Influence of Hydrophobic Coating on Ice Accretion on Aluminum Conductor

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***Abstract*—Ice accretion on high voltage power lines is a severe problem for power network and it can cause insulator flashover, wire breakage and tower falling down. In order to restrain ice accretion on the transmission lines and decrease these accidents, the icing accretion process on different hydrophobic aluminum conductors was investigated in low temperature in the paper. The results show that the hydrophobic coating can mitigate ice accretion at the initial spraying time, but it can not restrain the ice formation on the aluminum conductor surface. However, a superhydrophobic coating can largely prevent ice formation on the aluminum conductor surface except a few ice growth spots even though being sprayed for 90 min. The larger water contact angle and small water sliding angle of the superhydrophobic coating result the supercooled water droplets can not to be adhered stably, which restrained ice accretion on the aluminum conductor. The hydrophobic conductor have a water contact angle larger than the common aluminum conductor, which delay the formation time of a intact layer of ice compared with the common aluminum conductor. But its larger water sliding angle results the supercooled water droplet to be adhered and frozen on the surface easily, which lead to the intact layer ice formation.**

KEY WORDS: hydrophobic coating; aluminum conductors; ice accretion; superhydrophobic surface; water contact angle; water sliding angle

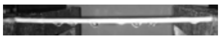
1. INTRODUCTION

Icing is a beautiful sight, but ice accumulation on high voltage overhead transmission lines cause many accidents in power systems. In order to assure the maximum reliability of the transmission system under ice stroms, various methods and techniques have been developed to reduce or eliminate ice accumulation on overhead transmission lines. Hydrophibicity would affect water frozen and alter ice form process. In order to find the effect, the ice accretion process of different hydrophobic aluminum conductor was experimened under supercooled water and low temperature in an artificial climatic chamber in the paper.

2. RESULTS AND DISCUSSION

Fig. 1~4 exhibit the ice accretion on different hydrophobic conductor.

As the superhydrophobic conductor have a larger water contact and small water slidding angle, water droplet can not adhere on the conductor surface stably, which result the superhydrophobic conductor can decrease icing weight and restrain ice layer formation as shown in Fig.5. The hydrophobic RTV and PTFE coated conductor have good hydrophobicity than common conductor, which results their decreasing icing weight and delaying ice formation time. But the RTV and PTFE coated conductor have a water slidding angle larger than 90^{o}, which result water droplet can be adhered and not be sheded easily. So they can only mitigate icing weight and delay ice layer forming time. The common conductor were hydrophilic, which wetted by water droplet easily and a whole ice layer was frozen quickly.


(a) icing for 1 min


(b) icing for 10 min

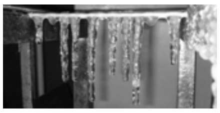

(c) icing for 30 min

Fig. 1 common conductor


(a) icing for 1 min


(b) icing for 10 min

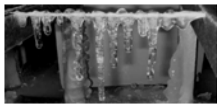

(c) icing for 30 min

Fig.2 RTV conductor


(a) icing for 1 min


(b) icing for 10 min

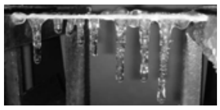
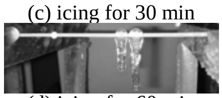

(c) icing for 30 min

Fig.3 PTFE conductor


(a) icing for 1 min


(b) icing for 10 min


(c) icing for 30 min


(d) icing for 60 min

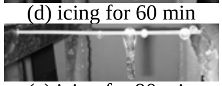

(e) icing for 90 min

Fig. 4 superhydrophobic aluminum conductor

3. CONCLUSION

Different hydrophobic conductor and common conductor was experimental under low temperature and supercooled water droplet. It demonstrated that the resulted superhydrophobic conductor can decrease icing weight and restrain ice layer formation as its larger water contact angle and small water slidding angle. However, hydrophobic RTVand PTFE coated conductor can only mitigate icing weight and delay ice layer forming time as their water slidding angle is larger. The common conductor is hydrophilic, which results it being wholy wetted by water droplet easily and a intact ice layer was frozen quickly under low temperature environment.

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Abstract—**Ice accretion on high voltage power lines is a severe problem for power network and it can cause insulator flashover, wire breakage and tower falling down. In order to restrain ice accretion on the transmission lines and decrease these accidents, the icing accretion process on different hydrophobic aluminum conductors was investigated in low temperature in the paper. The results show that the hydrophobic coating can mitigate ice accretion at the initial spraying time, but it can not restrain the ice formation on the aluminum conductor surface. However, a superhydrophobic coating can largely prevent ice formation on the aluminum conductor surface except a few ice growth spots even though being sprayed for 90 min. The larger water contact angle and small water sliding angle of the superhydrophobic coating result the supercooled water droplets can not to be adhered stably, which restrained ice accretion on the aluminum conductor. The hydrophobic conductor have a water contact angle larger than the common aluminum conductor, which delay the formation time of a intact layer of ice compared with the common aluminum conductor. But its larger water sliding angle results the supercooled water droplet to be adhered and frozen on the surface easily, which lead to the intact layer ice formation.**

KEY WORDS: hydrophobic coating; aluminum conductors; ice accretion; superhydrophobic surface; water contact angle; water sliding angle

Ⅰ. INTRODUCTION

Icing is a beautiful sight, but ice accumulation on high voltage overhead transmission lines cause many accidents in power systems, such as the 1998 ice storms in Eastern Canada and 2008 ice storms in South China[1,2]. How to assure the maximum reliability of the transmission system under ice stroms is a important work for electric utilities. So various methods and techniques have been developed to reduce or eliminate ice accumulation on overhead transmission lines. The active techniques such as thermal and mechanical are energy hungry and expensive to make and operate. The passive techniques such as icephobic coating are cheaper and environmentally friendly compared to active techniques as they do not need external energy to deicing or prevent ice accretion[3].

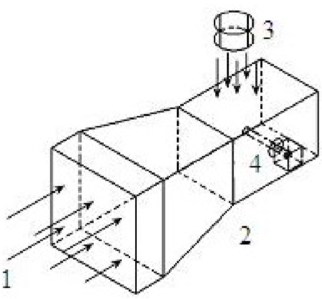
The surface with a water contact angle (CA) larger than 90º was defined as hydrophobic surface, which show that the surface can not be weted by water easility. Recently, a surface similar to the lotus leaves with a water contact angle (CA) larger than 150º have attracted great interest, which is called to be superhydrophobic surface. According to the surface characteristic of the lotus leaves, the superhydrophobic surface can be constructed by combining low surface free energy material and high surface roughness. With the excellent hydrophobicity, the superhydrophobic surface can be used in the area of such as water repellency, anti-adhesion and anti-fouling etc[4,5]. According to [6][7][8], the surface hydrophobicity can reduce the ice adhesion strength, which may result the mitigation of the ice acdcretion on the hydrophobic surface.

In the paper, hydrophobic aluminum conductor were constructed with different hydrophobic coat and the ice accretion process was experimened under supercooled water and low temperature in an artificial climatic chamber.

II. EXPERIMENTATION

All of the different hydrophobic surfaces were constructed on an aluminum conductor with diameter at 2.6 mm. The hydrophilic conductor was obtained by cleaning the sample in actone and drying at 70℃ for 4 h. The hydrophibic RTV conductor was obtained by depositing a RTV coating on the hydrophilic aluminum surface and drying in air for 48 h. The hydrophobic conductor PTFE conductor was constructed by depositing a PTFE emulsion on the hydrophilic sample and drying at 340℃ for 30min. The superhydrophobic surface was constructed by immering the hydrophilic sample into an etching agent aqueous solution for 1 min and then ultrasonically cleaned with deionized water to remove any residual particle, at last the etched sample was deposite with an hydrophobic stearic acid coating.

The icing experimental system were performed in an artificial climatic chamber with an environment temperature of -6 ℃. The water droplets with a temperature of 0 ℃ were sprayed by a nozzle. In order to simulate the drizzle and freezing rain, the diameter of water droplets colliding with the sample was 0.4-0.6 mm, which was measured by a stain method. A wind with 2.9-3.1 $m.s^{-1}$ was generated by a fan in a wind tunnel, which was used to simulate the wind distribution around an overhead transmission line in storm as shown in Fig.1. Before the samples were sprayed, they were placed in the -6 ℃ environment for 30 min to keep them being cold enough as the overhead transmission lines in storm. The ice accretion process were recorded by a SONY camera every 5min. The surface morphologies of the superhydrophobic aluminum samples were observed with a JSM-6490LV scanning electron microscope (SEM) at 20 kV. The water contact angles were measured with a sessile droplet method.

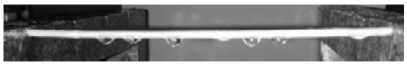


(1) cold wind; (2)wind tunnel; (3) spray nozzle; (4) experimental conductor.

Fig.1. The icing experimental system:

III. EXPERIMENTAL RESULTS

The ice accretion process of common hydrophilic aluminum conductor is shown in Fig. 2. It can be seen that the common aluminum conductor was covered by a whole water film quickly and some small icicle was freezon under its bottom even though at the first spraying time. With the increasing of the spraying time, the thickness of the ice layer and the length of the icicle increased as shown in Fig.2 (b, c). After 30min spraying, the maximal icicle increased to 7.4cm and the total ice weight reach to 11.1g. From the icing results, we can seen that the ice layer would be frozen and weight increased quickly on the commom aluminum conductor under low temperature and supercooled water droplet, which may results fatal accident for electric utilities.



(a) icing for 1 min

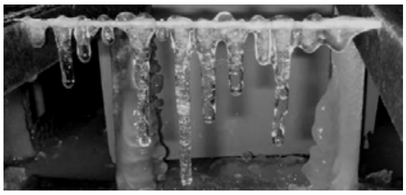
(b) icing for 10 min

(c) icing for 30 min

Fig. 2 Ice accretion on common aluminum conductor

(a) icing for 1 min

(b) icing for 10 min



(c) icing for 30 min

Fig. 3 Ice accretion on RTV coated aluminum conductor

The ice accretion on hydrophobic RTV aluminum conductor is shown in Fig. 3. It can be seen that the RTV conductor surface only be covered by some seperated water droplet at the first spraying time. Thus only some separate ice crystal was frozen on the conductor surface and no intact ice layer formed at the first spraying time, which slow down the icing rate and delay ice layer forming time. But with the spraying time increasing, the icing increased on the RTV conductor and ice layer formed gradually as Fig. 3(b, c). After 30min spraying time, the maximal icicle increased to 6.5cm and the total ice weight reach to 7.4g. Compared with the common conductor as shown in Fig. 2, we can seen that the RTV conductor can mitigate icing weight and delay ice layer forming time.

The ice accretion on hydrophobic PTFE aluminum conductor is shown in Fig. 4. Its surface icing process shows that the PTFE conductor can mitigate icing weight and delay ice layer forming time as hydrophobic RTV conductor. After 30min spraying time, the maximal icicle increased to 5.5cm and the total ice weight reach to 6.9g. It shows that the ice layer forming time was longer and ice weight was light for the hydrophobic PTFE conductor than the RTV conductor.

(a) icing for 1 min

(b) icing for 10 min

(c) icing for 30 min

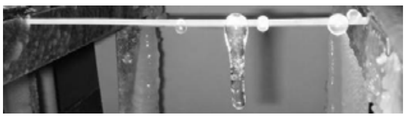
Fig. 4 Ice accretion on PTFE coated aluminum conductor

(a) icing for 1 min

(b) icing for 10 min

(c) icing for 30 min

(d) icing for 60 min



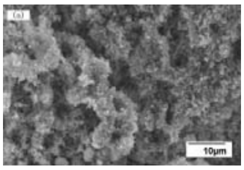
(e) icing for 90 min

Fig. 5 Ice accretion on superhydrophobic aluminum conductor

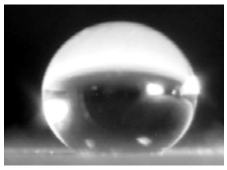
The ice accretion on superhydrophobic stearic acid aluminum conductor is shown in Fig. 5. From the result as shown in Fig. 5, the ice accretion on the superhydrophobic conductor is wholy different to the hydrophobic RTV ang PTFE conductors. No water droplet was adhered on the superhydrophobic conductor surface at the first spraying time as shown in Fig.5 (a). With spraying time increasing, partial water droplets were adhered on the conductor surface and frozen to ice crystal as shown in Fig.5 (b, c, d, e). The adhere intension of Part of the adhered ice crystal is very small and the adhered ice would slid off the conductor surface with the ice weight increasing as shown in Fig.5 (c, d, e). Even spraying with 90min, the length of the icicle was only 3.0cm and the total ice weight was 1.4g on the superhydrophobic conductor. Compared with the hydrophobic and common conductor, it can be seen that the superhydrophobic conductor can decrease icing weight and restrain ice layer formation.

Ⅳ. DISCUSSION

Ice was frozen from the adhered water droplet. Thus the characteristic of wettability and adherebility of the surface will affect the icing property[9]. For the superhydrophobic conductor, it have a excellent micronanoscale hierarchical surface structure as shown in Fig.6 (a), which would decrease the water-solid contact area. According to Cassie-Baxter model, a small water-solid contact area would result a larger water contact angle. Thus the resulted stearic acid coated conductor exhibit a excellent superhydrophobicity with water angle larger than 150^{o}. At the same time, the small water-solid contact area result a small interaction force between water droplet and solid surface, which lead the superhydrophobic surface have a water sliding angle small than 5^{o}. The larger water contact angle and small water sliding angle would be benefit for restrain water droplet adhering and ice accretion on the surface.



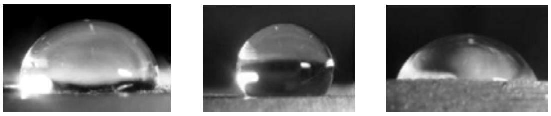
(a) surface microstructure



(b) water contact angle

Fig. 6 Surface statuses of the superhydrophobic aluminum surface

For the RTV and PTFE coated conductor, they have a plain surface and have smaller water contact angle than the superhydrophobic conductor as shown in Fig.7 (a, b) (water contact angle is 102.3º and 121.5º). For the common conductor, its water contact angle is only 63.5º as shown in Fig.7 (c), which smaller than the hydrophobic surface. Besides the differenceof the water contact angle, the water slidding angle of the RTV, PTFE coated surface and the common surface were wholly different to superhydrophobic surface. The adhered water droplet can not slid from the RTV, PTFE coated surface and common surface even though they were placed vertically as shown in Fig. 8. The small water contact angle ang larger water slidding angle of the RTV, PTFE coated conductor and common conductor would be benefit for water droplet adhering and ice forming.



(a) RTVsurface (b) PTFE surface (c) common surface

Fig. 7 Water contact state on different aluminum surface

(a) RTVsurface (b) PTFE surface (c) common surface

Fig. 8 Water contact state on different vertically placed aluminum surface

As the superhydrophobic conductor have a larger water contact and small water slidding angle, water droplet can not adhere on the conductor surface stably, which result the superhydrophobic conductor can decrease icing weight and restrain ice layer formation as shown in Fig.5. The hydrophobic RTV and PTFE coated conductor have good hydrophobicity than common conductor, which results their decreasing icing weight and delaying ice formation time. But the RTV and PTFE coated conductor have a water slidding angle larger than 90^{o}, which result water droplet can be adhered and not be sheded easily. So they can only mitigate icing weight and delay ice layer forming time. The common conductor were hydrophilic, which wetted by water droplet easily and a whole ice layer was frozen quickly.

Ⅴ. CONCLUSION

Different hydrophobic conductor and common conductor was experimental under low temperature and supercooled water droplet. It demonstrated that the resulted superhydrophobic conductor can decrease icing weight and restrain ice layer formation as its larger water contact angle and small water slidding angle. However, hydrophobic RTVand PTFE coated conductor can only mitigate icing weight and delay ice layer forming time as their water slidding angle is larger. The common conductor is hydrophilic, which results it being wholy wetted by water droplet easily and a intact ice layer was frozen quickly under low temperature environment.

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