Improvement of GVPI Insulation System Characteristics by Curing Process Modification

M. Shadmand

***Abstract*—**The curing process of insulation system for electrical machines plays a determinative role for its durability and reliability. Polar structure of insulating resin molecules and used filler of insulation system can be taken as an occasion to leverage it to enhance overall characteristics of insulation system, mechanically and electrically. The curing process regime for insulating system plays an important role for its mechanical and electrical characteristics by arranging the polymerization of chain structure for resin. In this research, the effect of electrical field application on in-curing insulating system for Global Vacuum Pressurized Impregnation (GVPI) system for traction motor was considered by performing the dissipation factor, polarization and de-polarization current (PDC) and voltage endurance (aging) measurements on sample test objects. Outcome results depicted obvious improvement in mechanical strength of the insulation system as well as higher electrical characteristics with routing and long-time (aging) electrical tests. Coming together, polarization of insulation system during curing process would enhance the machine life time.

***Keywords*—**Insulation system, GVPI, PDC, aging.

I. INTRODUCTION

GVPI insulation system is recognized as the most applicable electrical insulation system for electric machines, especially for small electrical motors which are considered as repeat products. Traction motors would be categorized in this group. Based on duty-cycle and insulation system, thermal class for traction motors, having proper mechanical and electrical characteristics, play determinative role in machine life-time duration. Creating balance between process and materials plays an imperative role to obtain desired electrical, mechanical, and thermal characteristics [1]. Electrical, mechanical and thermal characteristics of raw electrical insulation material have been the main subjects for insulation system improvement. Controlling the GVPI process parameters for each specific insulation system depends on the raw material characteristics such as mica tape accelerator type, filler value, resin viscosity, resin and hardener mixing ratio, so the GVPI process would be set up for intended insulation system characteristics.

Utilizing polarity identity of insulation system raw materials plays the main role in this research to enhance the final GVPI insulation system characteristics in terms of both electrical and mechanical properties. To achieve the ultimate aim of the research, applying the electrical field on insulation system during the curing step of GVPI process was considered, and electrical qualification tests like dissipation facture measurement, PDCA and voltage endurance test have been performed on sample bars.

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II. EXPERIMENTAL SETUP

A. Sample Preparation

The usual GVPI process for traction motors includes impregnation and curing processes of wound stator. To check the effect of electrical field application on insulation system during the curing process, sample stator bars (straight part) have been produced according to Fig. 1. To have clear view of the insulation system situation, especially for voltage levels higher than machine nominal value, sample bars were designed for higher voltage level which will be called U_n in the article. Traction motors encounter repeat starts and stops and normally works with frequency converters, and high domain inrush voltages are expected during their operation; accordingly, the insulation system was designed for U_n.

For voltage application on samples during the curing process, metal shields are used instead of stator core. The other layers of insulation system were applied according to nominal voltage for designed insulation system. The insulation resin of the system was epoxy, and the filler used for experiment was alumina.

All protection layers used for sample bars were designed according to intended tests plan and would be not applied on real machine. To have the same vision for insulation system cured with and without electrical field application during its curing, samples are divided into two parts (A and B). All manufacturing processes including green-bars manufacturing, taping, impregnation and curing process were the same for two samples groups, excepting the electric field applying on the group B during the curing process. The applied voltage was 500 V (DC) between conductor and the OCP layer of sample bars (metal cover).

III. EXPERIMENTAL RESULTS AND DISCUSSION

A. Thermal Conductivity

Application of electrical field during the curing process of insulation system would enhance the thermal conductivity of the system. How much would be improved the capability of insulation to dissipate the heat depends on the material and the shape of fillers inside the insulation system. Table I illustrates the filler characteristics inside the used insulation system. Using this type of filler inside the insulation system would hone the thermal conductivity of the insulation system by 1.4 times. The larger the filler size, the more effective to increase the thermal conductivity [2].

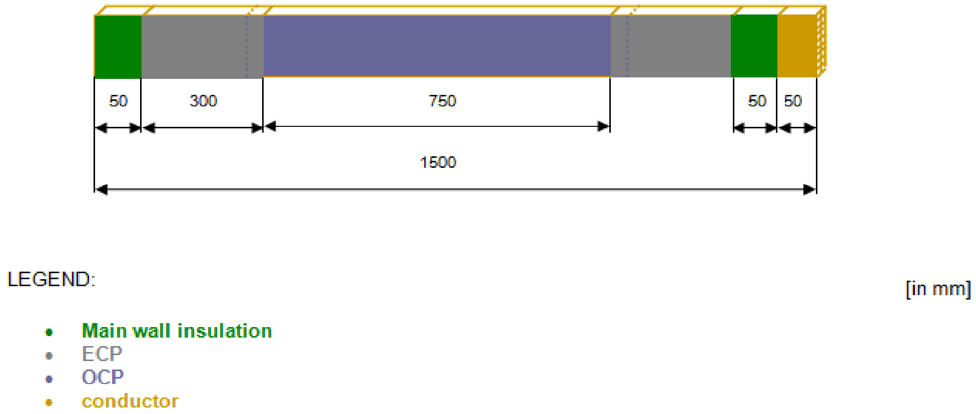

Fig. 1 Time-to-breakdown as a function of absolute humidity

TABLE I
PROPERTIES OF FILLERS FOR THE SPECIMENS

Mat.	Shape	Ave. particle length [μm]	Ave. particle thick. [μm]	Specific gravity ρ [g/cm^3]	Thermal cond. λ [W/m.°K]
Alumina	Plate-like	7	0.1	3.98	30

B. *Electrical Characteristics*

Obviously, both electrical and mechanical characteristics of the insulation system play essential roles for its life-time, and any changes in material, process, or design would change the system electrical and mechanical characteristics.

In this research, we have focused on electrical characteristics of the insulation system, and effect of new curing process on insulation system was considered through electrical point of view.

To consider the effect of electric field application on insulation system during the system curing, the following test was performed on sample stator bars: dissipation factor measurement, PDCA and voltage endurance [3], [4].

1. Dissipation Factor

Two groups of sample bars were produced (A and B) with the same dimension as depicted in Fig. 1. All bars were impregnated together and were cured under the same heating progress, yet the curing process of bars group B were under electric field application. For impregnating the samples with resin, heat (60 ºC) and vacuum (1.4 mbar) were applied in the vacuum tank simultaneously. Reaching the setting values for vacuum and temperature, resin flows into the tank till samples are immersed in. Then, 8 bars of pressure was applied on the resin surface by Nitrogen for 30 minutes. Pressure application time duration depends on bar dimension and number of insulation layers. After resin drainage, the curing process performed in two methods, with and without DC voltage application. The curing temperature was same for both groups. For group B which was cured under electrical field application, 500VDC was applied between the bar copper and metal shield.

Fig. 2 illustrates the dissipation factor measurement trend of samples. The applied voltage started from 0.2Un and increased up to 1.4Un with 0.2Un steps.

According to test results, the dissipation factor (tanδ) value for bars cured under electric field application is sensibly stable during the voltage increment (these bars have smaller tip-up values in comparison with samples cured without voltage application) that reckons the positive effect of electric field application on polymerizing the insulation resin molecules during its curing process. The first step of the dissipation factor measurement test shows the resin curing situation and as the insulation system resin was the same for both categories, the starting point for test is almost the same for all samples.

It must be noted that the dissipation factor measurement test results for all samples (groups A and B) are in acceptable criteria of international and internal standards. It means that the basic insulation system which was cured without electrical field application covers all technical requirements, yet the ultimate aim in this research is to enhance the quality of the product and extend the life-time of the products.

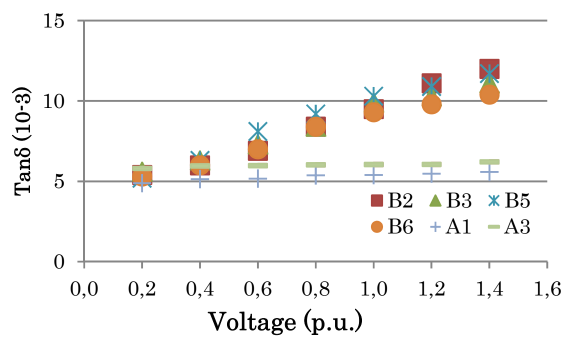

Fig. 2 Dissipation factor measurement of sample stator bars

2. PDCA

In alternative electrical machines, a part on insulation system internal loss goes to polarization and de-polarization on insulation system molecules during machine operation. This loss would cause to increase the insulation system temperature and finally would affect the system life time. Having sorted and well-bonded polymer chain structure for insulation system would decrease this type of loss. Theoretically application of DC electrical field would enhance the polymerized structure of the insulation system, and this would decrease the internal loss of the insulation system.

The PDC test is the most famous method which is used with appreciating modern and compact test apparatus. Beside all standardized test options defining to get accurate results, there are some other items which have considerable effects on the test output and acquiring conclusion, including the used insulation raw materials, type of insulation system, etc. [5]. In this part of research, the effect of electric field application on insulating system characteristics during its curing process was considered. To perform this, a 10-kV DC voltage source was connected to the samples (both types of A and B) and the PDC test performed on samples for 2000 seconds charging and 2000 seconds for discharging currents. Having less settling time during polarization period and less differentiation between PDCs are considered as advantages for insulation system. Figs. 3 and 4 show tests results.

According to tests results, there is some differentiation between samples A and B polarization and depolarisation currents and the settling time for both samples are almost the same (300 s). The polarization and depolarisation currents differentiation of samples A and B are depicted in Fig. 5 which illustrates less differential current for sample B which was cured under electric field. This result is compatible with the hypothesis of improving the insulation PDC characteristic cured under electric field.

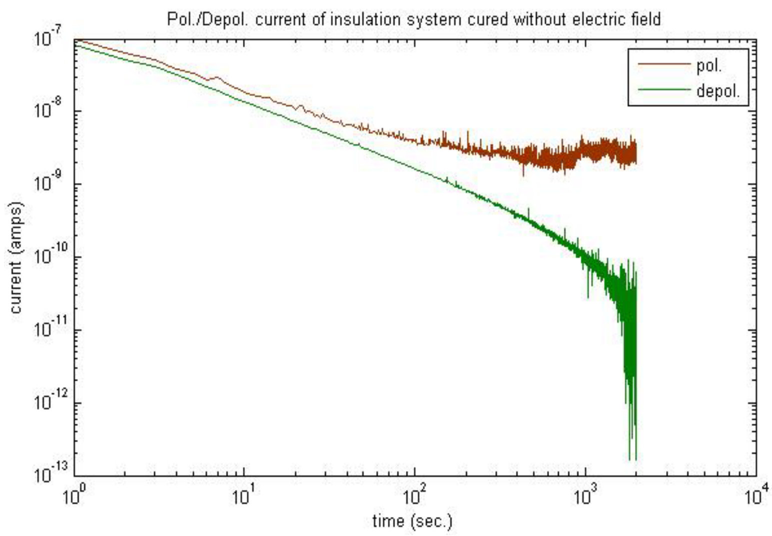

Fig. 3 Dissipation factor measurement of sample stator bars

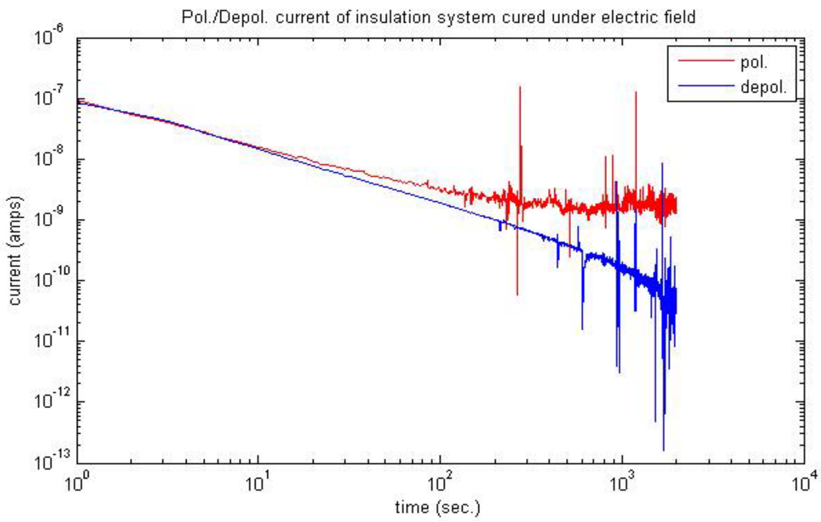

Fig. 4 PDC test on sample cured under electric field

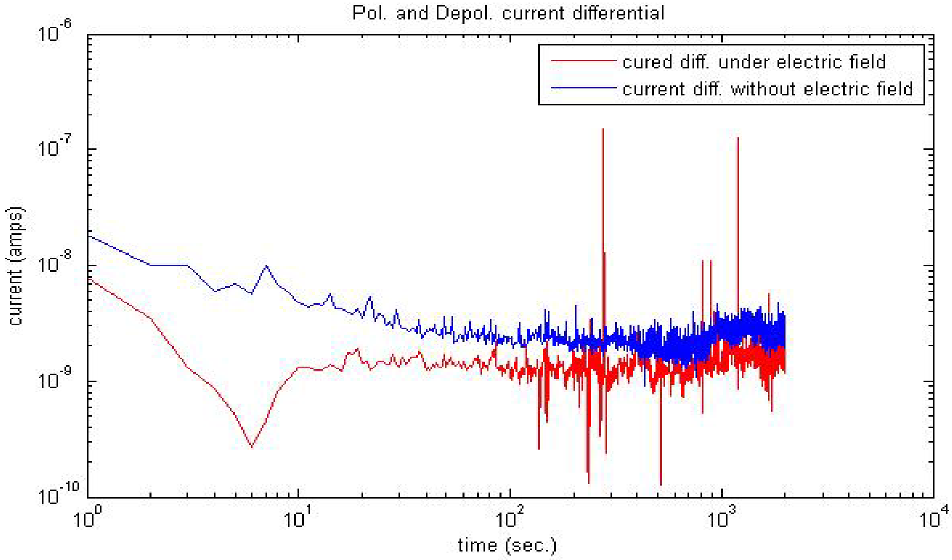

Fig. 5 Pol. and Depol. current differentiation for systems A and B

3. Voltage Endurance Test (VET)

Hypothetically and based on thermal characteristics sensible improvement by applying electric field on insulation system during is curing process, it is reasonable to predict resembling enhancement on life-time prospect of insulation system too. To consider this suggestion, 3Un voltage endurance test (VET) was performed on two sample bars of both groups A and B [6], [7]. Fig. 6 shows the VET tests results on samples and it is obvious to see the positive effect of voltage application on samples during their curing process. Theoretically applying electric field on un-cured insulation system would force the polar polymers of resin as well as fillers to redirect in the electric field flow direction and this causes to enhance the polymerisation of resin which would improve its characteristics in terms of electrical and mechanical.

Voltage endurance test is applied in two voltage levels with different acceptance criteria including $2.17U_n$ with minimum 500 hours' time duration without breakdown and $3U_n$ with minimum 10 hours' time duration without breakdown.

According to test results, both sample groups A and B have passed the minimum requirement for $3U_n$ VET test (10 hours), yet insulation B which was cured under electrical field application depicts considerably higher reliability.

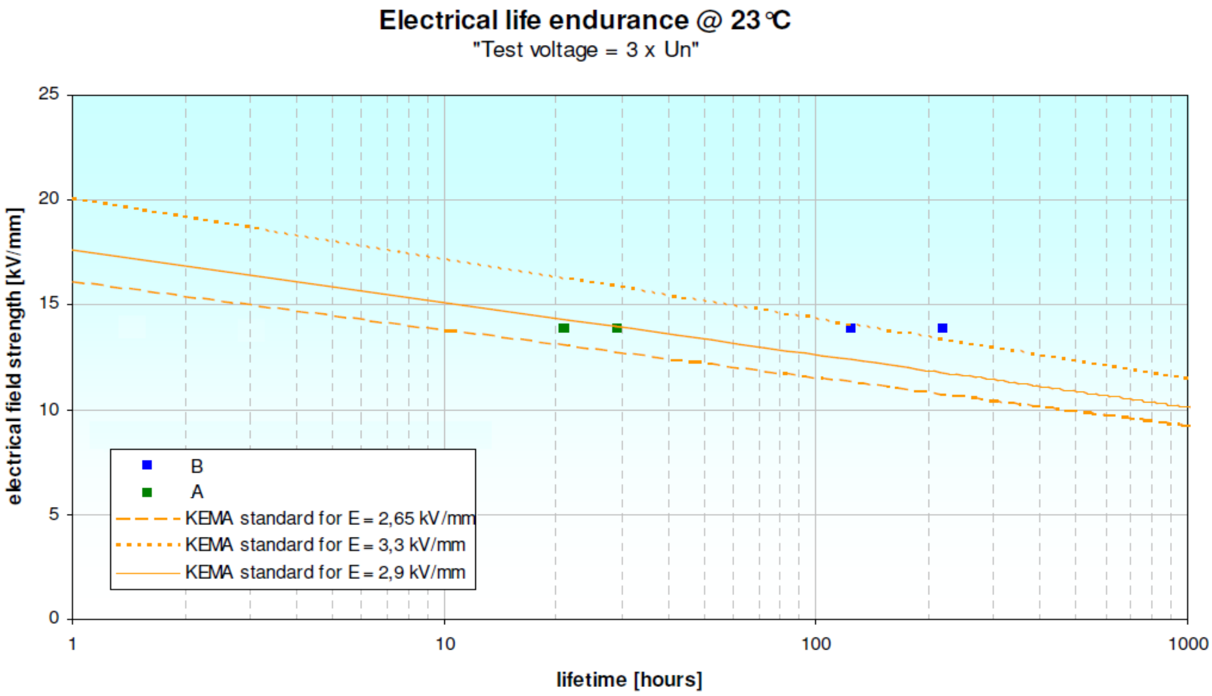

Fig. 6 VET test results on samples A and B (3Un)

IV. Conclusions

Insulation system of electrical machines is the centerpiece to determine the machine reliability and life-time. Raw material characteristics and manufacturing processes play the main role to achieve the desired insulation system.

Polar structure of insulation system raw materials, especially the resin and filler is a proper aspect which can leverage to enhance the insulation system quality. Application of electric field during the insulation system after impregnation process causes to establish a regular and tough polymerized structure which consequently produces a higher level of insulation system quality in terms of electrical, mechanical and thermal aspects. In this research, improvement of electrical characteristics of the insulation system was considered and based on tests results, insulation system quality enhancement was obvious.

Application of DC electrical field during insulation system curing process would arrange the polymerization process in same direction and would built up stronger and more tolerable polymer chains and based on performed tests results would improve the insulation system characteristics.

This method in industrial scale may not be applicable for big machines because it would need higher levels of electrical fields which may require vital modification on curing facilities, also it would have some safety issues. But, on smaller machines like traction motors and other motors in the same scale, it is applicable without considerable changes on manufacturing tools.

Acknowledgment

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