Analyze to Surface Leakage Currents on Super-hydrophobic Insulators under Icing Condition

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Abstract

Insulators coated with super-hydrophobic coatings pose excellent anti-icing performances. This paper focuses on the surfaces leakage current of super-hydrophobic insulator strings. The super-hydrophobic surfaces of the insulators were formed by treating the surface of glass insulator with the PDMS/nano-silica hybrid coating. The surface leakage current of the un-coated insulator string were also investigated for comparison. Analyses to the average value of leakage currents, maximum discharge pulse values, discharge impulse times and harmonic components of these two kinds of insulators were respectively concerned in this paper. The results showed that the insulator strings coated with super-hydrophobic coating posed reduced leakage current when compared with the un-coated insulator strings.

Index Terms - **super-hydrophobic, insulator string, icing, leakage current**

1 INTRODUCTION

Leakage current contains abundant information which can reflect the uncleanness degree, damp degree, withstand voltage and many other operation parameters of insulator strings [1-4]. Thus, the leakage current is very convenient to be monitored in electrical power systems. Further more, according to the time of leakage current pulses, pulse value and other parameters, the operation status of insulator strings can be judged [5-8].

Super-hydrophobic coating, as a new kind of anti-icing material for transmission lines [9-10], investigation to various properties of this kind of coating during icing is still at the initial stage. No report is found about the leakage current of super-hydrophobic insulator string under icing condition. In order to analyze the anti-icing performances of super-hydrophobic coating, it is necessary to carry out leakage current study of insulator string coated with super-hydrophobic coating under icing condition.

This paper presents the characteristics of leakage current of the ice covered super-hydrophobic insulator strings. The super-hydrophobic insulators were firstly prepared by spraying super-hydrophobic coating on glass insulators. Ice accumulation experiment was carried on the super-hydrophobic insulators. Surface leakage currents of the ice-covered super-hydrophobic insulator were record and analysed.

2 ICE ACCUMULATION EXPERIMENTS

2.1 TESTING FACILITIES

Ice accumulation experiments were executed at the High Voltage Laboratory of Chongqing University by using an artificial climate chamber shown in Figure 1. It mainly consists of a refrigeration system, a vacuum-pumping system, a spraying system and a wind velocity regulation system. The temperature in the chamber can drop to -45 °C by adjusting the proportional and differential system (PID). And the wind velocity inside can be controlled freely between 1 m/s and 3 m/s by a fan fixed in the end of the chamber. Water droplets with diameter of 10 μm ~ 100 μm can be generated by the spraying system which is composed of three fog nozzles and a water pump. The nozzles satisfies the IEC 60060-1 protocol standard. The power is connected to specimens through a 110 kV wall bushing.

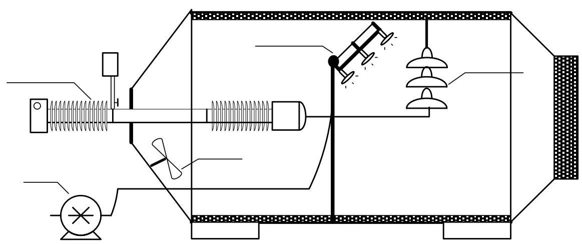


Figure 1 The schematic of the artificial climate chamber

2.2 TESTING SAMPLES

The super-hydrophobic insulator strings employed in this work were prepared by spraying the super-hydrophobic PDMS/nano-silica hybrid coating on the surface of disc glass insulators. Such kind of super-hydrophobic coating poses excellent hydrophobicity. The static water contact angle on the surface of the super-hydrophobic coating amounts over 162°. The insulators without any coating were employed in this work for comparison. The glass insulator surfaces are of hydrophilic. The static water contact angle on the surface of the glass insulator is approximately of 48°.

(a) (b)

Figure 2 Water flowing on surface of different types of insulator

(a) super-hydrophobic insulator string

(b) un-coated insulator string

Figure 2 shows the water flowing on surfaces of these two kinds of insulators. On the surface of insulator coated with super-hydrophobic coating, water flowed in several strips, no water films or water drops were observed on this surface after the water was turned off. However, a large area of water film formed on the surface of un-coated insulator and water drops stayed on this surface after the water flow was turned off. The above results indicate the super-hydrophobicity of the super-hydrophobic coating on glass insulators and the hydrophilicity of the un-coated glass insulators.

2.3 TESTING PROCEDURES

Firstly, Place the insulator string, composed of three insulator units, into the artificial climate chamber as shown in figure 1. Connect the leak current testing circuits as shown in figure 3. T is a Voltage Regulator, B is a test transformer, K is the artificial climate chamber, H is 110 kV Wall Bushing, which lead the high-voltage testing power to the insulator string, F is a 1000:1 Voltage Divider, Osc is the Digital Oscilloscopes, its two channels respectively used to display and measure the testing voltage and the leakage current.

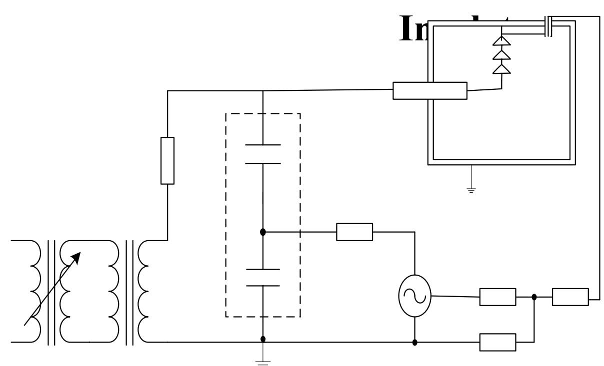


Fig 3 Test circuit

Subsequently, adjust the temperature and wind velocity in the chamber to -10° and 3 m/s respectively. The artificial rainfall, with a conductivity 80 μs/cm, was set to 3 mm/min of water fluxes. The ice accumulation experiment was carried out for 3 hours. Figure 4 shows the photographs of the insulator strings after 3.1 hours of ice accumulation experiment.

Finally, wait until the temperature in the artificial climate chamber raised to -2° - 0°. The accumulated ice begins melting and the discharge even the flashover of the insulator string take place most easily. Increase the voltage applied on the insulator string to 30 kV gradually, and begins to collect the leakage current.

(a) (b)

Figure 4 Photographs of accumulated ice on different types of insulator strings under icing condition

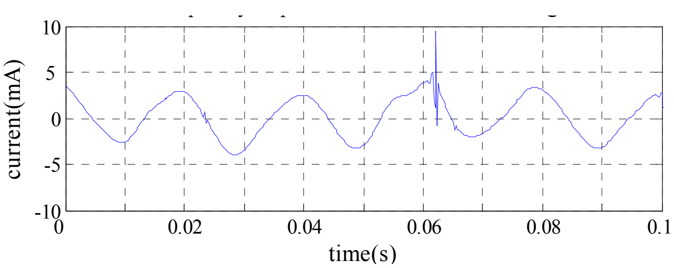
(a) super-hydrophobic insulator string

(b) un-coated insulator string

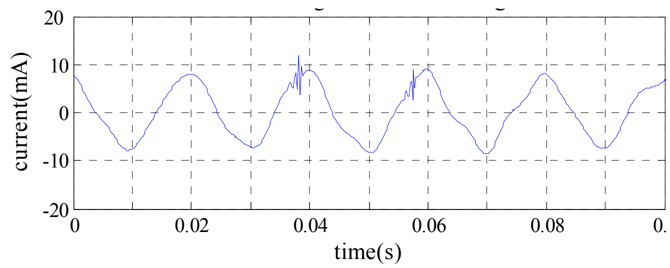
3 RESULTS

3.1 TIME DOMAIN WAVEFORM ANALYSIS

Figure 5 shows the leakage current waveforms of the super-hydrophobic insulator string and that of the un-coated insulator string after 3.1 hours of ice accumulation experiment. The leak current value of insulator string coated with super-hydrophobic coating is obviously less than that of the un-coated glass insulator string. The mean leakage current value of string coated with super-hydrophobic coating is 3.2 mA, which is only 38.55% of the mean leakage current value 8.3 mA of the un-coated glass insulator string. The leakage current waveform of the un-coated insulator string distorts, but the leakage current waveform of insulator string coated with super-hydrophobic coating is more nearly a sine wave.



(a)



(b)

Figure 5 Leakage current waveforms of different types of insulator strings under icing condition

(a) super-hydrophobic insulator string

(b) un-coated insulator string

3.2 DISCHAGE PULSE ANALYSIS

The discharge pulse times and amplitude of leak current were used to judge the amount and acuteness degree of discharge on insulator string surface. The discharge impulses in this work are divided into five levels, which are 5 mA level, 10 mA level, 50 mA level, 100 mA level and 200 mA level. Table 1 shows the discharge pulse times and maximum discharge pulse amplitudes of the two types of insulator strings within one minute. The applied voltage is 30 kV.

Table 1 Statistics of pulse discharge in one minute

Insulator type	Pulse times					Max. value (mA)
	5mA	10mA	50mA	100mA	200mA	
super-h.	632	39	3	1	0	129
un-coated	528	65	7	3	1	213

The total discharge pulse members of the insulator string coated with super-hydrophobic coating is 675 times, which is slightly greater than 604 times of un-coated glass insulator string. The 5 mA discharge pulse times of super-hydrophobic insulator string is 632 times, which is also beyond 528 times of insulator string without coating. However, the discharge pulse times of super-hydrophobic insulator string are obviously less than that of un-coated glass insulator string on the other discharge levels.

The maximum discharge pulse value of insulator string coated with super-hydrophobic coating is 129 mA, which is just 60.56% of the maximum discharge pulse value 213 mA of the un-coated glass insulator string.

3.3 SPECTRUM ANALYSIS

Finally, the spectrum of the leakage current of super-hydrophobic insulator string and that of un-coated glass insulator string is analyzed respectively. The result is shown in figure 6. The leakage current of insulator string coated with super-hydrophobic coating mainly contains fundamental frequency harmonic and triple frequency harmonic. The energy of the fundamental frequency harmonic is much bigger than the triple frequency harmonic. However, the leakage current of un-coated insulator string contains not only fundamental and triple frequency harmonic, but also the second frequency harmonic and many other noise components. The energy of fundamental frequency harmonic of un-coated insulator string is very close to the triple frequency harmonic. What's more, the higher harmonic of leakage current can cause distortion of the time domain waveforms, and this explains the results in figure 5.

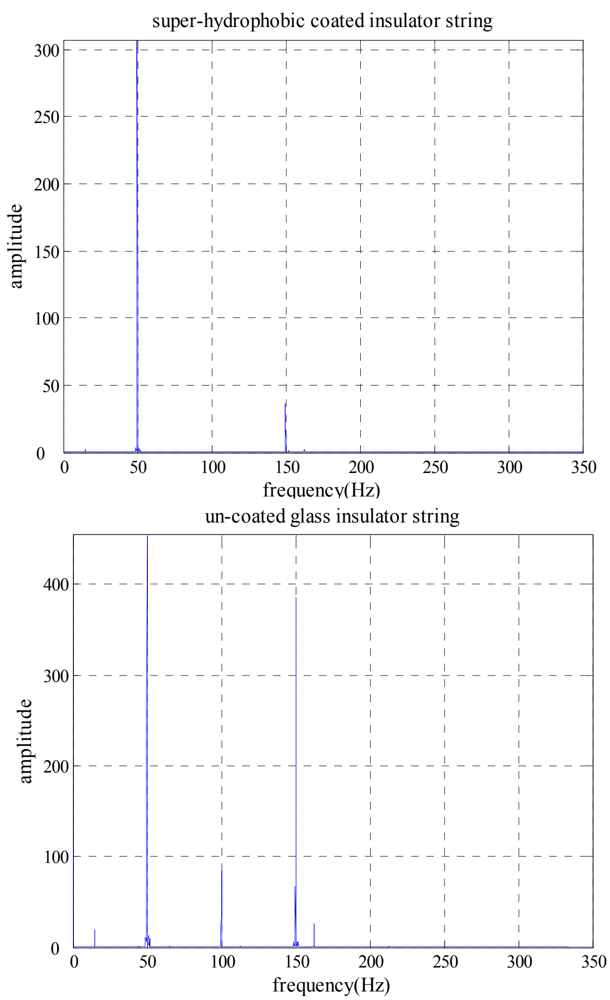


Figure 6 The spectrum graphs

4 CONCLUTIONS

This paper studies the mean value of leakage current, maximum discharge pulse value, discharge pulse times and harmonic component of super-hydrophobic insulator string under icing condition. The results of the above works are as follows:

1) The super-hydrophobic coating could pose excellent anti-icing performances on insulator strings.
2) The super-hydrophobic coating reduced the leak current value of insulator string.
3) The super-hydrophobic coating can increase the discharge pulse time of the insulator string. However, it can reduce the discharge pulse amplitude effectively.
4) The super-hydrophobic coating can reduce the higher frequency harmonic of leakage current, which can inhibit the distortion of the leakage current waveforms.

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