Study on the Measurement of Volt Ampere Characteristics of Silicon Carbide Stress Grading Materials

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Abstract. In order to optimize the design of the stress grading structure for the end-windings of high voltage (HV) electric machines, a suitable and convenient method for accurate measurement of Volt ampere characteristics became significant. In this paper, the volt ampere characteristics of the Stress grading coating (SGC) before and after impregnation were studied. The experiment found that the resistivity of SGC after the immersion paint was significantly improved. There were two orders of magnitude differences in resistivity before and after impregnation. For the sake of obtaining more accurate volt ampere characteristics of SGC after impregnation, a new method of pre electrode was proposed for the first time in this paper. The results showed that the current obtained by the method with pre electrode was larger and more accurate.

Introduction

With the developing voltage-class and capacity of electric machine or generator, the stress grading system of stator bar and end-winding plays an increasingly important role. The requirements of stress grading structure at the end-winding are more and more stringent [1-4]. The stress grading tape or stress grading paint filled with SiC powder material has become the main component of the pressure equalizing stress grading layer at the end of high voltage motor. In particular, SiC has nonlinear resistance characteristics (or nonlinear volt ampere characteristics), which can effectively prevent the generation of local high electric field intensity along the surface and prevent the occurrence of corona discharge along the surface. It has been widely used in the design and application of voltage balancing and stress grading of high voltage motor insulation.

The non-linear conductivity of SiC is the basis of obtaining excellent SGC, homogenizing the electric field at the end of motor and high Stress grading performance[5]. In the three-stage Stress grading structure of the motor, the surface inherent resistivity of each Stress grading layer is specified. Based on the actual insulation process (such as VPI impregnation) and the impregnation of insulating protective paint, the conductivity parameters of the Stress grading structural materials change[6].

This paper discusses the volt ampere characteristics of the SGC before and after impregnation. In this paper, a new test method of conductivity characteristic parameters of various Stress grading materials after impregnation was proposed, and the validity and applicability of the measurement method were evaluated. The test method for nonlinear conductive characteristics suitable for stress grading structure and material application was established which meets the requirements of design and screening of stress grading materials.

Study on the Volt ampere Characteristics of SGC before and after Immersion

The experiment used the method of repeating measurement of the same sample without breakdown. The DC voltage with different amplitude was applied to the SGC.
The relationship curve between the current passing through the sample and the applied DC electric field strength, and the relationship curve between the resistivity and the applied electric field strength were shown in figure 1 and figure 2. C-A was the original SGC, CI-A was the SGC impregnated with insulating paint, and the copper tape was used as the electrode.

It can be seen from Figure 1 that the current difference between the samples with and without impregnated paint was two orders of magnitude when the same electric field strength was applied.

Figure 2 showed the variation of the SGC resistivity($lg\rho$) with applied DC electric field ($E$). The higher the value of DC electric field, the lower SGC resistivity would be. The relationship between the surface resistivity and the applied electric field strength was a curve that approximates a straight line. The variation conforms to the stress grading property of the SiC material. It reduces the surface resistivity to reduce the surface electric field strength to achieve the purpose of stress grading.

![Figure 1. Current passing through the sample at different electric field.](image1)

![Figure 2. Resistivity at different electric field.](image2)

**Study on the Method of Measuring the Volt Ampere Characteristics of SGC after Immersion**

In the actual production process, the SGC on the stator bar needs to be immersed in insulating varnish. Due to the existence of the paint film, the way of directly sticking the electrode makes the measurement result have some degree of error. In this paper, a preset electrode method was proposed to measure the volt ampere characteristics of SiC SGC after impregnation with insulating paint, and the effect of different electrode arrangements on the measurement of volt ampere characteristics was compared by means of experiments.
Preparations of Experiment

The samples of SiC SGC with three different conductivities were named as A, B and C, respectively, according to their resistance values from low to high. After impregnating the epoxy anhydride resin varnish and the epoxy anhydride styrene resin varnish separately, the obtained SGC without preset electrodes were S-A, S-B and S-C, and D-A, D-B and D-C. The samples of SGC with preset electrodes were named as S-AY, S-BY and S-CY and D-AY, D-BY and D-CY.

1) Sample without preset electrode. The SGC length of the sample was 190mm. During the experiment, the copper tape was directly adhered to the two ends of the SGC sample as the electrode, and the electrode spacing was 10mm.

2) Sample with preset electrode. A low resistance SGC was wound around the epoxy tube as a preset electrode, the length of each preset electrode was 300 mm, and a spacing between adjacent two preset electrodes was 10 mm. Then, the SGC was wrapped in a half stack to obtain an SGC having a length of 30 mm, and the superposed portion of the SGC and each of the preset electrodes was 10 mm long. The copper tape was adhered to the low resistance SGC of the preset electrode as the electrode.

In the experiment, the output end of the power supply was connected with the copper electrode adhered on both sides of SGC. The micro galvanometer was connected in series with the experimental circuit, and the weak current passing through the sample was read out by the micro galvanometer.
**Results and Discussions**

S-A, S-B, S-C, D-A, D-B and D-C SiC SGC were respectively applied with 400-2000V DC voltage. The relationship between the magnitude of the current passing through the sample and the applied DC electric field under different voltage gradient was obtained.

![Graph](image1.png)

a) Epoxy anhydride paint sample

![Graph](image2.png)

b) Epoxy anhydride styrene resin paint sample

Figure 5. Comparison of the volt ampere characteristics with two methods.

As shown in the Figure 5, when the same voltage was applied to the same sample, the current through the sample with preset electrode was greater. Therefore, the current in the measurement results of volt ampere characteristics was relatively small. The way of preset electrode increased the contact area between the electrode and the sample as much as possible, and then reduced the error caused by the existence of paint film on the measurement results of volt ampere characteristics.

**Conclusions**

Based on the above experiment results and analysis, the following conclusions can be drawn:

1) The resistivity of SiC decreased with the increase of applied electric field strength, which was nonlinear. The SiC materials with the different nonlinear conductivities as the SGC could effectively decrease the local high electric field on the end-windings of high voltage machine.

2) Comparing the volt ampere characteristics of SGC before and after impregnation, it was found that the impregnating varnish changed the SiC content of SGC and its resistance value changed accordingly. After impregnation, SGC could withstand higher electric field strength and the resistivity had also been increased.
3) When the same voltage was applied, the current passing through the sample with preset electrode was greater. In order to obtain more accurate experiment results, the preset electrode is recommended to measure the volt ampere characteristics of SGC after immersion insulation.

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