Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 69 (2014) 1523 – 1528
Procedia Engineering
www.elsevier.com/locate/procedia

24th DAAAM International Symposium on Intelligent Manufacturing and Automation, 2013

V-A Characteristic Measuring of Stress Grading Tapes in the End-Winding of Synchronous Generators

Ondřej Krpal, Petr Mráz*

Faculty of Electrical Engineering, Univeristy of West Bohemia, Univerzitní 26, 306 14 Pilsen, Czech Republic

Abstract

In every electrical machine operating above 6 kV the partial discharges may occur on the surface of the stator bars or coils either between stator core or in the end-winding near the end of the stator core. The PD activity at the slot exit of the stator causes surface discharges which lead to a damage of the insulation and potential breakdown ending in shutdown of the machine. This can be prevented by applying stress grading materials such as semiconductive tapes or varnish. These materials with SiC particles used for this protection have nonlinear voltage - current characteristic which lowers the gradient of increasing voltage along the sruface. The paper describes surface discharges and deals with measurement of V-A characteristic of end-winding corona protection.

Selection and peer-review under responsibility of DAAAM International Vienna

Keywords: Synchornous generators; end-winding corona protection; surface dischrges; V-A characteristic

1. Introduction

The distribution of electric potential in the end-winding in high voltage rotating machines is unequal and therefore there must be applied materials which reduce the electric field gradient. Thus the occurrence of surface discharges is minimized. These materials are called stress grading system, semiconductive stress grading tape, anticorona protection or non-linear resistance grade. The name is based on its non-linearity of the electric current on voltage (fig. 1). These protections are applied with 2 cm overlap over conductive (slotted) protection.

* Corresponding author. Tel.: +420 377 63 4545.
E-mail address: okrpal@ket.zcu.cz

Selection and peer-review under responsibility of DAAAM International Vienna
doi:10.1016/j.proeng.2014.03.150

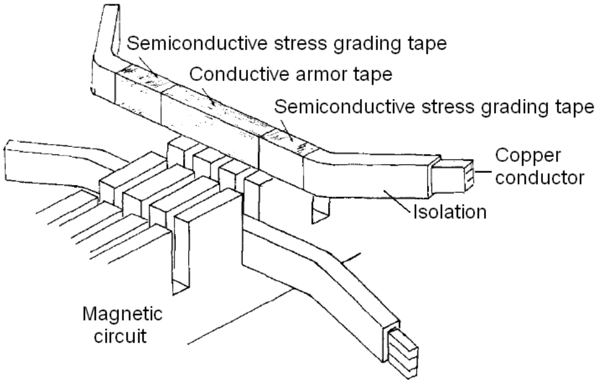

Fig. 1. Arrangement of the stator bars in synchronous generator [7].

1.1. End-winding corona protection

At the end winding area of rotating machines surface discharge (sometimes called also gliding or creeping discharge) can easily occurs. This is caused by strong electrical field gradient at interface of slot part and in the end-winding. [13]

Best way how to simulate and describe gliding discharge phenomenon is to use basic test arrangement as is displayed in figure 2a . Top electrode had circular shape and its diameter was 50 mm. Lower electrode had circular shape as well and its diameter was 75 mm. Insulating material was represented by block made of Poly(methyl methacrylate) (PMMA). Dimensions of this insulating material were 140x140 mm, thickness 10 mm. Top electrode was pressed to the insulating material by constant and defined pressure, which was ensured by spring located in a holder system of the top electrode.

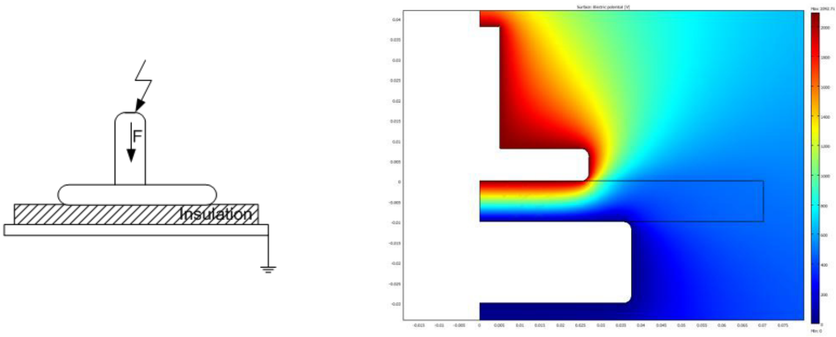

Fig. 2. (a) Basic test arrangement (b) Electrical potential model shows electrical stress of given arrangement.

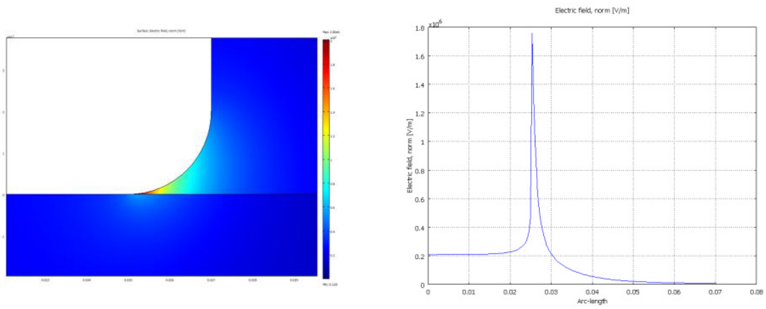

Fig. 3. (a) The highest electrical stress is on the interface of high voltage electrode and insulation material (b) Electrical field dependence on surface of insulating material (the diameter is from the centre of insulating material to its edge).

Inception voltage was 7.1 kV with apparent charge 1310 pC and extinction voltage was 6.8 kV for this arrangement. At the voltage level 10 kV apparent charge was 11.6 nC. It can be assumed that the charge values are relatively big and could have significant deterioration impact to insulation system.

Figure 1 shows the typical PD behaviour of gliding discharge at ϕ-q-n diagram. There is no phase shift during test voltage increasing. Gliding discharge activity is characteristic by two symmetric triangle diagrams, one is in positive half sinus wave and the second is on the negative half sinus wave of test voltage. The peaks are at 60° of phase in positive half sinus wave, respectively in 240° of phase in negative half sinus wave. In some cases the cluster in negative half sinus wave of test voltage can have smaller amplitude of charge. Only the size (the level of apparent charge) of diagram is changing with voltage increasing. [14]

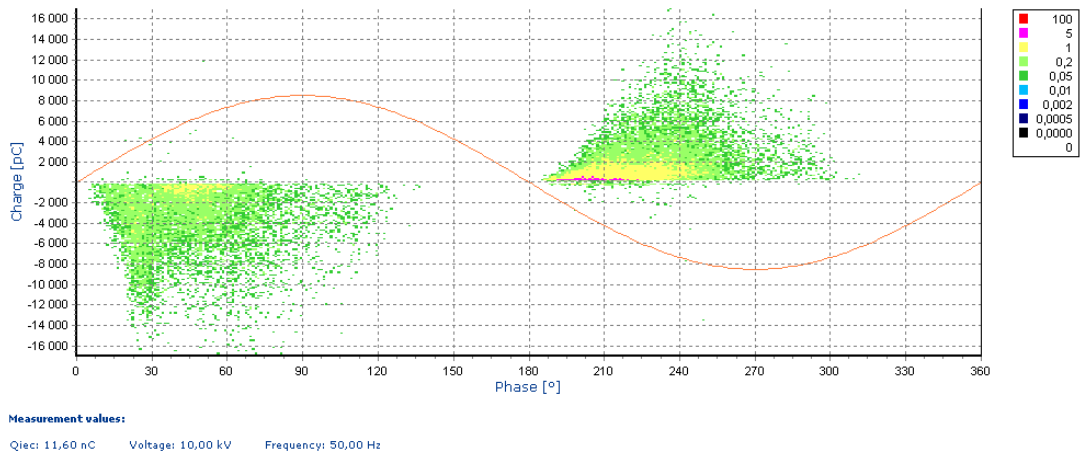

Fig. 4. Φ-q-n / PRPD pattern for gliding discharge.

At the same time the charge- voltage dependency is typically for gliding discharges (fig.5), [1-5]. All values are in the nC- range, with relative high dispersion behaviour, the PD activity is monotonously increased at higher test voltage.

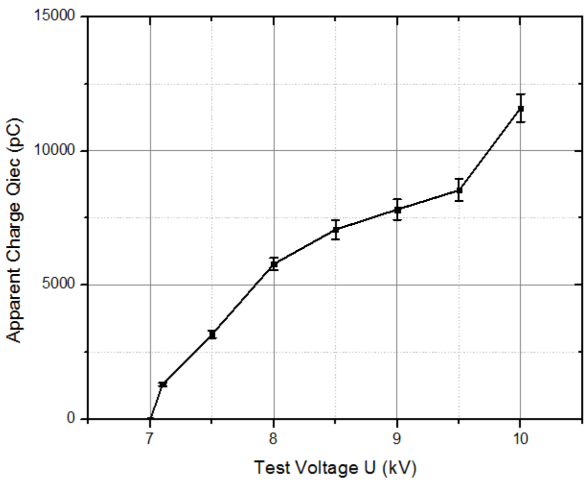

Fig. 5. Charge- voltage dependency of gliding discharge.

1.2. End-winding corona protection

End-winding corona protection is either varnish or a tape. The varnish is a modified phenolic resin with a semiconductive filler SiC. The tape consist of semiconductive filler SiC impregnated on a woven polyester tape with selvage.

The materials used for semiconductor protection are nonlinear, the resistivity varies in dependent on the supplied electric field (electric intensity). The materials are subject to the following requirements:

- The coefficient of nonlinearity β is used in the range β = 10-40 (by using semiconductor protection) and is given by:

$$\beta = 1 + \; [dln(\gamma)/dln(E)\,] \qquad (1)$$

β… nonlinearity coefficient [-];
γ…electrical conductivity [S · m-1];
E…value of the electric field [V · m-1].

- From the coefficient of nonlinearity follows the value of resistivity of the material depending on the applied electric field. In the weak electrical fields ($E < 1$ kV·mm^{-1}) the conductivity must be $\gamma < 10^{-10}$ S·m^{-1} (resistivity> 10^{10} Ω·m) in respect to the losses in material. For the intensity of 2 kV mm^{-1} (at f = 50 Hz) and relative permittivity ε = 10, the conductivity of the material should satisfy the condition that $\gamma >> \varepsilon\omega$, of which $\gamma >> 10^{-8}$ S·m^{-1} (ideally 10^{-7} - 10^{-6} S·m^{-1}).

- Another parameter defining the properties of the protective coating is permissible value of heat loss in insulation, which are determined by flowing electrical current. According to the actual measurement the value of flowing current in the end-winding corona protection should be less than about 50 μA, and the resulting Joule losses should not exceed about 0.2 W·cm^{-2} of surface insulation.

1.3. Properties modification of the semiconducting protection used in end-winding

SiC powder consisting of SiC grains that are always surrounded by a substance. Dielectric properties are determined by the contact zone at the microscopic level and the conductive paths are given by different local points at the macroscopic level. Therefore, to determine the electrical characteristics, both of these aspects need to be included. The behavior for the DC voltage is determined only by resistance at the contacts. If an AC voltage, the overall characteristics is determined by resistance, capacitance, but also the environment in which the powder is placed. The dependence of the component resistance on the electric field in the range from 1 kV / cm to 10 kV / cm is shown in figure 6a and particles of silicon carbide in figure 6b

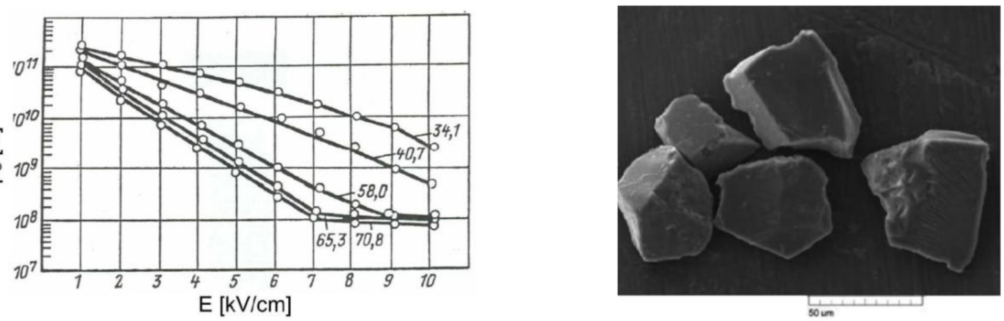

Fig. 6. (a) Effect of SiC concentration on rezistivity (b) Particles of silicon carbide.

- Shrinking the size of the main SiC particles increases the resistance of the composition and reducing nonlinearity coefficient β.

- There is a certain concentration of SiC powder in the component above which the value of resistance does not change (fig. 6a). When the concentration of SiC is higher than the limit, the component becomes porous and the resistance may decrease due to the penetration of moisture.

- Any type of powder and its concentration in the composite determines a certain critical value of electrical stress, above which stops decreasing of the resistance. The nonlinearity coefficient has a certain maximum.

1.4. Measurement of V-A characteristic of semiconductive tapes

Two samples of semiconductive tapes were examined. First sample A was brand new and curried 25 days after production. The second sample B was aged at 7°C for 695 days and curried after 2 years (exactly 712 days) from the production (simulating storing condition).

Both samples were winded on a glassfiber round timber with a diameter 40 mm and cured at 120°C for 2 hours. After the curing 11 bands of 10 mm width were placed around the round timber with a 10 mm distance from each other (fig 7). Thus, 10 gaps were made. The V-A characteristics were measured in all 10 gaps.

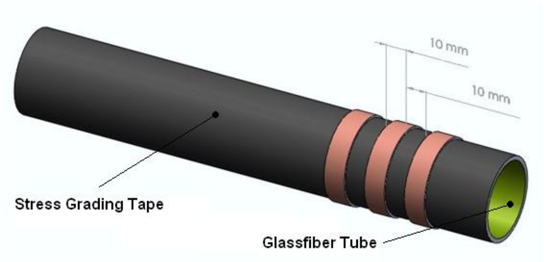

Fig. 7. Sample for the measuring.

The arrangement of the measuring is shown in figure 8. The voltage was increasing from 250 V up to 4 500 V with a 250 steps. Thus, both samples A and B were measured according to the standard SIB 14-07. The graphs are presented in figure 9 .

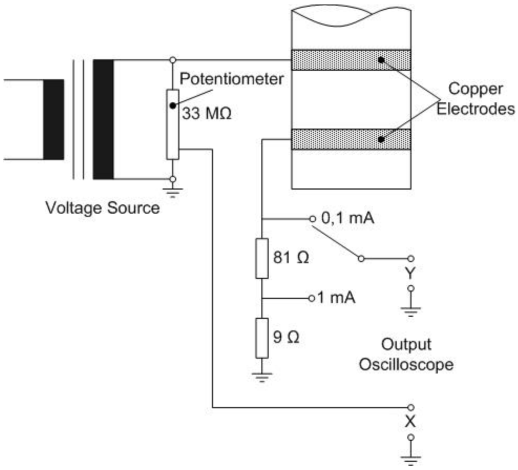

Fig. 8. Arrangement of measuring according to the standard SIB 14-07 [6].

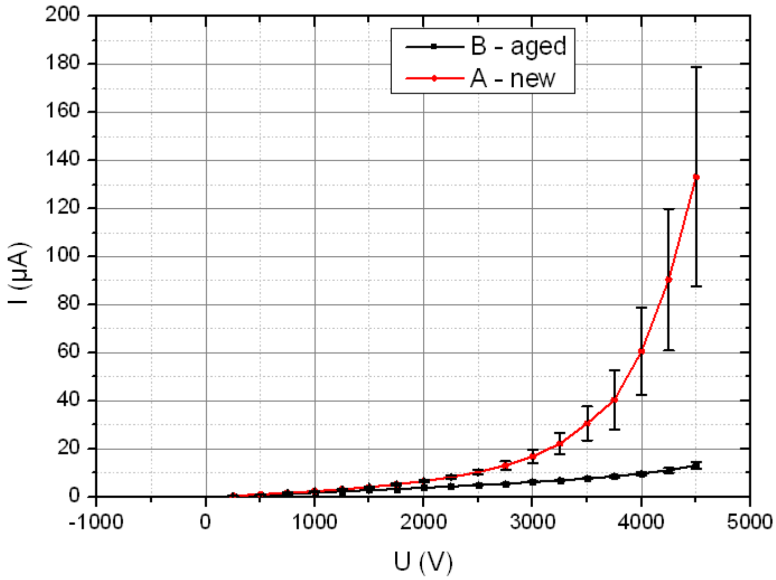

Fig. 9. V-A characteristic of measured samples A and B.

2. Conclusion

The graph shows two curves. The curve A is a non aged and curve B is an aged semiconducitve tape. From the courses of both curves it can be concluded that storing of the tapes is harmful to its properties and loosing its nonlinearity which is essential for the proper functioning of stress grading tape.

References

[1] Junhao Li; Wenrong Si; Xiu Yao; Yanming Li; , "Partial discharge characteristics over differently aged oil/pressboard interfaces," Dielectrics and Electrical Insulation, IEEE Transactions on , vol.16, no.6, pp.1640-1647, December 2009.

[2] Berg, G.; Lundgaard, L.E.; , "Discharges in combined transformer oil/paper insulation," Dielectric Liquids, 1999. (ICDL '99) Proceedings of the 1999 IEEE 13th International Conference on , vol., no., pp.144-147, 1999.

[3] Beroual, A.; Kebbabi, L.; , "Analysis of cumulative number and polarity of creeping discharges initiated at solid/liquid interfaces subjected to AC voltage," Electrical Insulation and Dielectric Phenomena, 2009. CEIDP '09. IEEE Conference on , vol., no., pp.380-383, 18-21 Oct. 2009.

[4] Kiiza, R.C.; Niasar, M.G.; Nikjoo, R.; Wang, X.; Edin, H.; Ahmed, Z.; , "Comparison of phase resolved partial discharge patterns in small test samples, bushing specimen and aged transformer bushing," Electrical Insulation and Dielectric Phenomena (CEIDP), 2012 Annual Report Conference on , vol., no., pp.88-91, 14-17 Oct. 2012.

[5] Hudon, C.; Belec, M.; , "Partial discharge signal interpretation for generator diagnostics," Dielectrics and Electrical Insulation, IEEE Transactions on , vol.12, no.2, pp. 297- 319, April 2005.

[6] Halbleitende Glimmschutzbander : Strom-Spannungsverlauf vom Glimmschutzbelag. - : Isola, 1978. 3 p.

[7] Roberts, A. Stress Grading for High Voltage Motor and Generator Coils. *IEEE*. 1995, 1, p. 26-31.

[8] Mentlík, Václav, et al. *Diagnostika elektrických zařízení*. Praha: BEN, 2008. 440 p. ISBN 978-80-7300-232-9.

[9] Záliš, Karel. *Částečné výboje v izolačních systémech elektrických strojů*. Praha: Academia, 2005. 135 p. ISBN 80-200-1358-X.

[10] Malamud, R.; Cheremisov, I. Anti-corona Protection of the High Voltage Stator Windings and Semi-Conductive Materials for Its Realization. *IEEE*. 2000, 1, p. 32-35.

[11] Malamud, R.; Schumovskaya, G.; Stepanova, T. The Development of Semiconducting Materials for Anti-Corona Protection Designs of Generator High Voltage Winding and their Testing at Cryogenic Temperatures.*IEEE*. 2008, 1, p. 420-423.

[12] Espino-Cortes, Fermin P., Edvard A. Cherney a Shesha Jayaram. Impact of Inverter Drives Employing Fast-Switching Devices on Form-Wound AC Machine Stator Coil Stress Grading. [online]. 2007, p. 16-28 [cit. 2013-02-19]. Availible at: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4068210.

[13] MRÁZ, Petr, Václav MENTLÍK a Josef PIHERA. Partial discharge activity of thermally aged stator winding bars. Annals of DAAAM for 2011 & Proceedings. 2011, roč. 22, č. 1. DOI.

[14] FILARETOV, V.F., A. N. ZHIRABOK a D TKACHEV. Non-parametric method for fault diagnosici in electrical circuit. Annals of DAAAM for 2012 & Proceedings. 2012, roč. 23, č. 1.