Ročník 2011 electroscope Číslo VI

Partial Discharges and Breakdown Voltage Diagnostics during Thermal Aging of Insulating Materials

J. Pihera [1], P. Mráz[1], R. Haller[2], V. Mentlík[1]
[1] Katedra technologií a měření, Fakulta elektrotechnická, ZČU v Plzni,
Univerzitní 26, Plzeň
[2] Katedra elektroenergetiky a ekologie, Fakulta elektrotechnická, ZČU v Plzni,
Univerzitní 26, Plzeň
E-mail : pihera@ket.zcu.cz, pmraz@ket.zcu.cz, rhaller@kee.zcu.cz, mentlik@ket.zcu.cz

Abstract:
This paper is focused on thermal aging and accompanied partial discharge diagnostics of two mainly used resin rich mica tapes, which are utilized as a part of insulation system of large rotating machines like turbo or hydro generators. The first tested specimen was mica composite material based on glass fibre and epoxy resin and the second one was composite based on PET and epoxy resin as well.

The specimens were tested under laboratory conditions. The materials were thermally aged and the changes of its physical and chemical properties were measured and evaluated. For accelerating the aging process different temperature values (170 – 186 °C) were chosen. The aging time was determined for each temperature value. Specimens of tested material were performed and cured as flat plate 100×100 mm. The measuring of these specimens was carrying out by test voltage at special electrode test setup. For comparing the aging process of the investigated material the trends of measured partial discharge (pd) parameters (inception voltage, extinguish voltage, peak charge level) were studied and described in dependence on exposure time, temperature and applied voltage during measurement.

INTRODUCTION

The operational lifetime of electrical machines is primary influenced by the insulation system quality. The operational lifetime of electrical insulating system is commonly determined, estimated and predicted in terms of accelerated laboratory aging of tested insulating materials. Accelerated aging could be applied as single factor aging like thermal or electrical aging or multiple factor aging as well. During the multiple factor aging all factors take effect together in the same time. Degradation of an insulation system occurs during the accelerated aging. The degradation is related to the physical and chemical changes within material structure. These changes are consequently detectable with physical or chemical test methods.

Partial discharge testing belongs to one of the high applicable test method of insulating materials within electrical machines. This non-destructive test method allows determining the degradation ratio or homogeneity of insulation.

The investigated mica resin rich composite based on glass fibre and epoxy resin was thermally aged and the changes of its physical- and chemical properties were measured during accelerated aging. Partial discharges (PD) were measured as well. The characteristic parameters according to IEC 20 670 as inception voltage (U_i), extinguish voltage (U_e) and apparent charge level (Q_{iec}) were measured and analysed.

At first the preliminary thermally aging lifetime curves of tested materials were performed. As a result of these tests the values of aging temperature and aging time for each temperature level could be determined [1]. Two values characterize the preliminary lifetime curve. First value is the maximal temperature; second one is the minimal endurance temperature. Maximal endurance temperature is given by eight hours endurance test. Minimal endurance temperature is given by temperature class and by the material manufacturer who declared lifetime of material for 30 years at this temperature. The eight hours maximal temperature was determined by the fact that the loss factor value was increased rapidly in comparison to the virgin state or according to the visual changes of specimen (deformations, delaminating, bending, deflection etc). The aging time was determined according to the preliminary lifetime curves ([1], fig.1). The aging temperature values are chosen according to the experimentally total duration and cost as well.

Four aging temperature values for glass fibre material (170, 175, 180, 186°C) and for PET material (170, 178, 186, 194°C) were chosen for material accelerated aging (table 1). The aging time was determined for each temperature value ([1], fig.1, table 1).

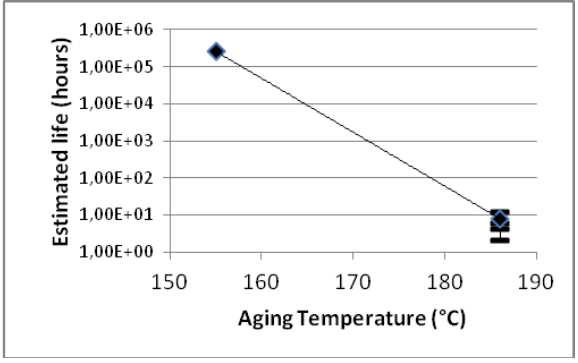

Fig. 1: Preliminary lifetime curve

Tab. 1: Aging temperature values and aging times

Temperature (°C)	**Aging time at given temperature (hour)**				
Glass fibre					
186°C	2	4	6	8	10
180°C	8	16	24	32	48
175°C	48	96	144	192	240
170°C	192	288	384	480	600
PET					
194°C	1	1,5	2	2,5	3
186°C	2	10	15	20	25
178°C	24	48	72	96	120
170°C	192	288	384	480	600

TEST PROCEDURE

Partial discharge measurement

The pd testing was performed using a commonly available test system[1], which allowed the measurement of the recommended IEC- magnitudes included the describing of the pd behaviour in a well known PRPD- pattern. The specimens of tested material were performed and cured as flat plate 100×100 mm, located in a special test setup and measured in a standardized pd test circuit[2] (fig.2, fig.3). The impact force F to the upper electrode was realized by a spring and had a constant value at each test.

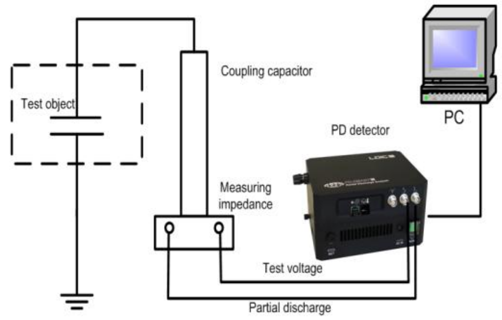

Fig. 2: PD circuit

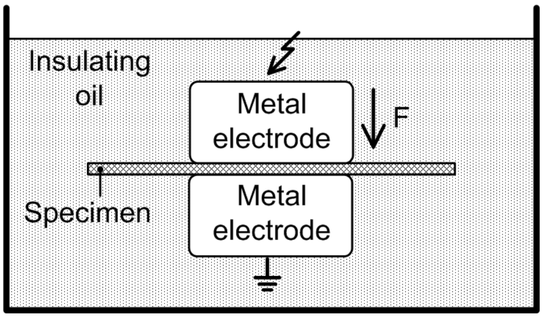

Fig. 3: Test setup

The measuring of partial discharges was performed according to the IEC 60270 [3] requirements with five specimens aged at one particular temperature and time. The following measuring procedure was carried out: The test voltage was increased up to the inception voltage U_i .When the inception voltage was reached this value was stored and the voltage was again increased up to 1,2 U_i (~14 kV). After 10 minutes at that value the test voltage was decreased stepwise (DU ~ 1 kV) down to the extinguish voltage U_e at each step the value Q_{iec} was measured Then the test voltage was decreased on 20 % (~ 9 kV) and the same procedure as described was repeated. Because of the statistic evaluation the procedure was repeated 7 times. It was assumed, that the electrical aging during these procedure can be neglected

Breakdown voltage measurement

Breakdown voltage was measured according to the IEC 60243-1 [2]. The breakdown occurs between 10 and 20 second after the moment the voltage was applied and linearly increased. The breakdown was detected by a breakdown detector and the value of voltage was stored. For each value of selected aging temperature and time 7 specimens were tested.

RESULTS OF PARTIAL DISCHARGE BEHAVIOUR

The pd behaviour of PET and glass fibre based material shows independent of the aging process (temperature, time) some significant difference. At low values of electrical intensity[3] the measured charge Q_{iec} of glass fibre are significant smaller than those of PET based material (Fig. 4). If the electrical intensity reaches a value of ~25 kV/mm, the measured charge is rapidly increased and exceeds even the value of the PET material. In the same case the PET specimen "started" at higher electrical intensity but with higher values of the measured charge.

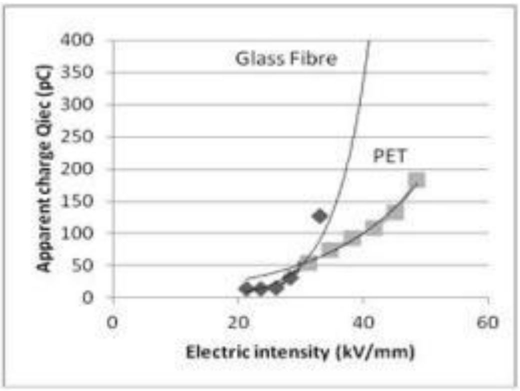

Fig. 4: Value Qiec versus electric intensity - results over the whole aging process (temperature, time)

---

[1] LEMKE PD SMART

[2] the noise level was under 3 pC threshold

[3] For a better generalizing of obtained results the electrical intensity (U/d) was calculated (d => sample thickness)

This behaviour is expressed also in the dependencies of the PD inception intensity at different aging temperature (Fig. 5).

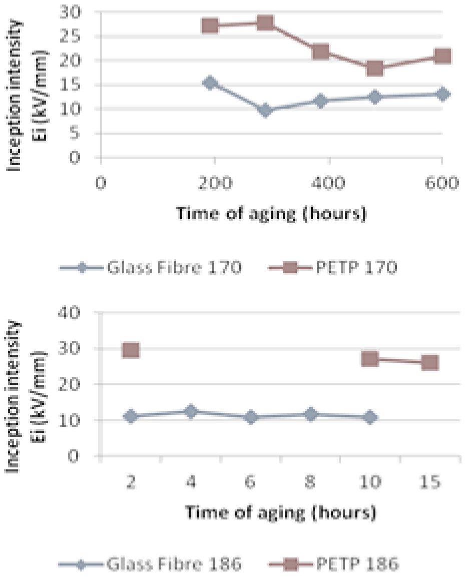

Fig. 5: Inception intensity of Glass and PET at aging temperature 170°C and 186°C

The inception intensity over the aging time at lower aging temperature (170 °C) shows a typical behaviour over the time- after some higher values the inception intensity decreases to a local minimum, but after that increases again (Fig. 5a). It seems to be some structural changes in the material could be occur. At higher aging temperature (186 °C) the inception intensity is more and less constant over the time (Fig. 6b). In both cases the inception intensity is significantly lower for glass fibre materials. It shall be noticed, that the range of the measured values related to the average value in case of PET is much higher (~30 – 50 %) than for glass fibre materials (15 – 25 %).

That means that the manufacturing process for the PET materials should have a larger complexity than the glass fibre insulation. Another question is the possible influence of cumulated internal charges on the aging process. If can be assumed, that the difference between the inception and extinguish intensity is a certain measure for internal cumulated charge, so can be seen, that only in case of PET materials a small change of charge intensity could be measured over the aging time at different aging temperature. At glass fibre materials this difference does not occur.

The typical PRPD- pattern at 14 kV and 170 °C are shown in Fig. 6. At higher aging temperature this pd- behaviour does not change its principal PRPD- characteristic, but their charge values are increasing.

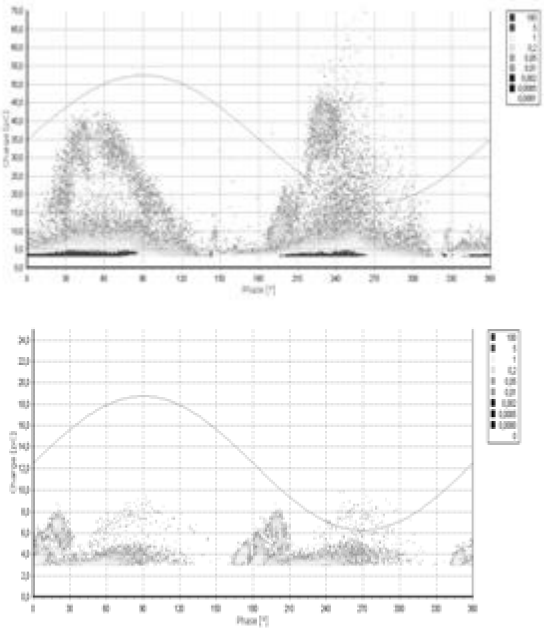

Fig. 6: PRPD- pattern for PET and Glass Fiber at 14 kV

BREAKDOWN VOLTAGE MEASUREMENT

Breakdown voltage and electric strength results respectively are presented in Fig. 7-9. There are shown average breakdown values for particular aging temperature and time in Fig. 7 for glass and PET material. There are the values of average values for all measured data and the values of ± s. There is evident the data are in the range of ± s. This could be represented as the breakdown voltage doesn’t show any aging process within the material during temperature aging. When the weibull probability plot is constructed from the breakdown data the differences are more evident as shown in Fig. 9. These pictures are build according to weibull probability with dependence on aging temperature.

There are shown other results of breakdown voltage in Fig. 8. These pictures follow life-time curves based on breakdown voltage. The construction of these curves is based on measured data and quadratic model calculation for particular breakdown criteria. The criteria are given as follows: Glass material – 90 kV/mm and PET material – 105 kV/mm.

The model is calculated for measured data and extrapolated for class temperature F (155 °C). Comparing the two materials there is evident that PET based material has better breakdown endurance and higher life-time. It is important to realize that the lifetime curve could be affected by “non-aging” process in breakdown data as described above and shown in Fig.7.

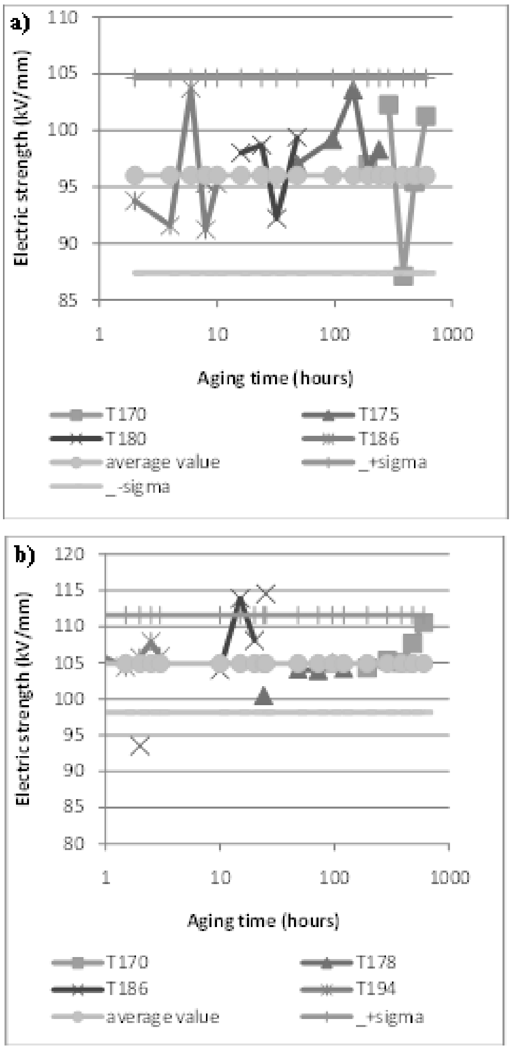

Fig. 7: Electric strength according to aging time – - a) Glass; b) PET

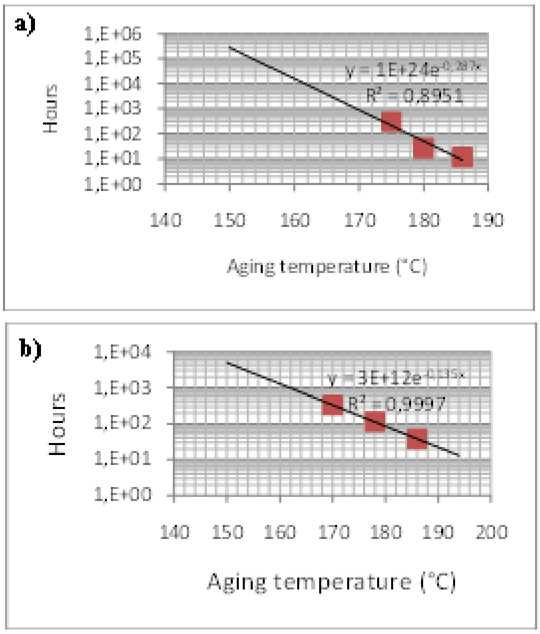

Fig. 8: Lifetime curve based on breakdown voltage- a) Glass; b) PET

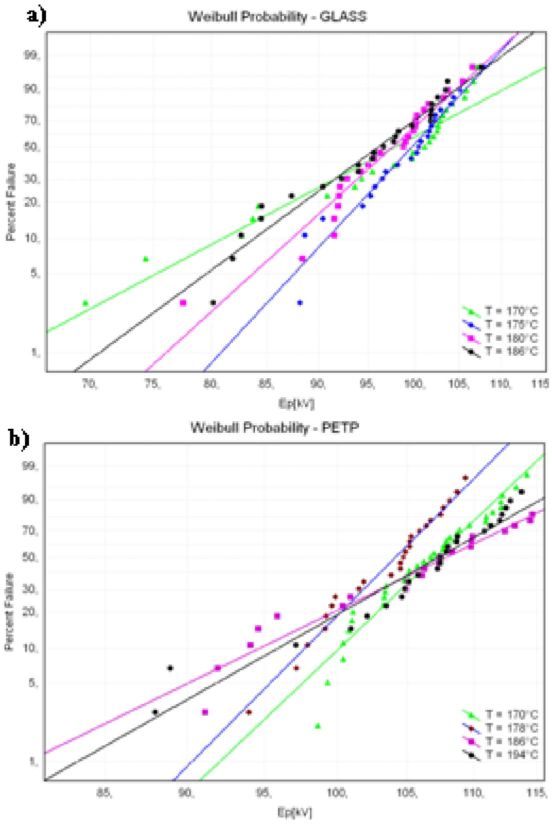

Fig. 9: Weibull Probability a) Glass; b) PET

CONCLUSIONS

There was shown the experiment of aging of two different materials in this article. The results of measuring the partial discharge and breakdown voltage was described and discussed as well. There was shown the partial discharges are more sensitive to detect the changes within material structure during thermal aging than the breakdown voltage test.

When comparing the materials of the partial discharge and breakdown strength the PET based material has higher values of breakdown strength, lower partial discharges Qiec values and higher inception intensity of partial discharges. When comparing the behaviour during aging, the inception intensity especially, the PET based material has significant decrease of the values. Glass based material doesn’t show the evident decrease of inception intensity and the curves are flat during aging.

It was shown that the pd measurement could be more sensitive to detect the changes within material structure during thermal aging than the breakdown voltage test.

The obtained results show that the PET based material is more robust against thermal aging than the glass fibre materials and, therefore, more appropriate for using in the insulation of large rotating machines.

For better understanding of aging process further investigation seems to be necessary.

ACKNOWLEDGMENTS

This research was funded by the Ministry of Education, Youth and Sports of the Czech Republic, MSM 4977751310 – Diagnostics of Interactive Processes in Electrical Engineering. The authors are grateful for the support of this program.

REFERENCES

[1] 1. Mentlik, V, at all.: Research Grant MŠMT Czech Republic, MSM 4977751310, Report 2010.
[2] 2. IEC 60 243-1 "Electrical strength of insulating materials - Test methods - Part 1: Tests at power frequencies".
[3] 3. IEC 60 270 "High-voltage test techniques - Partial discharge measurements".
[4] 4. Bezdekovsky, J., Krupauer, P. Statistical methods for appraisal of quality of stator winding insulation of big rotating machines , Electroscope, url: www.electroscope.zcu.cz, volume 2009, Number 1, last accessed: January 2011.
[5] 5. IEEE 1434-2000: IEEE Trial-Use Guide to the Measurement of Partial Discharges in Rotating Machinery.
[6] 6. Hudon, C., Belec, M. "Partial discharge signal interpretation for generator diagnostics" in: IEEE Transactions on Dielectrics and Electrical Insulation, April 2005, Volume: 12 , Issue: 2, pages: 297-319.

AUTHORS

Ing. Josef Pihera, Ph.D., Ing. Petr Mráz, prof. Ing. Václav Mentlík, CSc.; Department of Technologies and Measurement, Faculty of electrical Engineering, University of West Bohemia in Pilsen; Univerzitní 8, 306 14 Pilsen; e-mail: pihera@ket.zcu.cz, pmraz@ket.zcu.cz, mentlik@ket.zcu.cz.

prof. dr. Ing. Rainer Haller, DrSc.; Department of Electric power engineering and Ecology, Faculty of electrical Engineering, University of West Bohemia in Pilsen; Univerzitní 8, 306 14 Pilsen; e-mail: rhaller@ket.zcu.cz.