces of the samples in order to measure the A/R currents [20].

The B samples ($400 \times 41.2 \times 18.1 \text{ mm}^3$) were made up from copper bars (28 conductors with $2.65 \times 10 \text{ mm}^2$ in section), insulated with seven layers of mica tape CALMICAGLAS ($\frac{1}{2}$ superposition), pressed at 3 bar and 160°C for $t_p = 2.5$ hours.

All samples were thermally conditioned for 48 h at 190°C . The samples' accelerated thermal ageing was done in a Trade Raypa forced air flow oven with adjustable temperature varying between 30 and 250°C .

The experimental setup used to measure the A/R currents is presented in Fig. 2. The used Keithley electrometer can measure the current with a delay of 0.145 s after the applied voltage U_0 start. The mass loss during the ageing process was measured with a SHIMADZU AW220 electronic balance.



Fig. 2 – Experimental setup for absorption/resorption currents measurement: 1 – electrometer Keithley 6517, 2 – resistivity test fixture Keithley 8009, 3 – PC.

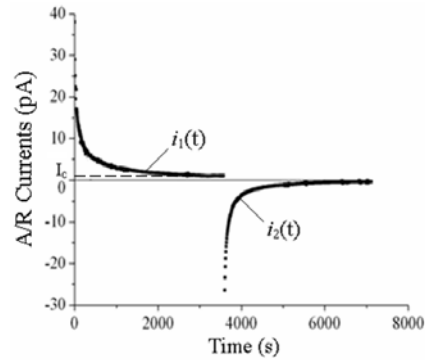


Fig. 3 – Time variations of the A/R currents for an unaged A sample ($U_0 = 1000 \text{ V}$).

2.2. MEASUREMENTS

To establish a quantitative relation between the values of the A/R currents and the ageing state of the samples, the currents have been measured for different ageing times β (between 0 and 1600 h) for the following ageing temperatures: $T_1 = 210^\circ\text{C}$, $T_2 = 230^\circ\text{C}$, and $T_3 = 250^\circ\text{C}$ (according to the Procedure IEC 60216) [30]. The used applied voltage was 500 and 1,000 V. Some experimental results are presented in section 3.

3. RESULTS AND DISCUSSION

Fig. 3 shows the variation as a function of time of the A/R current for an unaged A sample. The currents measurement (for $U_0 = 1,000 \text{ V}$) was done for a

relatively long time (2 h) in order to observe the moment at which $i_1(t)$ stabilizes (reaches I_c value) and the resorption current $i_2(t)$ becomes zero.

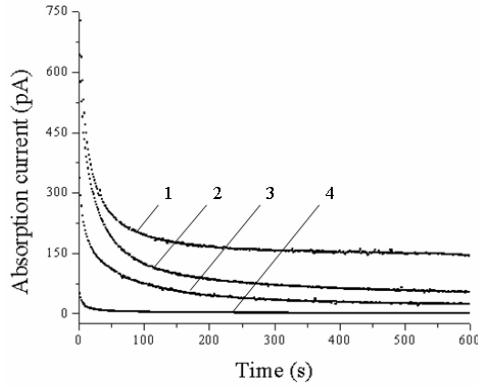


Fig. 4 – Time variation of the absorption current for short time aged A samples: 1 – unaged, 2 – $T_1 = 210$ °C and $\beta = 176$ h, 3 – $T_2 = 230$ °C and $\beta = 118$ h, 4 – $T_3 = 250$ °C and $\beta = 107$ h.

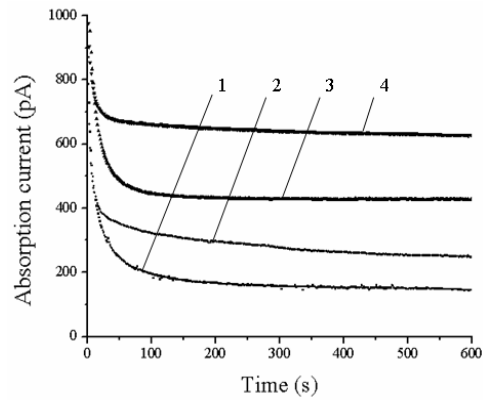


Fig. 5 – Time variation of the absorption current for long time aged A samples: 1 – unaged, 2 – $T_1 = 210$ °C and $\beta = 679$ h, 3 – $T_2 = 230$ °C and $\beta = 626$ h, 4 – $T_3 = 250$ °C and $\beta = 432$ h.

Because the software which was used could only gather $n = 1,000$ measurement points, the first values of the absorption current were recorded after about 7 seconds (and the start parts of $i_1(t)$ and $i_2(t)$ curves are missing). To obtain the first values of the currents, the measurement time has been reduced to 600 s.

In Fig. 4, the variations of medium absorption currents determined on five samples of type A are presented. It can be seen that, in the first part of the samples ageing process ($\beta \approx 100$ h), absorption current values decreased compared to the ones for the unaged samples. This is due to the elimination of polar products (solvents) and space charge left inside the samples after the fabrication process and, therefore, of the reduction of i_p and i_{sc} components from the absorption currents. Certainly, with the increase of the ageing temperature, particle elimination (diffusion) is faster, thus i_1 values are smaller (Fig. 4, curve 4).

Time variations of the absorption currents in A samples thermally stressed for longer periods of time are presented in Fig. 5. It is noticed that, for all ageing temperatures, current values increased with ageing time β , which was due to the degradation of epoxy resins molecules and generation of polar products (which led to the increase of the polarization current i_p) and charge carriers (electrons and ions), part of them fixed on the interfaces between the mica paper and glass texture layers, leading to the increase of the space charge current i_{sc} .

In Fig. 6 are presented the variation curves of the epoxy resin relative mass loss $\Delta m_r(\beta)$, defined by:

$$\Delta m_r(\beta) = \frac{m(0) - m(\beta)}{m(0)}, \quad (5)$$

where $\Delta m_r(\beta)$ is the epoxy resin relative mass loss, $m(0)$ is the initial mass of the samples' epoxy resin and $m(\beta)$ – the mass of the epoxy resin at ageing time β .

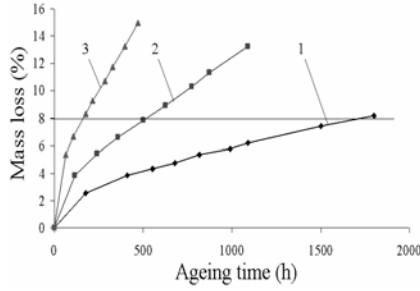


Fig. 6 – Mass loss variations with ageing time for A samples at ageing temperatures $T_1 = 210$ °C (1), $T_2 = 230$ °C (2) and $T_3 = 250$ °C (3).

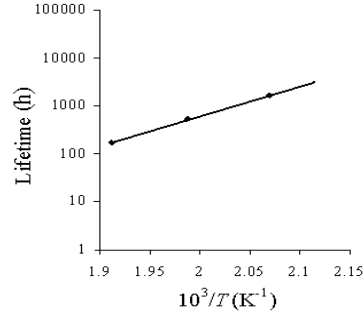


Fig. 7 – Lifetime curve for A samples corresponding to mass loss diagnostic factor and end-of-life criterion $\Delta m_{r,eol} = 8$ %.

Taking the end-of-life criterion $\Delta m_{r,eol} = 8$ % [31], the lifetime equation $\ln \beta = 14,448/T - 22,483$ is obtained. Using the lifetime duration curve (Fig. 7), insulation lifetime estimation was determined for two functioning temperatures: for $T_6 = 155$ °C, it is obtained $L_{m6} = 9.5$ years, while for $T_7 = 120$ °C, $L_{m7} = 182$ years.

The variations of the polarization index k_p with ageing time β , for A samples aged at 210, 230 and 250 °C, are presented in Fig. 8. It can be seen that, for $\beta = 0$, in all cases, the values of the k_p factor are small and that these values increase at the beginning of the ageing processes. Under heat effect, some electrons, ions and electric dipoles trapped in more significant hole traps are detrapped. Consequently, the i_{sc} and i_p currents increase and an important increase of the polarization index k_p values appears (Fig. 8).

The $k_p(\beta)$ curves have maximum values for the β values (named β_{max}) dependent on the ageing temperature. For the A samples, in the case of the 210 °C ageing temperature, $\beta_{max} \approx 450$ h. When the ageing temperature increases, the particles gather the escape energy faster, so the values of β_{max} decrease (for 230 °C, $\beta_{max} \approx 350$ h).

For β values bigger than the ones of β_{max} , the values of k_p decrease, due to the increase of the dipoles' and charge carriers' concentration (produced by the thermal degradation of the epoxy resins) and, therefore, to the increase of the polarization and space charge currents.

If the polarization index k_p is used as a diagnostic factor, for the end-of-life criterion set at $k_{p,eol} = 2$ (corresponding to visible superficial deteriorations of the

samples surfaces), from the curves presented in Fig. 8, the lifetime equation $\ln \beta = 16,769/T - 27.887$ is obtained. The lifetime duration values at 155 and 120 °C are $L_{k6} = 9.7$ years and $L_{k7} = 300$ years respectively (Fig. 9). The difference ΔL between the values of the lifetime estimation for the mass loss and the polarization index methods at $T_6 = 155$ °C is small: $\Delta L_{155} = 0.24$ %.

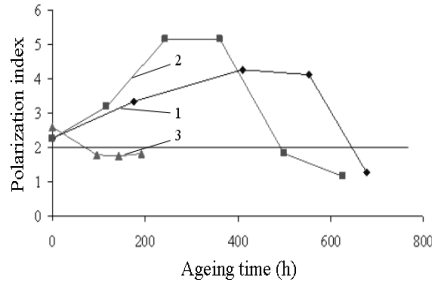


Fig. 8 – Variation of the polarization index k_p with ageing time β for A samples at $T_1 = 210$ °C (1), $T_2 = 230$ °C (2) and $T_3 = 250$ °C (3).

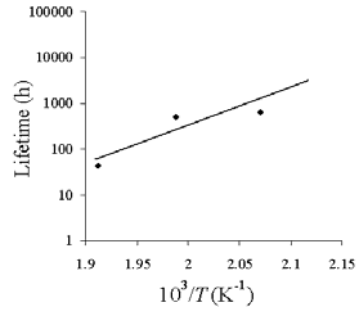


Fig. 9 – Lifetime curve for A samples corresponding to the k_p diagnostic factor and end-of-life criterion $k_{p,eol} = 2$.

The variation of the conductivity factor k_c with ageing time is presented in Fig. 10, while the lifetime duration curve – considering the end-of-life criterion $k_{c,eol} = 2$ – is shown in Fig. 11. In this case, the difference ΔL between the estimated lifetime values at 155 °C, obtained using the mass loss method (9.5 years) and the conductivity factor method (9 years), is bigger than for the polarization index method, respectively $\Delta L = 5$ %.

For the functioning temperature $T_7 = 120$ °C, the lifetime duration values obtained by the three methods well exceeded 100 years.

However, it should be noticed that the calculated lifetime values do not take into account other stresses of insulation systems during their service. For multiple synergetic stresses, lifetime duration values are smaller [1].

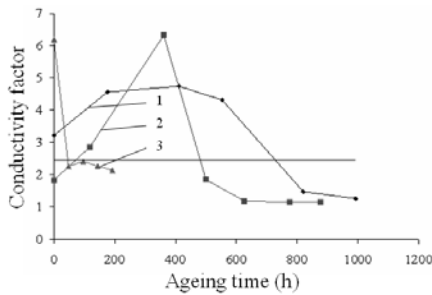


Fig. 10 – Variation of the conductivity factor k_c with ageing time β for A samples at $T_1 = 210$ °C (1), $T_2 = 230$ °C (2) and $T_3 = 250$ °C (3).

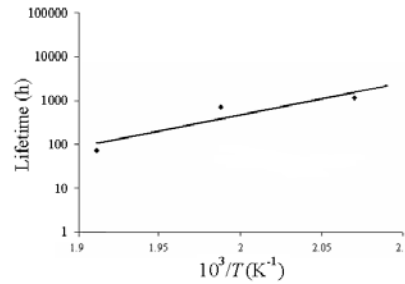


Fig. 11 – Lifetime curve for A samples corresponding to the k_c diagnostic factor and end-of-life criterion $k_{c,eol} = 2$.

4. CONCLUSIONS

The analysis of the absorption/resorption currents (and particularly of the currents given by the space charge) can offer important information concerning the ageing of electrical machines insulation systems.

The values of lifetime L obtained based on the absorption currents (using k_p and k_c as diagnostic factors) are relatively close to the ones obtained using mass loss determination (for $T_6 = 155$ °C, the variations do not exceed 5 %), which confirms the accuracy of the results obtained through A/R method.

The method of absorption/resorption currents presented in this paper is a nondestructive one and can be easily applied for the lifetime estimation and for the diagnosing and monitoring of insulation systems of high power electrical equipment in service (through off-line measurements).

The estimation of the insulation systems' degradation based on the comparison of the absorption/resorption currents obtained on the B samples will be presented in a next paper.

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REFERENCES

1. P. V. Notinghamer, *Materials for Electrotechnics*, Politehnica Press, Bucharest, 2005.
2. F. W. Peek, *Dielectric Phenomena in High Voltage Engineering*, McGraw Hill, New York, 1929.
3. * * *, IEEE Guide for the Statistical Insulation Voltage Endurance Data, ANSI/IEEE Std. 930, 1987.
4. V. M. Montsinger, *Loading Transformers by Temperature*, AIEE Trans., **61**, pp. 742–749 (1942).
5. T. W. Dakin, *Electrical Insulation Deterioration Treated as a Chemical Rate Phenomenon*, AIEE Trans., **67**, pp. 113–122 (1948).
6. P. Paloniemi, *Theory of Equalization of Thermal Aging*, IEEE Trans. on Electr. Insul., **16**, pp. 1–30 (1981).
7. L. Simoni, *A general approach to the endurance of electrical insulation under temperature and voltage*, IEEE Trans. on Electr. Insul., **16**, pp. 277–289 (1981).
8. T. S. Ramu, *On the Estimation of Power Apparatus Insulation under Combined Electrical and Thermal Stress*, IEEE Trans. on Electr. Insul., **20**, pp. 70–78 (1985).
9. B. Fallou, C. Burguiere, J. F. Morel, *First Approach on Multiple Stress Accelerated Life Testing of Electrical Insulation*, Proc. of CEIDP, pp. 621–628, 1979.
10. G. C. Montanari, M. Cacciari, *A Probabilistic Life Model for Insulating Materials Showing Electrical Thresholds*, IEEE Trans. on Electr. Insul., **24**, pp. 127–137 (1989).

11. J.-P. Crine, J.-L. Parpal, Ch. Dang, *A New Approach to the Electric Aging of Dielectrics*, Proc. of CEIDP, Leesburg, Virginia, pp. 161–167, 1989.
12. T. Tanaka, A. Greenwood, *Advanced Power Cable Technology*, CRC Press, Boca Raton, 1983.
13. G. Bahder, T. Garrity, M. Sosnowski, R. Eaton, C. Katz, *Physical Model of Electric Aging and Breakdown of Extruded Polymeric Insulated Power Cables*, IEEE Trans. on Power Appar. and Syst., **101**, pp. 1378–1388 (1982).
14. G. C. Montanari, *A Comparative Investigation of Electro-Thermal Endurance Models for Insulating Materials and Systems Characterization*, IEEE Electr. Insul. Mag., **13**, 3, pp. 13–25 (1997).
15. P. V. Notingher, *Le calcul des durees de rupture des dielectriques solides*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **31**, 2, pp. 133–144 (1986).
16. C. L. Griffiths, J. Freestone, R. N. Hampton, *Thermoelectric Aging of Cable Grade XLPE*, Proc. of the IEEE-ISEI, Arlington, pp. 578–582, 1998.
17. L. A. Dissado, G. Mazzanti, G. C. Montanari, *The Role of Trapped Space Charges in the Electrical Aging of Insulating Materials*, IEEE Trans. on Electr. Insul., **4**, pp. 496–506 (1997).
18. J. Biernat, J. Jarnicki, K. Kaplon, A. Kuras, G. J. Anders, *Reliability Considerations in Accelerated Life Testing of Electrical Insulation with Generalized Life Distribution Function*, IEEE Trans. on Power Syst., **7**, 2, pp. 656–664 (1992).
19. R. E. Droper, B. J. Moore, R. H. Rehder, *Insulation System Evaluation for Rotating Machinery*, IEEE Electr. Insul. Mag., **11**, 4, pp. 19–25 (1995).
20. S. Busoi, P. V. Notingher, L. M. Dumitran, *Estimation of the Degradation State of Medium Power Machines Insulation by the Polarization Index*, Proc. of Joint Int. Conf. “Materials for Electrical Engineering”, Bucharest, 2008, pp. 420–425.
21. M. Farahani, H. Borsi, E. Gockenbach, *Dielectric Response Studies on Insulating System of High Voltage Rotating Machines*, IEEE Trans. Dielectr. Electr. Insul., **13**, 1, pp. 383–393 (2006).
22. G. C. Stone, E. A. Boulter, I. Culbert, H. Dhirani, *Electrical Insulation for Rotating Machines. Design, Evaluation, Aging, Testing and Repair*, 1st Edition, Wiley-Interscience, 2004.
23. G. C. Montanari, A. Cavallini, *Insulation Condition Assessment of Power Equipments in Electrical Assets Based on On-line Monitoring of Partial Discharges*, Proc. of Int. Conf. on Condition Monitoring and Diagnosis, Beijing, pp. 1–6, 2008.
24. A. Wichmann, *Two Decades of Experience and Progress in Epoxy Mica Insulation Systems for Large Rotating Machines*, IEEE Trans. Power Appar. and Syst., **PAS-102**, pp. 74–82 (1983).
25. M. B. Srinivas, T. S. Ramu, *Multifactor Aging of HV Generator Stator Insulation Including Mechanical Vibrations*, IEEE Trans. Electr. Insul., **27**, pp. 1009–1021 (1992).
26. P. V. Notingher, Cristina Stancu, L. M. Dumitran, P. Notingher jr., Aleksandra Rakowska, K. Siodla, *Influence of the Ageing State of Insulation Systems on Absorption/Resorption Currents*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **53**, 2, pp. 163–177 (2008).
27. P. V. Notingher, L. M. Dumitran, S. Busoi, E. Balescu, G. Tanasescu, *The Use of Conductivity Factors for Estimating the Degradation State of Insulation Systems of Medium-Power Electrical Machines*, Proc. of Int. Conf. on Cond. Monit. and Diag., Beijing, pp. 126–129, 2008.
28. G. Reza, E. David, *Condition Assessment of Rotating Machine Winding Insulation by Analysis of Charging and Discharging Currents*, Proc. of IEEE Int. Symp. Electr. Insul., Toronto, 2006, pp. 336–339.
29. L. Rux, B. McDermid, *Assessing the Condition of Hydrogenerator Stator Insulation Using High-Direct Voltage Test Method*, IEEE Electr. Insul. Mag., **17**, 6, pp. 27–33 (2001).
30. * * * IEC PUBLICATION 60216-1, *Electrical Insulation Materials – Properties of Thermal Endurance–Part 1: Ageing Procedures and Evaluation of Test Results*, Fifth Edition, 2001–07.
31. R. Bruetsch, H. Brandes, A. Debuissou, B. Marasic, M. Schulz, *Polyesterimide Resins for Rotating High Voltage Machines*, Coil Winding Int. & Electr. Insul., **30**, pp. 20–28 (2007).