

Development and Investigation of a New Kind of Anti-icing Coating with Ice-melting Performance

Zhang Rui, Yi Xianjie, Wan Xiaodong
SGEPRI, Wuhan, 430074, China

Abstract—In order to find a technically feasible and economically reasonable anti-icing coating for transmission line insulator, in cooperation with related universities, we have developed and tested more than 70 formulations and batches of ice melting coating focus on high-water-repellent, electro-thermal, light-heating and contains low freezing point metal organic sol. By using artificial climate chamber simulating natural icing conditions for insulators and conductors, we have performed large number of tests analyzed and compared various anti-icing coating and their effects where gathered a large number of experimental data and technological breakthroughs. Studies have shown that simply improving the coating surface hydrophobicity for insulator in order to achieve anti-icing has some limitations, the anti-icing effects delivered by electro-thermal and light-heating methods is not ideal, the ice -melting anti-icing coating has potential for further development. Studies suggest that anti-icing materials for insulators should still focusing on superhydrophobic surface, adjust micro-structure of the surface, integrating characteristics of organic metal compounds for ice melting, constructing nano-structures on the coating which with ice-melting characteristic to improve the superhydrophobic for preventing icing. The same time, by choosing insulators with large umbrella angle achieve effective deicing. Preventing icing as main tactic, with melting ice and deicing as assistance, can improve the integrated effect of anti-icing coating.

Key words — transmission-line ; isolator ; anti-icing coating; water-repellent ice-melting

1. INTRODUCTION

The power system safety operation may be seriously threatened by the problems such as the ice coating or snow accumulation on the transmission lines and insulators. The damages to the transmission lines caused

by the ice coating may be mainly embodied in the following two aspects: 1) the tower mechanical load may be increased and the accidents such as damaging the hardware, broken lines and collapsed towers and so on may easily occur while it exceeds the designed tolerant capacity; and 2) the insulator flashover voltage may be lowered so as to easily cause the icing flashover accidents. It has been shown by most of the operation experiences that the ice coating for the insulator and conductors may be further intensified while any insulator icing flashover tripping occurs and the system may not be reclosed successfully and after the shutdown of the transmission lines; as may be the main reason of the ice damage accidents such as broken lines and collapsed towers and so on. The typical case was that there were large areas of ice coating in the transmission lines so as that the powers might be collapsed and lines were broken as well as the power supply might be broken down and the national economics losses might be heavy because the it rained and snowed continuously in large range of China southern area for a few days in January, 2008 [1]. At present, the electric power development strategy of “nationwide interconnection, sending power from west to east and mutual supply between south and north” is being implemented as well as 1000kV AC EHV and ± 800 kV DC EHV transmission lines are being constructed; and the ice coating issue has become the serious hidden trouble influencing the safety operation of the EHV/UHV transmission lines. Therefore, to lower and prevent the ice coating flashover in the insulator shall be one key technology for solving the icing damage issue and ensuring the power grid safety operation. Currently, the technology research on preventing and controlling the ice coating in the transmission lines and insulators focuses on the insulator ice coating flashover characteristics, the de-icing methods and so on[2-8]. The present prevention and control measures to the insulator ice coating issue may include changing the insulator

suspension modes, utilizing the semiconductor glazed insulators, anti-icing coatings, and mechanical de-icing and other methods. The prevention and control measures to the transmission line ice coating may include the thermal de-icing, mechanical de-icing and the de-icing coatings and other methods. The coatings may be used to realize the ice coating prevention and control for the transmission lines and insulators based on the following two aspects: on one hand, there have been the similar practical applications of coatings for the de-icing and snow protection for planes, cars and trucks, trains, roads and so on; on the other hand, it has been found in the operation experiences that various RTV anti-pollution flashover coatings widely used in the current power systems may play some certain roles of preventing ice coating and lowering the ice coating, but the effects may be greatly different in various regions. Therefore, how to draw lessons from implementing the ice coating prevention and control technologies in other fields and study the proper anti-icing coatings for the power systems have become the current focal point. On the other hand, the anti-icing coatings which may be applicable for insulators may also be applicable for the transmission lines, but not vice versa. Thus, this study focused on developing the anti-icing coatings for insulators.

The research direction on the anti-icing coatings is mainly that some fillers are added during the coating preparation processes so as that one layer of high hydrophobicity coating which is similar to the lotus leaf and the rain, ice or snow adhesive force in the coating surface may be lowered or the photothermal agent(s) and electrothermal materials may be added to enhance the coating thermal effect and realize the de-icing effect [9-18]. However, most of the above researches are in the early stage and exploration process in the laboratories; moreover, they are mainly limited to the transmission lines and the systematic research on the insulator anti-icing coatings has not been carried out. Based on the domestic and abroad research situations and technology development trends, the further study on the low ice point type ice melting coatings has been carried out in emphasis in this study.

2. THEORETICAL BASIS

The development of the ice melting type coatings is

based on the water solid-liquid phase transition theory. Water is one kind of material with relatively special phase transition effect other than other kinds of pure substances, whose density is maximum at 4°C; thus, the natural convection is relatively special in the ice-water phase transition system. There are two natural convection regions in the temperature change area between the ice surface and surrounding water during the icing process, namely, the upward natural convection region close to the ice layer surface whose temperature is 0°C and the downward natural convection region outside the layer whose temperature is 0°C. During the early melting ice process, the water film is relatively thinner and the heat transfer mainly depends on the heat conduction; while the melting area expands, the natural convection effect driven by the buoyancy force may play the dominating role. The downward water solidification and ice melting may be influenced by the natural convection, which are in fact controlled by the unstable heat conduction within the ice layer whose interface is moving and the convection coupling between the ice surface and water during the phase transition process. In general, the pure water solid-liquid phase transition temperature is 0°C, which may be easily influenced by many factors such as the atmospheric pressure, electrolytes and small organic molecules and so on. As is known to all, it has been widely used in the actual life that the electrolytes such as NaCl and so on may be added to ice or snow to accelerating the ice and snow melting processes [19-20], such as de-icing for roads and airport runways in winter and so on. However, this method is not suitable for the transmission lines whose insulation performance requirements may be very high. Therefore, it is the key to developing the ice melting coatings to select non-electrolytes which may lower the water solid-liquid phase transition temperature.

2.1 The water ice point influenced by the variety of material

The organic metal compounds (whose codes are DS and DG, respectively), polyethylene glycol (PEG) and distilled water are prepared into 10% (mass-volume percentage concentration) water solutions, for which the phase transition analysis has been carried out together with the 1% water solutions prepared with distilled water and polyvinyl acetate (PVA) by utilizing the differential

scanning calorimeter (DSC); and the analysis results are shown in Table 1.

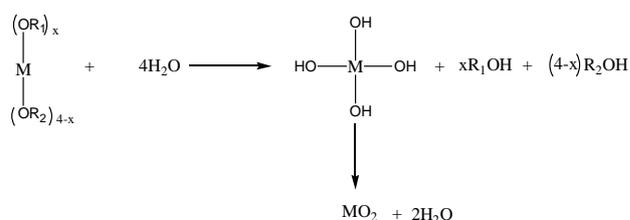
Table 1: The ice point influenced by the variety of material

Material	Distilled water	PVA (1%)	PEG (10%)	DS (10%)	DG (10%)
Melting ice point (°C)	-0.294	0.658	-0.294	-2.761	-4.353
Melting heat (J/g)	264.384	271.462	264.667	162.201	159.342

It may be shown from the test results listed in Table 1 that the water melting ice temperature is not influenced greatly by two kinds of water-solubility oligomers; moreover, PVA causes the water melting ice temperature may be increased slightly; on the other hand, the water melting ice temperature may be lowered greatly by adding the small organic molecule DS and DG (with relatively larger lowering extent from -0.294°C to -4.353°C). As may demonstrate that the solid-liquid phase transition may occur below -4.353°C by adding small organic molecules, namely the solid ice may be melted. By comparing and analyzing the ice points and melting heat data, it may not be difficult to find that the heat required to realize the ice-water phase transition is become smaller as the ice melting ice temperature is lowered; furthermore, it may also be demonstrated that not only the ice-water phase transition temperature but also the energy required for such phase transition may be lowered by mixing the small organic molecules so as to ensure that the ice may be melted while the ambient temperature is -4°C .

2.2 The ice melting mechanism for adding the organic metal compounds

The organic metal compounds may be reacted with water; on one hand, some small organic molecules may be released to lower the ice melting temperature; on the other hand, the metal oxides may be generated. The reaction formula may be given in Figure 1.



(Where: R1OH and R2OH represent the small organic molecules, respectively, such as DG and DS, which may lower the ice melting temperature.)

Figure 1: the molecule reaction formula of the organic metal compounds and water

It may be shown from the above reaction that the organic metal compound is reacted with the water molecules; thus, on one hand, some small organic molecules may be released to lower the melting ice point; on the other hand, the metal oxide may be generated. The polarities of the small organic molecules and organic coatings are considerably different so that they may be necessarily gathered automatically and migrated downwards to the interface between the ice coating and the coatings and permeated into the ice phase by the hydrophilic induction action of the ice coating so as to lower the interface ice melting temperature and prompt the solid-liquid phase transition of the ice coating. The occurrence of the liquid water in the interface between the ice coating and the coatings may accelerate the dissolution of small organic molecules; therefore, the hydrolyzation of the organic metal compound may be accelerated so as to release more small organic molecules which may lower the ice melting temperature to further promote the melting of the ice coating. Because there is no any electrolytic dissociation effect for small organic molecules in water, their solution conductivities may not be increased rather than those of the inorganic electrolyte solutions.

Because the organic metal compound may be dispersed into the coatings in the colossal state; the metal oxide which is formed through its being decomposed in water may be dispersed into the coatings in the nanometer scale so as to greatly increase the specific surface area of the metal oxide. On one hand, such dispersion state may enhance the interactions between the metal oxide and the organic coatings and improve the insulation performance of coatings; on the other hand, the generated metal oxide (through properly selecting the metal ion to control the

variety of the metal oxide) may have some certain spectrum absorption thermal effect so as that the surface temperature may be increased by absorbed the energy of the external environment sunlight and the melting of the ice coating may be accelerated as well as the ice coating reformation may be prevented.

2.3 Lowering the ice point influenced by the various partition ratios

It has demonstrated in researches that the heat absorption capacity of the solid ice (including the additive(s)) may be increased in the linear mode while the temperature is increased; while the ice solid-liquid phase transition occurs, the temperature does not vary obviously; however, there may be one absorption peak in the thermal absorption first-order derivative curve because the phase transition thermal absorption capacity is increased sharply, by means of which the phase transition point temperature variation may be studied and the research direction of the anti-icing coatings may be guided. The analysis results of the temperature rise phase transition processes by using the differential scanning calorimeter (DSC) for the partition ratios listed in Table 2 are shown in Figures 2, 3 and 4, which are derived from the re-formulation of DS, DG and PEG together with distilled water, respectively.

Table 2: the various material partition ratio scheme

No.	The partition ratio scheme	No.	The partition ratio scheme
1-0	Distilled water	1-6	6% DS+4% PEG
1-1	5% (w/v) DS	1-7	8% DG+2% PEG
1-2	10% (w/v) DS	1-8	6% DG+4% PEG
1-3	10% (w/v) DG	1-9	4% DG+6% PEG
1-4	10% (w/v) PEG	1-10	4% DS+6% PEG
1-5	8% DS+2% PEG	1-11	1% (w/v) PVA

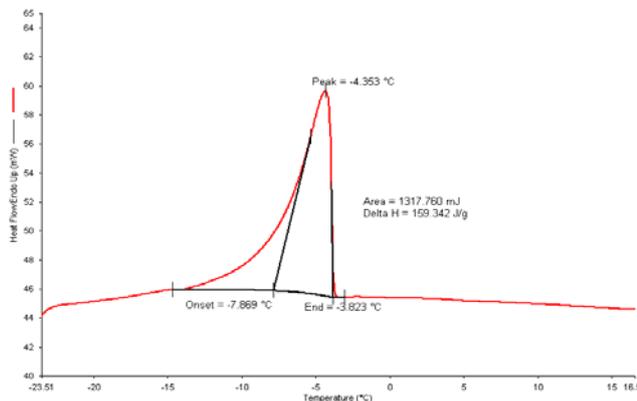


Figure 2: the temperature rise phase transition curve

for 10% PEG-water solution

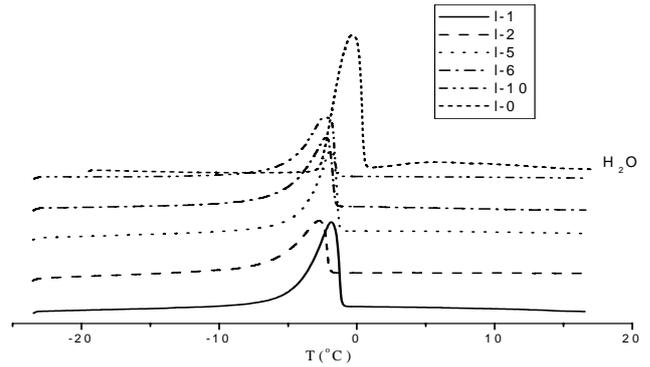


Figure 3: the ice melting temperature influenced by the re-formulation of DS and PEG

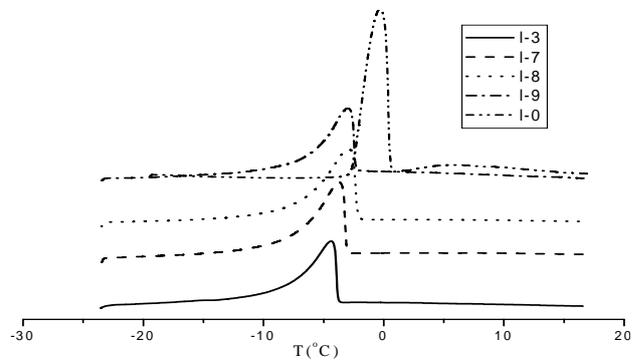


Figure 4: the ice melting temperature influenced by the re-formulation of DG and PEG

The results in Figures 2, 3 and 4 may show the following conclusions:

1) It may be shown that the heat absorption capacity may be increased greatly while the temperature rises from -20°C to -7.8°C ; while the temperature rises to 4.353°C , which is the corresponding ice melting temperature, the heat absorption capacity is maximum; while the temperature rises up to -3.823°C , the ice is melted completely into liquid water; then the heat absorption capacity will be increased in the linear mode again and the heat absorption first-order derivative curve tends to be gentle; and the entire process melting heat is about 159.342J/g . The melting peak for the practical heat absorption curve is wider than that of the simulated result in Figure 2; as may indicate that the ice melting is started from -18°C and is completely turned into liquid water at -3.823°C . These results show that 10% PEG is one kind of the eutectic material made of PEG and water molecules. Because the melting point of PEG is lower

than that of water, phase transition for PEG may first occur so as to lower the crystallization degree of the eutectic material and prompt the ice melting as well as result in lowering the melting temperature of the entire system while the temperature is increased.

2) It may be shown that the ice melting temperature lowers from -1.857°C to -2.761°C while the concentration of the single aqueous solution of DS is increased from 5% (as shown in Curve 1-1) to 10% (as shown in Curve 1-2); as may indicate that the ice melting temperature is lowered while the concentration of the aqueous solution of DS is increased. The DS and PEG are re-formulated and the total solute concentration is controlled at 10%; on the other hand, the corresponding ice melting temperature drop extents are -1.857°C , -2.233°C and -2.343°C in turn while the PEG concentration is increased to 2% (as shown in Curve 1-4), 4% (as shown in Curve 1-6) and 6% (as shown in Curve 1-10) and the DS concentration is decreased to 8%, 6% and 4%, respectively; as may demonstrate that the re-formulation of PEG and DS may take the synergistic interaction for lowering the ice melting temperature; moreover, while the PEG concentration is increased and the ice melting temperature is lowered, it may dominate lowering the ice melting temperature.

3) In Figure 4, the PEG and DG are re-formulated and the total solute concentration is controlled at 10%; while the PEG concentration is increased to 2% (as shown in Curve 1-7), 4% (as shown in Curve 1-8) and 6% (as shown in Curve 1-9) and the DG concentration is decreased to 8%, 6% and 4%, respectively, the corresponding ice melting temperature drop extents are -3.730°C , -2.960°C and -2.996°C in turn. It may be shown from the above test results that the ice melting temperature is lowered while the PEG concentration is increased; on the other hand, the ice melting temperature does not drop obviously while the concentration is more than 4%; as may indicated that the ice melting synergistic interaction may not be generated through the re-formulation of PEG and DG.

The test results may comprehensively indicate that the water solid-liquid phase transition process may be changed and the ice melting temperature may be lowered by adding the organic metal compound(s) in distilled water; and the main conclusions are listed as follows:

1) The ice melting temperature may be lowered

significantly by adding the small organic molecules such as DG corresponding to the optimum effect, namely 10% DG concentration may cause the ice melting temperature drops from -0.294°C to -4.353°C .

2) There is no obvious influence on the ice melting temperature and no any ice melting activity by adding the single partition ratio water-solubility oligomer.

3) There is no any synergistic interaction for lowering the ice melting temperature through the re-formulation of the water-solubility oligomer (PEG) and small organic molecules and the application concentration of the small organic molecules may be lowered. The re-formulation effect of PEG and DS is advantage over that of PEG and DG.

3. THE DEVELOPMENT PROCESSES OF THE LOW ICE POINT TYPE ICE MELTING COATING

3.1 The coating preparation

The small organic molecules which may be dissolved into water and lower the ice melting temperature are generally the polar molecules; they are difficult to be mixed evenly with the non-polar organic coatings and the original performance of the coatings may be ensured. Therefore, the small organic molecules which may lower the ice melting temperature may be reacted with the metal ions to generate the metal compound colossal; on one hand, the organic molecule polarity may be weakened and the dispensability in the organic coatings may be improved; on the other hand, the organic metal compound is stable in the dry environment, but it may release the small organic molecules with water; moreover, the proper metal ions may be selected to control the hydrolytic rate of the organic metal compound and further regulate the release rate of small organic molecules.

3.2 Selecting the various partition ratios

The de-icing coatings prepared according to the partition ratios described in Table 2 are brushed on the white iron sheets, which are dried in natural environment for using. The double-surface ice coating may be carried out for 19 minutes in the vertical white iron sheets by utilizing the spraying mode and under the ambient temperature of $-8^{\circ}\text{C}\sim 5^{\circ}\text{C}$; then the ambient temperature is controlled within the range of $-5^{\circ}\text{C}\sim -1^{\circ}\text{C}$ and various types of ice

melting effects may be observed. The variation trends of the ice coating in the white iron sheet sample surfaces vs. the ice melting time are shown in Figure 5.

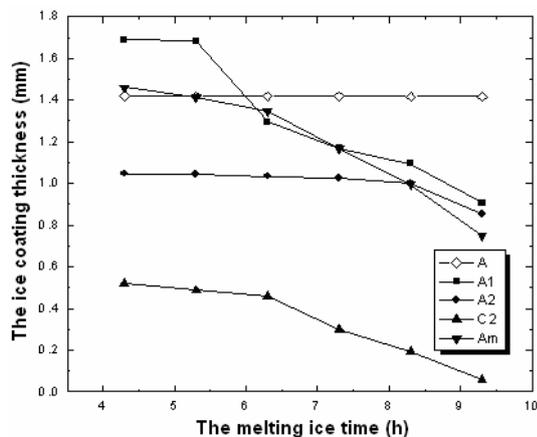


Figure 5: the variation trend on the coating surface icing vs. the ice melting time

The test results in Figure 5 may indicate that the thickness of the ice coating in the PRTV coating surface does not vary significantly; as may demonstrate that the ice melting performance may not be provided by the PRTV coatings; whereas, the good ice melting performance may be given after the PRTV coatings are modified with the organic metal compound(s), whose variation trends are shown in Curves A1, Am and C2; based on the field observation, it may be found that there exists water between the coating and the ice coating after a period and the liquid water is increased gradually along with the lasting time; some certain ice layer begins to be separated in the region with the relatively thin ice coating after 90 minutes and the ice coatings made of A1 and Am samples almost fall off after 9 hours. Among 6 kinds of preparation coatings, A1 coating may provide the optimum melting performance and the melting rate may be 0.17mm/h in average.

3.3 The recycle application long-term effect

For verifying the long-term effect of the development low ice point type ice melting coatings, the second time ice melting tests are carried out as for the de-icing coating sample sheets whose first time ice melting tests have been carried out and which have been dried naturally in air for 24 hours; and the test results are shown in Figure 6.

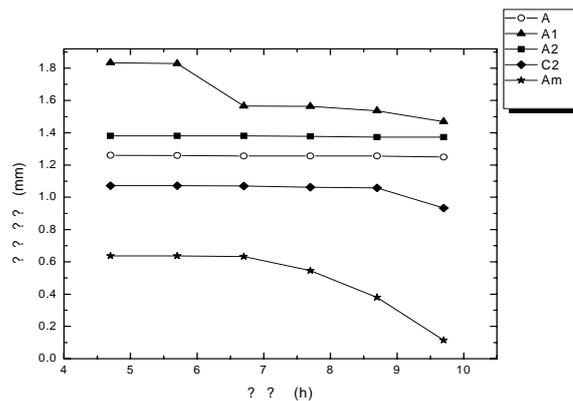


Figure 6: the variation trend on the coating icing vs. the ice melting time after the secondary ice coating process

The test results in Figure 6 may indicate that the high ice melting rate may still be kept in the second time ice melting tests for the de-icing coating; as may demonstrate that the long-term ice melting effect may be provided by the de-icing coatings; in comparison with the results of the first time ice melting tests, the ice melting response time is generally lagged for the coatings other than A1 and Am coatings. For example, as for C2 coating, the ice melting periods during the first and second time ice melting tests are about 6.4 hours and more than 8.8 hours, respectively; and the latter lags about 2 hours to the former. As for A2, coating, the ice melting period during the first ice melting test is 8.4 hours; in contrast, the ice melting acceleration phenomena was not observed after 10 hours since the second time ice melting test was started. The cause for such ice melting acceleration lagging may be possibly that some certain amount of the organic metal compound has been consumed during the first ice melting test so as that the organic metal compound concentration in the coating may be lowered and the organic metal compound difference between the internal coating and the ice coating interface may be decreased as well as the transportation potential energy may be correspondingly decreased to lag the hydrolysis reaction time of the organic metal compound. Therefore, the careful research and analysis on the coating surface morphology and the composition change shall be carried out in future.

4. THE ICE COATING TEST RESULTS AND ANALYSIS

4.1. The test conditions

The artificial ice coating contrast tests are carried out in the small-scale artificial ice coating laboratory whose net

dimensions are 4.2m (length) x 3.2m (width) x 3.2m (height). The test voltage is 100kV; the air-cooling refrigeration unit (35kW) is equipped, whose minimum temperature may reach -20°C. The indoor temperature, pressure and relative humidity real-time measurement system (HOBO weather station), the spraying water pre-cooling system, the automatic spraying system, the automatic temperature detection system and so on are equipped.

With controlling the spraying droplet particle diameter, the wind speed and the ambient temperature, the various ice coating type tests may be carried out. As for the specific tests, the water temperature is controlled within 2°C~5°C and the ambient temperature is controlled within -2°C~-5°C; the variations on the initial icing time and temperature as well as the amount of ice coating are studied, respectively.

4.2 The sample sheet contrast tests

The sample sheets are prepared according to the requirements listed in Table 3; the ice coating tests are carried out under the temperature of -8°C~-10°C; and then the ice melting tests are carried out to observe the ice coating effects for various types of sample sheets. The corresponding results may be shown in Figures 7 and 8.

Table 3: the contrast test sample sheets

No.	Sample number	Description
1	W	The blank glass sheet
2	P	The high hydrophobicity de-icing coatings (coated in the glass sheet and the static state contact angle being 160°)
3	Q	The low ice point type ice melting coating (coated in the glass sheet)
4	X	The blank iron sheet
5	Y	The high hydrophobicity de-icing coatings (coated in the iron sheet and the static state contact angle 160°)
6	Z	The low ice point type ice melting coating (coated in the iron sheet)

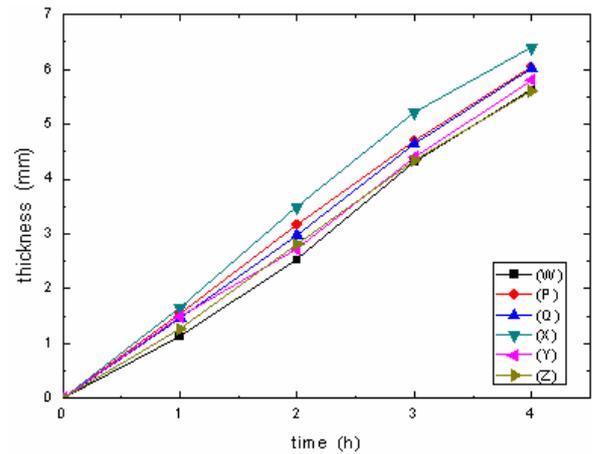


Figure 7: the relation on the ice film thickness vs. time during the ice coating process

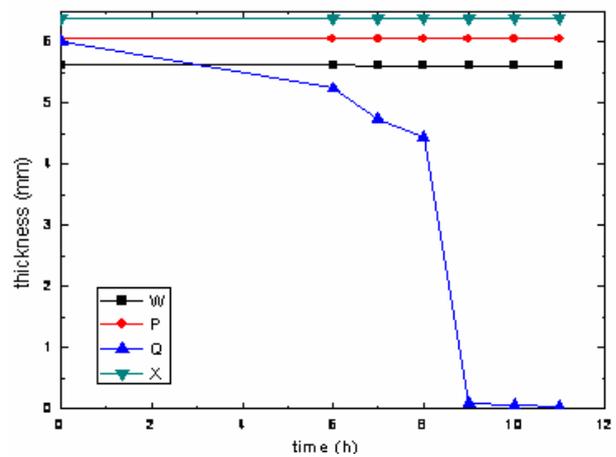


Figure 8: the relation on the ice film thickness vs. time during the ice melting process

The test results in Figure 7 may indicate that the ice coating amount in the X (namely the blank iron sheet) is the largest and the ice film thickness is maximum in view of the ice coating amount; and the ice coating rates for other sample sheets are relatively equal. Because the ice coating amount and the ice film thickness are relatively large, there is no significant difference between various sample sheets and the ice coating rates are relatively equal; and the early stage ice coating rates are slightly low for Q and Z sample sheets. The test results in Figure 8 may indicate that the ice melting capacity may be provided by the prepared low ice point type ice melting coatings under the temperature of -5°C~-1°C; although the early stage ice melting effect is not remarkable, the liquid material between the ice film and the sample sheet surface may be gradually increased along with the precipitation of the ice melting material; and finally the ice file may fall off from the surface.

4.3. The insulator test

The insulator ice coating contrast tests are carried out under the same conditions and the contrast samples include the insulators coated with the high hydrophobicity coatings. The results of the insulators may indicate that the ice regions close to the steel caps of the insulators may appear while and the ice surfaces are rough as well as there exist the air clearances between ice and the insulator surfaces after about 9 hours; and the separation state may occur (as shown in Figure 9). It may be found based on the field test observations that there is no any ice coating in the insulator surface dropping from the coating surface; as is different from the phenomenon observed in the vertical sample sheet ice coating tests; whereas, it may be observed that there exists some liquid water in the interface between the coating and the ice coating, which forms the phenomenon similar with the bubbles. The results based on many tests may indicate that the first bubble generally occurs in the coating surface after 3 hours and then the ice layer is melted gradually; the bubble range will be expanded along with the lasting time; however, the ice layer may fall off automatically and difficultly within the limited test period and the artificial mode may easily cause the ice layer to fall off. It may be thought based on the analysis that the large insulator diameter and the small shield inclination angle shall be the main cause resulting in the unobvious de-icing effect.

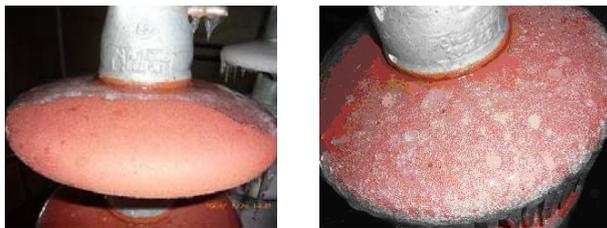


Figure 9: the insulators coated with the ice melting coatings after 9 hours

The insulator upper surface inclination angle is generally only 5°; the thickness of the ice coating in the central region is small and the outer edge ice coating thickness is large due to the gravity effect during the ice coating process. While the ice layer induces the organic metal compound in the coating to be decomposed and release the low ice point material; the ice coating (with low thickness) in the central region of the insulator may be melted first to form one ice ring, whose inner diameter is smaller than the outer diameter of the insulator; thus, the ice ring may still remain around the insulator surface and

may not fall off; as may be greatly different from phenomenon during the ice melting process of the ice coating tests for the indoor vertical suspension sample sheets. While the melting process in the insulator surface lasts continuously, the inner diameter of the ice ring around the insulator are enlarged unceasingly and the ice coating thickness is lowered gradually; however, the formed ice ring is still covered around the insulator. Only while the inner diameter of the ice ring around the insulator is no less than the outer diameter of the insulator, the ice ring may fall off from the insulator so as to complete the entire de-icing process. At this point, the insulator surface ice melting time may also be related to the shield structure characteristics and the outer diameter size except for the insulator ice coating thickness.

On the other hand, because the ice coating temperature is too low, the small organic molecules to lower the ice melting temperature may not take effect at about -5°C and the most appropriate ice melting temperature range is -3°C~-1°C; while the temperature fluctuation range is too large, the ice melting process may be carried out while the temperature is relatively large but the re-solidification may occur under the lower temperature so as to form the “melting - solidification” cycle.

Although the insulator ice melting results are not very ideal, the systematical study on the low ice point type ice melting coatings containing the metal organic compound(s) has been carried out through a large number of experimental study and theoretical analysis; and it has been observed during the test processes that there exist the liquid phase in the interface between the ice coating layer and the coatings during the ice melting process; as may demonstrate that the ice melting effect is remarkable. The research achievements may affirm that such low ice point ice melting coating research approach may be utilized to solve the ice coating issue for the power system as well as the further research direction may be clarified.

5. CONCLUSIONS AND RECOMMENDATIONS

1). Based on the water solid-liquid phase transition theory, the organic metal compounds are used to modify PRTV anti-pollution flashover coatings so as that one kind of high hydrophobicity ice melting type de-icing coatings may be prepared, which may lower the water

ice point temperature.

2). The prepared low ice point type ice melting coating may lower the water ice point temperature from 0°C to -4°C and cause the ice coating in the vertical white sample iron sheets may fall off completely after 9 hours; and the ice melting and ice falling effects are relatively remarkable.

3). As for the insulator tests, it may be observed that there exists some liquid water in the interface between the coating and the ice coating layer; the ice melting regions (or points) may be increased and enlarged along with the lasting time; however, the ice layer may not fall off naturally because the insulator shield inclination angle is relatively small.

4). The existing test results may indicate that the coatings developed in this project may play some certain de-icing and ice melting functions as for those non-heavy icing regions where the ice coating temperature is among -3~0°C, which may be applicable to not only the insulator but also the overhead electrical conductors.

5). For realizing the engineering applications, the organic metal compound structure and composition shall be further adjusted; it shall be controlled that the organic metal compound in the de-icing coatings may be decomposed with water and the rate of releasing material which may lower the ice melting temperature shall be controlled; and the coating preparation processes shall be improved; in addition, the insulators with large shield inclination angles may be taken into account for application so as to enhance the de-icing effect.

6). A large number of research results may demonstrate that the super hydrophobic coatings may decrease the ice coating rate in the early stage; moreover, the nanometer structure constructed in the coating surface may lower remarkably the ice coating amount; therefore, there will be broad application prospects for such ice melting type coatings and the relevant researches shall be further carried out.

6. REFERENCES

[1] HU Yi, Analysis and Countermeasures Discussion for Large Area Icing Accident on Power Grid [J], High Voltage Engineering, 2008, Vol.34: 215-218 [in Chinese]
[2] LIU Yun-peng, GAO Son1, HUANG Dao-chun etc., Icing Flashover Process and Its Influential Factors of Long Insulator Strings on the EHV Transmission Line [J], High Voltage Engineering, 2009, Vol.36:

557-559 [in Chinese]

[3] GU Shan-qiang, CHEN Jia-hong, CAI Wei etc., Experimental Analysis and Engineering Designing of Laser De-icing Technology for Transmission Lines [J], High Voltage Engineering, 2009, Vol. 36: 2243-2247 [in Chinese]
[4] SHAN Xia, SHU Naiqiu, Discussion on Methods of De-icing for Overhead Transmission Lines [J], High Voltage Engineering, 2006, Vol. 32: 25-27 [in Chinese]
[5] Long Xiaole, Bao Wujun, Guo Yinglong, Wu Qingming, Study of Coagulated Ice on Power Transmission Conductors [J], Journal of Wuhan University of Hydraulic And Electric Engineering, 1996, 29(5): 102-107 [in Chinese]
[6] JIANG Xingliang, YI Hui, Transmission Line Ice Coating & Protection [M], Beijing: China Electric Power Press, 2002, 169~170 [in Chinese]
[7] JIANG Xingliang, ZHANG Lihua, De-icing and Anti icing of Transmission Lines [J], High Voltage Engineering, 1997, 1(23): 73-76 [in Chinese]
[8] Yuan Jihe, Jiang Xinliang, Yi Hui, etc., The Present Study on Conductor Icing of Transmission Lines [J], High Voltage Engineering, 2003.6, Vol. 30(1): 6-9 [in Chinese]
[9] Liu Sheng-feng, The New Pigment Synthesis and Study of The Selectively Absorptive Coating of Solar Spectrum [J], Acta Energetica Solaris Sinica, 1994, 15(3): 300-304 [in Chinese]
[10] Liangliang Cao, Andrew K. Jones, Vinod K. Sikka, Anti-Icing Superhydrophobic Coatings [C], Langmuir 2009, 25(21), 12444-12448
[11] Xu Zhihai, Liao Weiyan, Jia Zhidong, Research and Progress of the Semiconductor RTV Ice-covering-proof Coating [C], High-voltage Professional Committee 2007 Academic Conference Proceedings, Chinese Society for Electrical Engineering (CSEE), 2007 [in Chinese]
[12] JIANG Xing-liang, XIAO Dai-bo, SUN Cai-xin, Application Prospect of Hydrophobic Coatings on Anti-icing of Transmission Lines [J], Southern Power System Technology, 2008.4: 13-18 [in Chinese]
[13] CAO Feng, GUAN Zi-sheng, LI Dong-xu, Preparation of Material Surface Structure Similar to Hydrophobic Structure of Lotus Leaf [J], Journal of Materials Science and Engineering, Vol.25, No.4: 602-605, 2007.8 [in Chinese]
[14] Guo Xinglin, Xie Qiongdan, Zhao Ning, etc., Developments of Bionic Polymers [J], Progress in Chemistry, 2004, 16 (6): 1023-1029 [in Chinese]
[15] Zhang Yan, Yang Kai, Wang Xianming, Research progress of hydrophobic coating [J], China Coatings, 2007, 22 (5): 42-44 [in Chinese]
[16] Su Changhong, Chen Qingmin, Research progresses of the Surface Similar to Lotus Leaves [J], Chemistry (Online Preview Version), 2007 [in Chinese]

- [17] JIANG Lei, Super-Hydrophobic Nanoscale Interface Materials: From Natural To Artificial [J], *Chemical Industry and Engineering Progress*, 2003, 22 (12): 1258-1264 [in Chinese]
- [18]Hu Xiaohua, Wei Xiwen, Chen Bei, Development of Ice-Over Resistant Coatings for Electric Transmission Lines [J], *Paint & Coatings Industry*, 2006, 36(3): 8-10 [in Chinese]
- [19]Wu Tianrong, Cao Boxing, Xu Li, The development and progress of chemical snow melting and de-icing agents in foreign countries [J], *Inorganic Chemicals Industry*, 1989-5: 28-32 [in Chinese]
- [20] Wang Xiaoguang, Zhang Yadong, The research progress and development direction of snow-melting agent [J], *Inorganic Chemicals Industry*, 2007-3: 8-10 [in Chinese]
- [21] Wu Xiaomin, Xu Wangfa, Wang Weicheng, etc., Experimental Study on Super-Cooled Drop Freezing on Cold Surfaces [C], *Heat and mass transfer academic conference proceedings, Chinese Society of Engineering Thermophysics*, 2003: 325-328 [in Chinese].