Inhibiting ice accumulation on conductors using sleeves treated with super-hydrophobic surfaces

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Abstract

Ice accumulation on transmission lines often lead to great damage to the power systems. Super-hydrophobic surfaces are proposed for anti-icing of electrical power equipment. This paper presents a novel anti-icing method for conductors with super-hydrophobic sleeves. The super-hydrophobic sleeves were prepared by forming PDMS/nano-silica hybrid coating on the outer surface of polyester sleeves. Hydrophobicity of the outer surface of the super-hydrophobic sleeve was investigated. Ice accumulation experiments were carried on the super-hydrophobic sleeve coated conductors and the polyester sleeve conductors. Ice accumulation morphology on the conductors coated with the super-hydrophobic sleeve and that on the conductors coated with the polyester sleeve were studied. Accumulated ice on the two types of conductors, coated with the super-hydrophobic sleeve and the polyester sleeve, were also investigated after different periods of ice accumulation experiments. The results showed that the super-hydrophobic sleeve were effective in inhibiting ice accumulation on conductors.

Index Terms - **super-hydrophobic, sleeve, anti-icing, conductors, ice accumulation**

1 INTRODUCTION

In the cold-climate regions of the word, ice accumulations on transmission lines often result in many operation problems of the electric power systems, such as line trip, line breaking, tower failures, conductor galloping, insulator flashover and communication interruption. These operation problems lead to long period of electric power outages at normal operating phase to-ground voltage [1], and thus result in tremendous economic losses to many countries. It is very necessary to employ anti-icing methods to reduce or avoid ice accumulations on transmission lines.

Super-hydrohobic coatings could repel water so extremely that water droplets can not stay on such kind of surfaces. Hence, the super-hydropohobic coatings are proposed for anti-icing and anti-snowing of power equipments. Using super-hydrophobic surfaces for anti-icing do not need additional energies and fit for the anti-icing of long distance transmission lines. Publications [2] investigated the ice repellent performances of the super-hydrophobic coating. The result showed that super-hydrophobic surfaces were excellent in preventing adhesion of snow. Publication [3], [4], [5] and [6] showed that the super-hydrophobic surfaces with low water-contact angle hysteresis possessed small ice adhesion strength than that with high water-contact angle hysteresis. These works illustrate that the super-hydrophobic surfaces are promising outdoor insulation materials used for anti-icing of electric power networks.

This paper presents the anti-icing performances of conductors covered with the super-hydrophobic sleeves, with super-hydrophobic outer surfaces. The super-hydrophobic sleeves were prepared by forming the PDMS/nano-silica hybrid coatings on the outer surfaces of polyester sleeves. Icing experiments were carried on conductors covered with the super-hydrophobic polyester sleeves. The ice accumulation morphology and accumulation ice weight on the covered conductors were studied.

2 FORMATION OF SUPERHYDORPHOBIC COATING ON POLYESTER SLEEVES

2.1 PREPARATION OF THE SUPER-HYDROPHOBIC SLEEVES

The super-hydrophobic sleeves were prepared by forming the PDMS/nano-silica hybrid coating on the outer surfaces of the polyester sleeves. Polyester sleeves, with the inner diameter of 50 mm, were made by rolling polyester films with the thickness of 0.1 mm. The PDMS/nano-silica hybrid coating were formed on the ounter polyester sleeves by two steps as follows: First, the outer surface of the cleaned polyester sleeves were sprayed with the PDMS/nano-silica hybrid glutinous liquid and placed in an oven at 60 °C for 5 minutes to obtain PDMS-coated polyester sleeves. Secondly, the PDMS-coated polyester sleeves were sprayed with the nano-silica coating and placed in the oven at 100 °C for one hour.

2.2 HYDROPHOBICITY OF THE OUTER SURFACE OF THE SUPER-HYDROPHOBIC SLEEVE

The water contact angle system, model of Drop Meter A-20, was employed to evaluate the hydrophobicity of the surface of the super-hydrophobic sleeve. Figure 1(a) shows the shape of a water droplet on the surface of the super-hydrophobic sleeve, obtained by the water contact angle system. The water droplet was spherically stayed on the surface of the super-hydrophobic sleeve. The water contact angles on the surface of the super-hydrophobic sleeve were in the range between 160° and 165°. The average value of the measured contact angles was 163°. The result indicated the super-hydrophobicity of the superhydrophobic sleeve.

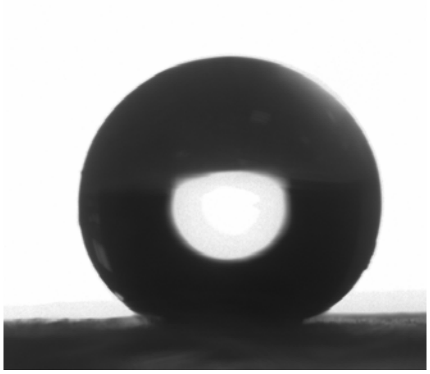

Figure 1. The shape of a 9.5-μL water droplet on the surface of the super-hydrophobic sleeve.

3 ICE ACCUMULATION EXPERIMENTS

3.1 TESTING FACILITIES

Ice accumulation experiments were executed in the multi-functional artificial chamber at the High Voltage Laboratory and Insulation Technological laboratory of Chongqing University. Figure 2 shows the schematic of the multi-functional climate chamber featuring an inner diameter of 7.8 m and an inner height of 11.6 m. It mainly consists of a refrigeration system, a vacuum-pumping system, a spraying system and a wind velocity regulation system. The lowest temperature in the artificial climate chamber can be adjusted to -45 °C ± 1 °C.

A relatively uniform wind is obtained using a system of ten fans placed in a tapering box with a diffusing honeycombpanel. The wind velocity in the artificial climate chamber can be adjusted freely between 0 m/s and 12 m/s by such ten fans. Water droplets with diameter of 10 μm ~ 100 μm can be generated by the spraying system, consisting of two rows of fog nozzles and a water pump. The nozzles, satisfying the IEC 60060-1 protocol standard [7], were mounted on an oscillating support vertical to the axis of the conductors. The spraying

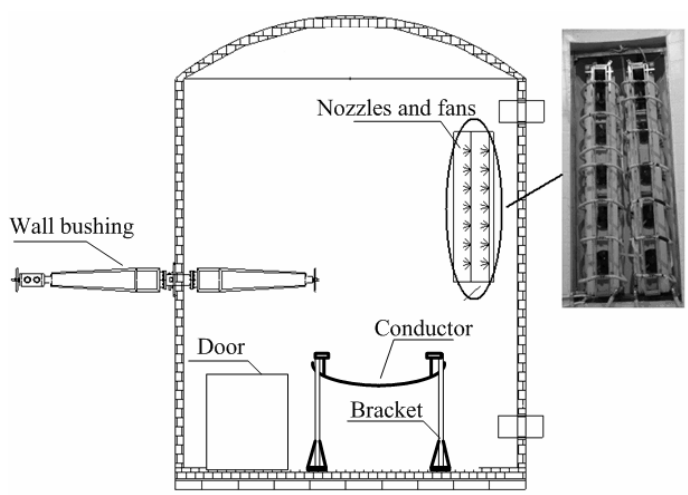

Figure 2. Schematic of the multi-functional artificial climate chamber in Chongqing University.

system is 3.36 m in height and 0.43 m in width. The oscillating movement helps to make the water droplets distributing uniformly along the conductors.

3.2 TESTING SPECIMENS

Conductors, coated respectively with the polyester sleeve and the super-hydropobic polyester sleeve, were employed in this work. The super-hydropobic polyester sleeves were fabricated by forming the PDMS/nano-silica hybrid coating on the polyester sleeves. Diameters of the two types of polyester sleeves were both of 50 mm, and thickness of the polyester films used for preparing polyester sleeve were 0.1mm. The conductors employed in this work are both model of LGJ-240.

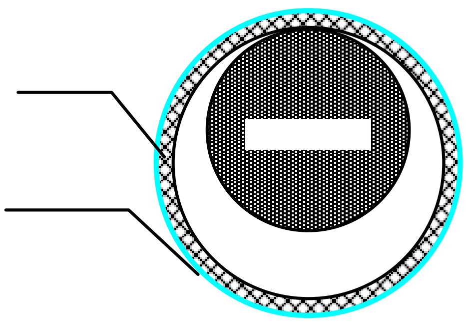

Figure 3. Schematic of the conductor coated with the super-hydrophobic sleeve

3.3 EXPERIMENT PROCEDURES

After the two conductors were placed on the bracket in the multi-functional artificial climate chamber, the air temperature in chamber was set at -5 °C. The wind velocity in the chamber was set at 5 m/s. Water droplets with conductivity of 255μs/cm were continuously sprayed on the tested specimens with 90 L/h·m^2 of water fluxes. The diameters of the water droplets were approximately 80μm. Then the wet-grown accumulated ice was formed on the tested specimens. The ice accumulation experiment parameters are shown in Table 1.

Table 1. Ice accumulation experiment parameters

Droplet (μm)	Freezing water conductivity (μs/cm)	Freezing water flux (l/h·m^2)	Air temperature (°C)	Wind velocity (m/s)
80	255	90	-5	5

When the ice accumulation was carried for 30 min, the spring system was stopped. The temperature in the chamber was kept at -10 °C for 10 min to make sure the accumulated ice on the specimens is hardening. The ice accumulation morphologies on the test specimens were recorded with a camera. The weights of the accumulated ice on the specimens were measured by a balance, after the accumulated ice on the uncovered parts of the conductors were removed. Subsequently, the above stated experiment was repeated for another 5 times.

4 RESULTS

4.1 ICE ACCUMULATION MORPHOLOGIES ON SPECIMENS

Figure 4(a) shows ice accumulation morphology on the conductor coated with the super-hydrophobic sleeve. A small quantity of ice was adhered on the surface of the super-hydorphobic polyester sleeve. The ice layer adhered on such sleeve is thin and weak. And the ice layer only covered on the top surface of the super-hydrophobic sleeve. The bottom surface of the super-hydrophobic sleeve was free of ice. Some small icicles formed on the super-hydorphobic polyester sleeve. On the contrary for the conductor coated with the polyester sleeve as shown in Figure 4(b). A large quantity of ice was

(a)

(b)

Figure 4. ice accumulation morphologies on the two conductors coated with different sleeves

(a) the super-hydrophobic sleeve

(b) the polyester sleeve

adhered on the polyester sleeve. The ice layer adhered on the polyester sleeve was thick. And the ice layer covered both the top and bottom surface of the polyester sleeve. Much more icicles formed on such sleeve. The icicles were very long and thick. The above stated indicate that the super-hydrophobic sleeve posed excellent performances of inhibiting ice accumulation on conductors.

Figure 5 illustrates the temporal evolution of ice accumulation on the two conductors, coated with the super-hydrophobic sleeve and the polyester sleeve respectively. Over the entire duration of icing test, the weight of ice on the conductor coated with the super-hydrophobic sleeve remained constantly lower than that of ice on the conductor coated with the polyester sleeve. Furthermore, the weight gain of ice on the conductor coated with the polyester sleeve was faster than that of ice on the conductor coated with the super-hydrophobic sleeve, evidenced by the steeper slope of the blue round symbol line. At the end of the 3-hr ice accumulation experiment, the ice weight on the conductor coated with the super-hydrophobic sleeve was only approximately tenth of the ice weight on the conductor coated with the polyester sleeve.

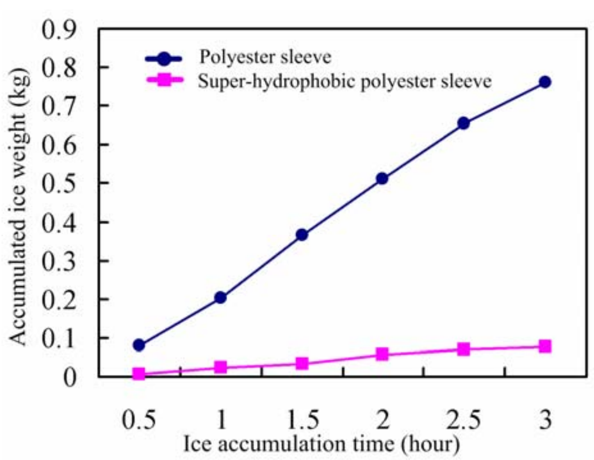

Figure 5. Accumulated ice weights on the two conductors coated with different sleeves.

5 CONCLUTIONS

Super-hydrophobic sleeve was fabricated by forming PDMS/nano-silica hybrid coating on the outer surface of the polyester sleeve. Ice accumulation experiment was carried on the conductor coated with the super-hydrophobic sleeve to examine the anti-icing performance of the super-hydrophobic sleeve. The results of this work are concluded as follows:

1) Super-hydrophobic surface, with average water contact angle of 163°, was formed on polyester sleeve by forming PDMS/nano-silica hybrid coating on the outer surface of the polyester sleeve.
2) Relative to the polyester sleeve, the super-hydrophobic sleeve was demonstrated to be more effective in retarding the ice accumulation, and in weight gain of accumulated ice on conductors.

6 ACKNOWLEDGEMENTS

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