Effect of Winding Coil Diameter on AC Insulation Breakdown Voltage of Polyamideimide/Nanosilica Wire

Jae-Jun Park† and Myung-Ha Woo
Department of Electrical and Electronic Engineering, Joongbu University, Goyang 10279, Korea

Jae-Young Lee
Hydrogen Fuel Cell Parts and Applied Technology Regional Innovation Center, Woosuk University, Wanju 55315, Korea

Se-Won Han
The Korea Electrotechnology Research Institute, Changwon 51543, Korea

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The AC insulation breakdown voltage was investigated for seven types of winding coils made of polyamideimide (PAI), flexural PAI (nanosilica 5 wt%) and anti-corona PAI (nanosilica 15 wt%) wires with various winding coil diameters of φ5, φ15 and φ25 mm. The winding coil was made of enameled wire with an enamel thickness of 30–50 μm, and the rectangular copper wire had a thickness of 0.77–0.83 mm and width of 1.17–1.23 mm, respectively. The insulation breakdown voltages of the original PAI coils with diameters of φ5, φ15 and φ25 mm were 7.30, 6.58, and 5.95 kV, respectively, and those values decreased as the winding coil diameter increased, regardless of the wire types.

Keywords: Enamel insulated wire, Coil diameter, Insulation breakdown voltage, Nanosilica

1. INTRODUCTION

In recent years, environmental issues have emerged as a global concern, and the energy efficiency in industrial motors has become more important, with many modern industrial motors now equipped with inverters or adjustable-speed drives to achieve a high efficiency. Also, inverter power supplies implement the pulse modulation (PWM) technique, for which insulated gate bipolar transistors (IGBTs) are used as high speed switching devices, to improve the controllability of the motor torque and to reduce the switching loss [1-3].

Polyamideimide (PAI) enameled wires exhibit good thermal and electrical insulation properties. Polyamide is a type of polymer with a high insulation breakdown strength and good heat resistance, mechanical strength and chemical resistance. Therefore polyamide-insulated wires have been used in harsh environmental conditions [4-6]. Polyimides are used in inverter-fed motor windings and in high-pressure coils for electric translators, and in recent years, elements allowing for high-speed switching, such as insulated-gate bipolar transistors (IGBTs), have been developed for use as inverter power devices.

The electrical strength of the enameled wire, is evaluated by measuring the insulation breakdown voltage using various methods [7], including (1) close contact with the cylinder, (2) twisted pairs, (3) U-bend specimen in shot bath and (4) Coil-wound specimen in a shot bath. All test voltages are applied with an AC voltage with a nominal frequency of 50 Hz or 60 Hz. The test voltage is applied from zero and increases at a uniform rate until breakdown.

In this study, the insulation breakdown voltage was investigated using coil-wound specimen in shot bath prepared using PAI enameled rectangular wires.
2. EXPERIMENTS

The PAI wires were prepared starting with rectangular copper wires with thickness of 0.77 to 0.83 mm and width of 1.17 to 1.23 mm, respectively, and coating them with seven types of PAI/nano-silica (15 wt%) enamels (Sam Dong Co., Ltd., Korea) with enamel thickness of 30 to 50 μm. The first wire was coated with original PAI, the three types for the second group were coated with double layers of flexural PAI and anti-corona PAI (nanosilica 15 wt%), and the three types for the third group were coated with double layers of flexural PAI (nanosilica 5 wt%) and anti-corona PAI (nanosilica 15 wt%). Type_1 and Type_4 were dried at 220 °C, Type_2 and Type_5 were dried at 240 °C, and Type_3 and Type_6 were dried at 260 °C.

The AC insulation breakdown voltage was tested in a shot bath, as shown in Figure 1. The insulation breakdown voltage was measured at a speed of 0.5 kV/s until the electrical insulation breakdown took place.

3. RESULTS AND DISCUSSION

Figure 3 shows the Weibull statistical analysis (Weibull++ 7.0) for an insulation breakdown voltage of the original PAI wires with various winding coil diameters at 60 Hz, and the Weibull parameters such as shape, scale, and B10 value were obtained from each Weibull plot and are listed in Table 1. That is to say, the shape parameter could be obtained from the slope, meaning that the data distribution and the scale parameter were obtained from the AC insulation breakdown voltage by which 63.2% of the cumulative probability was expected to fail. The B10 value represented the AC insulation breakdown voltage with a 10% cumulative probability. The insulation breakdown voltages at φ5, φ15, and φ25 mm were 7.30, 6.58, and 5.95 kV, respectively, and those values decreased as the winding coil diameter increased.

Figure 4 shows the Weibull statistical analyses for the insulation breakdown voltage of Type_1 wires with various winding coil diameters at 60 Hz. Type_1 was made of double layers with flexural PAI and anti-corona PAI (nanosilica 15 wt%), and the Weibull parameters were obtained from each Weibull plot and are listed in Table 2. The insulation breakdown voltages of Type_1 wires at φ5, φ15, and φ25 mm were 7.09, 6.44, and 5.77 kV, respectively, and those values decreased as the winding coil diameter increased. The insulation breakdown voltages for the Type_1 wires were slightly lower than those of the original PAI wire, and this means that the nanosilica in the anti-corona PAI (nanosilica 15 wt%) layer did not play a significant role in the electrical insulation.

Figure 5 shows the Weibull statistical analyses for the insulation breakdown voltage for wires of various types with a coil diameter of φ5 mm at 60 Hz. The Weibull parameters were obtained from each Weibull plot and are listed in Table 3. The Weibull parameters for wires of various types with a coil diameter of φ5 mm at 60 Hz, as obtained from Fig. 3.
The AC insulation breakdown voltage was investigated in winding coils of various diameters, including φ5, φ15, and φ25 mm. The winding coil was made of PAI/nanosilica enameled wires with an enamel thickness of 30~50 μm. The enamel has two layers made from flexural PAI or flexural PAI (nanosilica 5 wt%) and anti-corona PAI (nanosilica 15 wt%). The insulation breakdown voltages of the original PAI coils with φ5, φ15, and φ25 mm were 7.30, 6.58, and 5.95 kV, respectively, and those values decreased as the winding coil diameter increased regardless of the type of wire used. The order of the insulation breakdown strength was as follows: original PAI > flexural PAI/anti-corona PAI (nanosilica 15 wt%) > flexural PAI (nanosilica 5 wt%)/anti-corona PAI (nanosilica 15 wt%). This means that the nanosilica did not play a significant role in providing electrical insulation.

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