STUDY ON NATURAL ICE-MELTING PROCESS OF INSULATOR BY THERMODYNAMIC ANALYSIS

by

Rui-Wen ZHOU[a], Yong-Can ZHU[a*], Yi TIAN[b], and Ji CHAO[a]

[a] College of Electronics and Information, Xi'an Polytechnic University, Xi'an, China
[b] State Key Laboratory of Electrical Insulation and Power Equipment, Xi'an Jiaotong University, Xi'an, China

Original scientific paper
https://doi.org/10.2298/TSCI211014106Z

Insulator flashover caused by atmospheric icing is a serious accident with high frequency. The flashover risk on insulators during ice-melting process is higher than that during icing accretion process. Therefore, it is of great theoretical significances and engineering value to carry out research on risk prediction methods of ice-melting flashover on insulators. Firstly, this paper presents a thermal balance equation of the iced insulator surface for icing natural melting process and calculates the main influencing parameters of the ice-melting process by thermodynamic analysis. Secondly, this paper extracts the meteorological data from great numbers of on-site ice-melting flashover cases to calculate the meteorological condition with the highest flashover risk. On the basis of this, to judge the state of freezing or melting, a thermodynamic criterion of freezing and melting state is proposed, and the finite element analysis is applied to model iced and non-iced insulators, and the temperature distribution, the wall heat transfer coefficient distribution of the air-flow field are analyzed. The results suggest that the local micrometeorological temperature and the heat transfer coefficient have the greatest impact on the ice-melting process of insulators. The structure of insulator will be changed by the covered ice, ended up to a cone-like structure which will weaken the influence of the vortex on the central leeward side. The heat dissipation and melt characteristics of iced insulator will be quite different from that of non-iced insulator.

Key words *iced insulator, ice-melting flashover, meteorological data, thermal balance equation, thermodynamic analysis, flashover risk prediction, finite element analysis*

Introduction

Insulator flashover caused by atmospheric icing is a serious accident resulting in the trip accidents with high frequency in the power system, which seriously affects the safety and stability of the power system in cold climate regions [1, 2]. As a special kind of pollution, icing is easy to adhere to the insulator. During the icing growth and stabilization stage, there is generally no bridging icicles between two insulator sheds, or no liquid film formed on the insulator, so that the electrical insulation strength of the insulator is still relatively high, and the probability of icing flashover is relatively low. As the temperature rises, under the combined action of solar radiation, air-flow, leakage current and other factors, the surface of the icing layer will melt first, forming a water film (melted water on the rime icing surface will be absorbed by its own

[*] Corresponding author, e-mail: 286844943@qq.com

porous structure, forming sponge ice mixed with ice, and water). The surface contamination of the insulator and the conductive ions precipitating from the icing water will greatly weaken the insulation strength of the insulator, and the flashover risk is the greatest during this period [2-5]. Therefore, it is of theoretical value and practical engineering significance to carry out research on the natural melting model of iced insulator and the evaluation of icing flashover probability to realize the prediction and early warning of icing flashover based on meteorological forecasts and meteorological data collected from local weather bureaus and field test.

By far, in power transmission system most of the research on ice melting mainly focuses on the thermal melting of iced overhead lines, and methods such as DC melting method, AC melting method, and pulse current melting have been proposed [6-9]. However, due to differences in energy sources and icing structures, the aforementioned methods cannot be directly used to predict the melting time of insulators. In addition, the uncontrollable ice melting energy which totally depends on the natural environment, is responsible for a slow ice melting process. Under the influence of the inconstant meteorological conditions, the melting water may freeze again [10-12], called *freeze-thaw cycle*, as a result, the model of icing and melting for iced insulator is very complicated. Moreover, due to the complexity of the morphology of insulator's icing, parameters such as convection heat transfer and heat conduction cannot be directly calculated by empirical formulas [9, 13], which also requires to model for the iced insulators, and updates the model constantly according to the icing morphology.

Based on the statistics of the meteorological data during the failure period of a large number of melting flashover cases of iced insulators, this paper analyzes the meteorological conditions with the highest ice-melting flashover risk and establishes a 3-D simulation model of the insulator and its surface icing (shaped in ice shell). Moreover, the paper performs finite element analysis (FEA) on its temperature field, convective heat transfer coefficient distribution and peripheral air-flow field, obtains the icing and melting law of different parts of the insulator under the influence of solar radiation, air-flow and leakage current, and establishes an early-warning method of ice melting based on meteorological data.

Thermo analysis of natural melting process and flashover risk for icing insulator

Factor analysis for insulator icing flashover

Operation experience and flashover experiment of iced insulators have shown that in addition known information such as insulator sub-categories and anti-icing flashover measures, the icing flashover process of insulators is significantly affected by factors such as the icing type, icing length and bridging state, the state of ice melting, and pollution degree [14].

With the rising ambient temperature and the increasing leakage current on the surface of the insulator, ice-melting will first appear on the surface of the ice layer where the icing flashover risk will increase. During the ice-melting process, the flashover characteristics of the insulator greatly depend on the pollution degree, icing grade, the icicle length, and the bridging state. The pollutant attached to the surface of the insulator before icing accretion or attached to the ice layer is precipitated largely during the ice-melting, which greatly weakens the insulation performance of the insulator, significantly increases icing water conductivity and the surface leakage current, thus sharpens the flashover risk [14]. In addition, the more serious the icing degree, the more uneven the voltage distribution on the insulator string, and the easier it is to form a continuous water film when the icing melts, which will greatly increase the probability of forming conductive paths and induce flashover of insulators [15]. As shown in tab. 1, compared with low density soft rime, glaze and hard rime (mixed rime) grow faster and are easier to form icicle bridges between two insulator sheds, resulting icing flashover with a higher frequency [16].

Table 1. Influencing factors of insulator icing flashover

Influencing factors	Analysis of influencing factors
Icing type	Glaze and hard rime are in high density, grow fast and have strong adhesion. The flashover risk of glaze and hard rime is higher than that of rime in low density
Icing grade	The more severe the icing degree, the easier it is to form a conductive path, and the higher risk it is of icing flashover
Icicle length	The longer the icicle, the easier it is to the bridging of insulator shed spacing with icicles, and the higher risk it is of icing flashover
Insulator pollution	The more severe the pollution degree of the insulators, the higher conductivity of the icing water, and the higher risk it is of icing flashover
Insulator characteristics	Under the same voltage level, the longer the insulator string, the lower risk of icing flashover. The material and type of the insulator also have a direct impact on the risk of icing flashover
Altitude	Under the same experimental conditions, generally the higher altitude, the higher risk of icing flashover
Air pressure	Under the same experimental conditions, generally the higher pressure, the lower risk of icing flashover

Factors analysis for insulator ice-melting process

The physical process of natural melting of iced insulators

According to the more than 100 ice-melting flashover cases of insulator covered with glaze, hard rime, soft rime, wet snow and other different icing types, the micrometeorological conditions during the icing accretion and melting of the insulators are statistically analyzed, as shown in tab. 2. The statistical results show that during the icing accretion the micro-meteorological characteristics of insulators have a temperature range of –9~0°C with an average temperature of –3.2°C, and a maximum wind speed of 9 m/s with the average wind speed of 3.9 m/s. During the ice-melting the temperature range is –4~0°C, the average temperature is about –2 °C, and a maximum wind speed of 5 m/s with the average wind speed is about 2.8 m/s.

Table 2. Meteorological data statistics for the ice-melting flashover cases on insulators

Icing type	Average temperature during ice-accretion [°C]	Average wind speed during ice-accretion [ms^{-1}]	Average temperature during ice-melting [°C]	Average wind speed during ice-melting [ms^{-1}]
Wet snow	–1.4	2.0	–2.5	1.5
Hard rime	–3	7.0	–1	2.5
Glaze	–4	4.0	–3	1.5
Hard rime	–3	3.5	–1.5	3.8
Wet snow	–4.4	2.5	–2	2.5
Glaze	–3	5.0	–2	4.0
…	…	…	…	…
Glaze	–2	3.5	–1.3	4.1

Since the heat leading to the natural melting of insulators comes from the environment, the ice-melting energy is uncontrollable engendering a slow ice-melting process. Under the complicated meteorological conditions, the melting droplets may freeze again, namely a freeze-thaw cycle. The freeze-thaw cycle in the natural melting process can cause changes in the icing structure and easily cause insulator flashover accidents. Similar to the high current ice melting model, the heat conservation equation is the theoretical basis for judging the state of icing freezing or melting.

Analysis of thermal balance on the surface of iced insulator

The natural melting process of insulator icing is affected by factors such as icing structure, micrometeorological temperature, solar radiation, wind speed, wind direction, insulator leakage current*, etc.* The heat balance process on the icing surface of insulator during the natural melting can be calculated and analyzed:

$$Q_n + Q_J + Q_s - Q_{cq} - Q_{sr} - Q_e = 0 \tag{1}$$

where Q_n is the heat generated by solar radiation, Q_{cq} – the heat generated by the heat convection on the surface of ice layer (during the melting process the ambient temperature may be higher than the needed energy leading ice-melting, so that the air-flow will cause the internal energy of the ice layer to increase), Q_{sr} – the short-wave radiation of the ice layer, Q_J – the current Joule heat (for the ice-melting process, this item is estimated by the insulator leakage current), Q_s – the sum of other subtle heat during the ice-melting process, and Q_e – is the ice vaporization latent heat. Among them, Q_n, Q_J , and Q_s are heat absorption, while Q_{cq}, Q_{sr}, and Q_e are heat release.

– Heat generated by solar radiation

Solar radiation is an important energy source for insulator ice-melting in cold regions, but the ice layer will reflect incident solar radiation, which would result in a heat loss. The heat generated by solar radiation can be expressed:

$$Q_n = \left(1-\alpha\right) I \tag{2}$$

where I is the incident solar radiation [Wm^{-2}] and α – the ratio of the icing reflecting the incident solar radiation energy, namely the reflectivity. According to the shape of ice and snow, α can be changed from 0.4-0.8 [17].

– Heat generated by heat convection on the surface of ice layer

Based on the Newtonian cooling formula, the calculation formula for the heat loss of heat convection on the surface of ice layer is [18]:

$$Q_{cq} = h\left(T_{\mathrm{is}} - \mathrm{T}_{\mathrm{air}}\right) \tag{3}$$

where h is the convective heat transfer coefficient which represents the heat transfer capacity between the interactive surface of fluid and solid. It is only related to the shape and position of the insulator and the physical characteristics of the external air-flow, such as wind speed, and is not affected by the insulator density, thermal conductivity and specific heat capacity. Under the same meteorological conditions, the higher convective heat transfer coefficient would cause the stronger heat dissipation capacity of the insulator surface, and it is less likely to reach the critical point of ice-melting temperature, therefore, h can be one of parameters predicting ice-melting process by using the FEA. The T_{is} is the surface temperature of the ice layer and T_{air} – the air temperature.

– Heat flux generated by short-wave radiation

All things in nature are constantly emitting short-wave thermal radiation into space, and simultaneously they are constantly absorbing the thermal radiation emitted by other objects [19]. The external short-wave radiation of the ice layer in the melting period:

$$Q_{sr} = \varepsilon\sigma_0\left[(273+T_{\rm is})^4-(273+T_{\rm air})^4\right] \tag{4}$$

where ε is the total emissivity of the icing surface to the black body that equals to 0.95 approximately and σ_0 – the Stefan-Boltzman constant.

– Leakage current Joule heat

When the insulator surface is covered with raindrops or ice crystals, the value of the leakage current along the surface will increase greatly, which will generate more Joule heat on the surface of the insulator, which will accelerate ice-melting near the surface of the ice layer, the Joule heat generated per unit area of the insulator per unit time:

$$Q_J = \frac{UI}{A} \tag{5}$$

where I is the leakage current of the insulator, U – the operating voltage, and A – the equivalent area of the iced insulator which is set to be 1.1 times of the initial area of the tested insulator in this paper.

– Latent heat of vaporization

The heat of vaporization of the ice layer can be calculated:

$$Q_e = \frac{\varepsilon_{\rm w} L_{\rm v} h\left(e_{\rm is}-e_{\rm air}\right)}{C_p P} \tag{6}$$

where $\varepsilon_{\rm w}$ is the molecular weight ratio for water vapor, $L_{\rm v}$ – the latent heat of vaporization, C_p – the specific heat capacity of air, P – the static air pressure, $e_{\rm is}$ and $e_{\rm air}$ are the saturated vapor pressure corresponding to the icing surface temperature and the air temperature, respectively, and Q_e – the latent heat of icing vaporization, is about 0.2-0.3 times of Q_{cr} generated by the heat convection of ice layer.

– Parameter magnitude analysis

According to the average micrometeorological conditions resulting in ice-melting flashover analyzed previously, this paper assumes that the external air-flow is under standard atmospheric pressure, the temperature on the icing surface is $T_{\rm is}$ = 0 °C, the air temperature $T_{\rm air}$ = –4 °C, the leakage current of the insulator is 0.1 mA, the wind speed is 4 m/s, and the solar radiation is 150 W/m^2.

Excluding the influence of other small values, incorporating the aforementioned meteorological data into eqs. (2)-(6) could estimate the numerical magnitudes of the six calorific values in the heat balance equation of the natural melting process, the magnitudes of the heat loss and the heat absorption during the ice-melting process are shown in fig 1. The results show that the heat generated by solar radiation, Q_n, the heat generated by external shortwave radiation, Q_{sr}, and heat convection, Q_{cq}, have a great-

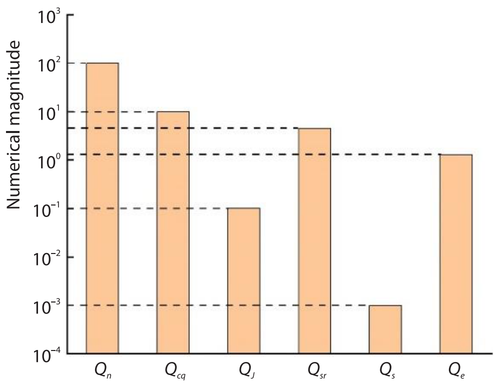

Figure 1. Numerical magnitudes of the parameters in the energy conservation equation

er impact on the heat balance process of the icing surface, while the heat caused by external shortwave radiation, Q_{sr}, and Joule heat, Q_J, caused by leakage current and the latent heat of vaporization, Q_e, have little effect on the heat balance process.

In order to simplify the boundary conditions of the simulation model, solar radiation and external shortwave radiation heat can be embodied by the temperature on the surface of insulators, and heat convection coefficient could represent wind speed, heat convection and other physical characteristics of the external air-flow.

The thermodynamic criterion for the state of icing freezing and thawing based on heat balance equation

There is a freeze-thaw cycle in the natural melting process of icing layer. The freeze-thaw state is determined by the thermal equilibrium of its surface. The empirical eqs. (2)-(6) are used to calculate the values of heat by putting them into eq. (1) and assume that the temperature of the ice layer on the surface of the insulator is 0 °C. If the calculation result on the left side of eq. (1) is greater than 0, it means that the heat absorbed by the ice layer is greater than the heat released, and the excess heat will cause the ice layer to melt. On the contrary, if the calculation result on the left side of eq. (1) is less than 0, it means that the heat absorbed by the icing layer is not enough to engender the ice-melting and remain in icing accretion process. Therefore, the freeze-thaw state criterion of the insulator can be characterized:

$$\begin{aligned} Q_n + Q_J + Q_s - Q_{cq} - Q_{sr} - Q_e &\geq 0 \quad \text{ice-melting} \\ Q_n + Q_J + Q_s - Q_{cq} - Q_{sr} - Q_e &< 0 \quad \text{no ice-melting} \end{aligned} \tag{7}$$

In view of the non-ideal icing structure of insulator, each heat value in the critical freeze-thaw criterion may not be directly calculated by the aforementioned empirical formulas. The insulator string is considered as a whole, so it is impossible to judge the temperature distribution of windward, leeward, dayside, and nightside. For this reason, this paper transforms the aforementioned influencing factors into the second and third types of boundary conditions for the natural melting model of iced insulator, proposes a freeze-thaw criterion, and performs FEA on the steady-state temperature of the iced insulator. By simplifying the criterion, if the temperature of the insulator surface is all lower than 0 °C, it indicates that the heat absorbed by the icing layer is not enough to engender ice-melting. If the temperatures of the local areas of the iced insulator are higher than 0 °C, it means that the ice layer is showing signs of melting under this meteorological condition. Therefore, the freeze-thaw state criterion of the insulator can be simplified:

$$\begin{aligned} T_{is} &< 0 \quad \text{no ice-melting} \\ T_{is} &> 0 \quad \text{ice melting} \end{aligned} \tag{8}$$

Finite element analysis for judging the melting state of insulators

Modelling for air-flow field of iced insulators

The FEA is an important method for analyzing the velocity field, temperature field and external air-flow field of iced insulators. This method first establishes a set of mathematical and physical equations of fluid mechanics, then numerically discretizes the object to be solved, and then performs numerical calculations on the equation set, getting the calculation result on each discrete point. This topic takes the LXY-160 type suspensionughened glass insulator as the research object. The specific parameters of the insulator model are shown in tab. 3.

Table 3. Dimensions of tested insulator

Model	Shed material	Length [mm]	Nominal disc diameter [mm]	Nominal creepage distance [mm]	Appearance
LXY-160	Toughened glass	155	280	380	

Through the analysis of the factors affecting the natural melting process and the surface heat balance process, it can be concluded that factors in the heat balance model of iced insulator, such as solar radiation and convective heat transfer, which are directly related to the surface temperature, have a greater impact on the heat balance process of iced insulator and can be calculated by the air-flow field. While energy sources that are not directly related to the surface temperature, such as solar thermal radiation, leakage current Joule heat, can be converted into the second type of boundary conditions and applied to the surface of the insulator model.

In order to verify the feasibility of the method under the premise of a low calculation amount, the insulator string is set to contain only three insulators. Considering that there is not much difference of the simulation results among upper, middle and bottom insulator sheds, the author only takes the middle shed as the analysis object. The author first focuses on the various coefficient distributions on the surface of insulator, thus ice layer attached to the insulator is negligible. The fluid simulation domain is modeled as a box, which is 0.8 m wide, 1 m long, and 1.5 m high. Based on the aforementioned meteorological data statistics, the critical ice-melting conditions will be calculated by the special software ANSYS, and we carried out multiple numerical simulations by setting up different inlet velocities and inlet temperatures to observe the effects on the flow field distribution of speed, temperature and heat convection of different parts on insulator. In addition, the residual monitors of energy, velocity and turbulence model parameters are set as $1e^{-11}$, $1e^{-6}$ and $1e^{-6}$, respectively. The simulation model for judging the melting state of insulators can effectively converge with the iteration number of 800~1200. The model parameters are shown in tab. 4.

Table 4. Dimensions of simulation boundary conditions

Mesh section	Inlet temperature [°C]	Inlet velocity [ms^{-1}]	Heat flux [Wm^{-2}]	Air-flow direction	Relative residual	Mesh elements number	
						Insulator	Airstream field
	–4~0	2~5	200	Figures 3(a) and 3(b)	10^{-3}	$1.8 \cdot 10^{6}$	$3.2 \cdot 10^{6}$

Simulation result analysis

Figures 2-4 show one of the simulation results (the inlet temperature is set to 3 °C, and the inlet wind speed is set to 5 m/s. The cross-sectional view of the velocity field around the insulator umbrella skirt is shown in figs. 2(a) and 2(b). When the air-flow flows through the insulator, the velocity range of the air-flow field around the insulator sheds is about 0-5.99 m/s, and the velocity range of air-flow field around the steel cap is about 0-8.06 m/s. The graphs illustrate that the largest flow velocity point of insulator shed and steel cap are all in front of the air separation point. And due to the blocking effect of the shed and the steel cap, the air-flow velocity at the back of the insulator is small.

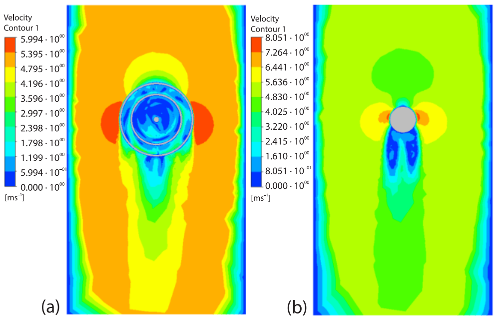

Figure 2. Speed field around insulator shed and steel caps; (a) the horizontal cross-section of the insulator shed and (b) the horizontal cross-section of the steel cap

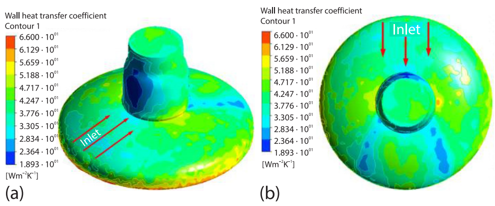

Figure 3. The wall heat transfer coefficient distribution on the insulator; (a) 3-D view and (b) top view

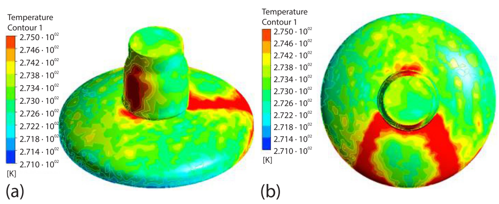

Figure 4. Temperature distribution on the insulator; (a) 3-D view and (b) top view

As shown in figs. 3(a) and 3(b), under the special structure of the insulator, the convective heat transfer coefficient at the windward stagnation point is significantly smaller than that on both sides, and the closer to the upper end of the steel cap, the more significant this characteristic. The air-flow velocity of the region near the air-flow separation point on both sides of the shed is relatively high, so this region witnesses a high convection heat transfer coefficient and a strong heat dissipation capacity. In addition, under the influence of the vortex in the external flow field, the convective heat transfer coefficient of the central area on the leeward side where the vortex exists increases, which is companied by the improving heat dissipation capacity. From figs. 4(a) and 4(b), it can be found that the heat loss rate of the leeward side vortex is slightly higher the adjacent areas on both sides where vortex does not exist, the heat is concentrated, and the temperature is higher. The heat dissipation near the windward stagnation point of the steel cap is relatively slow, so the temperature is relatively high. It can be predicted that for insulators under mild icing conditions, signs of ice-melting may be more likely to appear at the windward stagnation point of the steel cap and the center of the leeward surface on the adjacent sides of the shed.

Analysis for melting flashover cases of iced insulator

Take a severe icing case on a transmission-line in Shanxi as an example. The fault period in this area was moderate freezing rain throughout the day, precipitation was 26.2 mm, wind speed was approximately 1~2 m/s, ambient temperature was around –2~1 °C, relative humidity was about 99%, the icing type of insulator was glaze, the thickness was about 5mm, and the calculated heat flow was 192 W/m^2 including solar thermal radiation and leakage current Joule heat. After the weather improved, atmospheric icing on the transmission-line began to melt and fall off, causing the insulators to flashover.

Set the boundary conditions of the model according to the on-site weather conditions of this case: air inlet temperature of –2 °C (271.1 K), air velocity of 2 m/s, and air-flow direction perpendicular to the insulator string. Because the icing structure of glaze is long and thin on the site with the high convection heat transfer coefficient and the fast heat dissipation [20], the icing type of glaze is relatively difficult to melt under the same weather conditions. When the ice on the insulator shed melts, the melted droplets overflow along the icicle, which may lead to form water film and conductive path and increases the risk of insulator flashover. Therefore, in order to simplify the model, this article only considers the icing shell on the surface of the shed and steel cap and analyzes the distribution of temperature and convective heat transfer under uniform icing conditions. The calculation results are shown in figs. 5 and 6, compared with the two sides of the icing shell on the insulator, the convective heat transfer coefficient at the center of the leeward area is lower, which result in a slower heat dissipation and a higher surface temperature. Comparing figs. 4 and 5, the icing accretion on the surface of the insulator changes the structure of the insulator, forming a cone-like structure, which significantly weakens the influence of vortex on the leeward side.

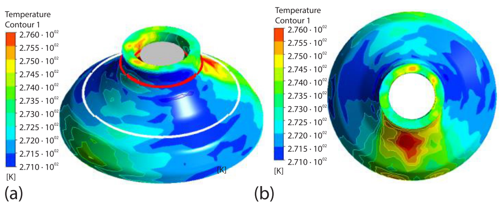

Figure 5. The temperature distribution on the icing covered insulator shell; (a) 3D view and (b) top view

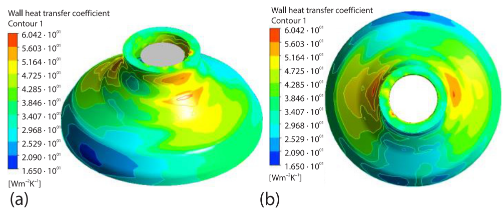

Figure 6. The distribution of wall heat transfer coefficient on the icing covered insulator shell; (a) 3D view and (b) top view

Figure 7 shows the distribution curve of the temperature and convection heat transfer at the horizontal section of the insulator shed and steel cap, where the default angle at the center of the windward surface in the abscissa is 0° (360°). As shown in fig. 6(a), the white line is the section of the insulator shed, and the red line – 1 is the section of the steel cap. In order to study the characteristics of ice-melting in different regions of the insulator shed and steel cap, solar radiation and other heat are uniformly applied to the surface of the insulator, regardless of the influence of the solar radiation angle. Therefore, each part of the insulator follows rules that the region high in convection heat transfer coefficient would be fast in the surface heat dissipation and low in the surface temperature. As shown in fig. 7(a), under the influence of leeward side vortex, the convection heat transfer coefficient in the leeward area of the insulator steel cap

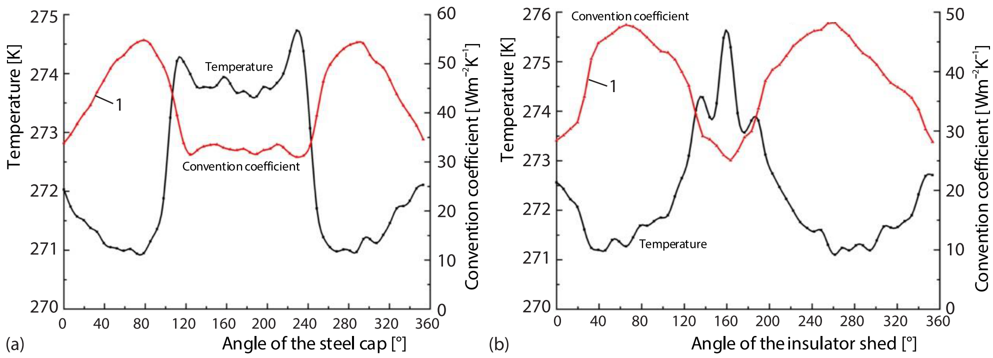

Figure 7. The distribution curves of temperature and wall heat transfer coefficient for different parts on insulator; (a) ice covered on the steel cap and (b) ice covered on the insulator shed

(120-240°) is the lowest, and the temperature is significantly higher than that of other areas on the steel cap, which is about 0-1.5 °C, so it is prone to icing accreting and melting in the leeward central areas. The air-flow separation point (110° and 230°) has a low convective heat transfer coefficient, the lowest heat loss and the highest local temperature (about 1.5 °C).

Insulator shed is affected by the diameter and icing slope, so there is a significant difference in convective heat transfer and temperature distribution between the position of the shed and the steel cap. The temperature range of the iced shed only in the leeward region of 140-210° is about 0-2.3 °C with the highest temperature point around 160° (about 2.3 °C) where the icing shell are more likely to melt than other regions. The highest temperature of the insulator shed is slightly higher than that of the steel cap, so that part of shed may appear signs of ice-melting earlier than that of steel caps.

Under the meteorological conditions given in the case, the temperature of the regions near the insulator steel cap and umbrella skirt exceeded 0 °C. According to the criterion of freezing and thawing shown in eq. (8), the icing shell in these regions began to melt, and the flashover risk is relatively high. This is consistent with the actual conditions in the melting flashover cases of the iced insulator, which verifies the effectiveness of the method.

Conclusions

In this paper, based on the FEA analysis, the iced and non-iced insulators models were established by thermodynamic analysis, the meteorological data of insulator melting flashover cases as input parameters of the model were simulated by FLUENT, which is a feasible method to narrow the meteorological conditions of ice melting to a range of critical freezing-melting conditions, which could be taken as the prediction criterion and a source of data for the future machine learning training model. The conclusions are as follows.

- Solar radiation, heat convection on the iced surface, and thermal radiation are the main influencing factors of the heat balance process on the surface of iced insulator during the natural melting, which embody in the temperature and heat convection distribution on the surface of iced insulator.
- Due to the influence of atmospheric vortex, the heat in the leeward central area of the non-iced insulator dissipates quickly, while the adjacent area within about 10°, which is not affected by the atmospheric vortex, dissipates slowly with a high temperature.
- In the process of icing accretion, the icing on the surface of the insulator changes its physical structure, forming a cone-like structure, which greatly weakens the influence of vortex on the leeward side. The central area on the leeward side dissipates heat slowly, and signs of ice-melting are prone to appear. The melting laws of iced and non-iced insulators are quite different.
- When ice accretion is moderate and stable, the convective heat transfer coefficient on the leeward side of the insulator shed and the steel cap is relatively low, but the heat transfer strength of the steel cap is higher than that of the shed. When the air-flow direction of the transmission-line site and the sunshine direction form an angle of 140-210°, it is easier to lead to ice-melting and the flashover risk will prohibitively high.

Acknowledgment

This work was supported by the Key research and development projects in Shaanxi Province (Program No. 2021GY-306), Scientific Research Program Funded by Shaanxi Provincial Education Department (Program No. 20JK0663), Xi'an Science and Technology Plan Project (2019217114GXRC007CG008-GXYD7.12).

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Paper submitted: October 14, 2021
Paper revised: May 7, 2022
Paper accepted: May 9, 2022