Study on characterization method of icing degree of Porcelain and Glass insulators based on icing thickness of equivalent diameter

Zhang Zhijin[1], Zheng Qiang[1], Jiang Xingliang[1], Zhu Chengzhi[2]

1. State Key laboratory of Power Transmission Equipment& System Security and New Technology
Chongqing University, Chongqing 400030, China
2. State Gird Zhejiang Electric Power Company, Hangzhou 310007, China

***Abstract*-The structure of insulator is more complicated than that of transmission line and the shape and distribution of icing on the surface of insulators are different to each other. So the method of using icing mass, which is dissimilar to current characterization methods of icing degree of transmission lines, is hard to exactly characterize icing degree of insulators. Based on typical Porcelain and Glass insulators, this paper studied the measurement method of the equivalent diameter of insulators with configuration parameters and did the icing experiments in Xuefeng Mountain Natural Icing Station (XMNIS). The icing thickness of the equivalent diameter of insulators is investigated and compared to verify the characterization method of the equivalent diameter of insulators. The results show that:**

(1) Based on equation of the equivalent diameter of insulators deduced by equal-area method, the equivalent diameter of insulators is related to configuration parameters. The larger the sheds and areas of insulators are, the bigger the equivalent diameter of insulators is.

(2) There are obvious windward side and leeside on the surface of icing insulators in natural icing environment. Meanwhile, the icing of insulator is related to icing time, meteorological parameters and its structure.

(3) The icing thickness of the equivalent diameter of insulators is concluded from equal icing volume. More serious the icing on insulator surface is, the thicker the icing thickness of the equivalent diameter of insulator is.

***Key words*: insulator, the equivalent diameter, natural icing, icing thickness, icing degree, characterization method**

I. INTRODUCTION

Flashover of iced insulator string is a kind of transmission line icing disaster. Power grid accident caused by flashover of iced insulator could destroy the network structure and threaten the safety operation of power system [1-3]. With the development of UHV engineering projects in China, higher requirements are demanded for the reliability service of power system. Researches on icing insulators would provide engineering significance and value to it.

Average ice thickness and ice mass are commonly used to characterize ice degree of insulators. Different researchers would adopt different ice degree characterization parameter while studying icing performances. Reference [4] proposed an evaluation method for icing severity of insulator string through statistical analysis of icicle bridging degree. Test results show that, under a certain operating voltage, as icing time increases, the icicle bridging degree of insulator string increases sharply at first till it reaches and keeps at saturation. Reference [5] used the ice mass of insulators, the ice thickness of insulator surface, and the length and diameter of ice ridge to do researches on icing process. The results indicate that these parameters grow nonlinearly with the increasing of time, and the growing degree of ice mass slows down with the increasing of time. Reference [6] analyzed the influences of both wind velocity and electric field on the variations of icicle growth, ice weight, ice density, ice thickness while studying influence of wind velocity and electric field on ice accretion of composite insulators. Scholars at home and abroad also select ice thickness of rolling conductor monitoring to describe ice degree of insulators [7-8]. Reference [9] deduced the relation between ice thickness of rolling conductor monitoring and ice mass of insulator string.

Structure of insulator is more complicated than that of transmission line and icing shape and distribution on insulators surface are different to each other. So it is hard to accurately characterize the real icing process of insulators through ice thickness of rolling conductor monitoring, ice mass and average ice thickness. A standard characterization parameter of icing degree is essential. By taking typical porcelain and glass insulators as research objects, this paper proposed a method of calculating equivalent diameter of insulator which is based on structure parameters of insulator. And the icing experiments was conducted in Xuefeng Mountain Natural Icing Station to research icing thickness of the equivalent diameter of insulator

II. CHARACTERIZATION METHOD OF INSULATOR ICINGDEGREE

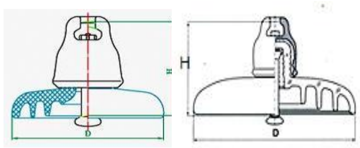
A. *Test Samples and Facilities*

Two string of XP-300 porcelain insulators and LXY-300 glass insulators are selected in this paper. The parameters and sketch of tested insulators are shown in Table 1 and Figure 1.

Table 1. The structure parameters of tested insulators

Type	D/mm	L/mm	H/mm	S/cm^2	M/kg
XP-300	322	385	192	2455	13.5
LXY-300	320	485	195	3138	10.7

D-shed diameter, *L*-creepage distance, *H*-structure height, S-surface area, M- insulator mass



(a) XP-300 (b) LXY-300

Figure1. Sketch maps of the tested insulators

The icing experiments of these two insulator strings were conducted in Xuefeng Mountain Natural Icing Station. Before the experiment, clean tested insulators and install them on the top of steel shelf for glaze icing. The arrangement of insulators is displayed in Figure 2. It is hard to measure ice mass variation directly so an indirect way with strain gauge load cell was adopted to regulate the variation of ice mass. It is necessary to calculate the original mass of insulators. Taking weights of insulators into consideration, 300kg strain gauge load cell was selected to record the variation of ice mass of insulator string. The PortLog is a compact rugged industrial grade data logging weather station which would automatically measure temperature, wind speed, wind direction and relative humidity and other parameters during icing process. It would record real-time data and logging interval could vary from 1min to 60 min according to user's need. Logging interval was set as 1 min during the experiment and the maximum recording time is 64 Days. Export the data file of weather parameters after the experiment.

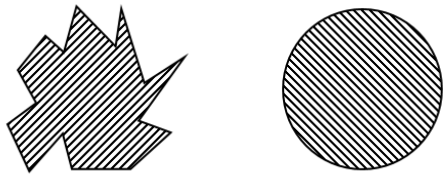
Figure 2. Arrangement of insulators

B. *Equivalent Diameter of Insulators*

The irregular shape and complex structure of insulators on transmission lines lead to different ice accretion process and ice shape. In order to study the icing growth process of different insulator, a standard variable that relates to insulator structure parameters is needed.

In engineering applications, the equivalent diameter of an object with irregular cross section is often used to characterize its physical characterization [10], as is shown in Figure 3. The cylinder with the equivalent diameter of D can be taken to describe the physical size of an irregular object with the cross section area of S, and the relationship between the equivalent diameter D and the cross section area Scan be described as:

$$D=2\sqrt{\frac{S}{\pi}} \tag{1}$$



(a) Cross section of irregular sample (b) Cross section of equivalent diameter cylinder

Figure 3. Equivalent diameter of irregular sample

The calculating method of the equivalent diameter depends on the practical research problem. Icing on insulator is actually a process in which over cooling water droplets in the air, under the influence of airflow, collides with the surface of insulator and then be captured and frozen in the surface. Therefore, for insulators in gas liquid two-phase flow, more attention should be paid to their surface area. Based on thoughts above, the insulator can be equivalent to a cylinder whose surface area is identical with that of the insulator and height is the creepage distance. As is shown in Figure 4, the diameter of the cylinder is the equivalent diameter of the insulator. The expression of equivalent diameter of insulator is:

$$D_{eq} = \frac{S}{\pi \times L} \tag{2}$$

Where S is the surface area of the insulator and the L is the creepage distance.

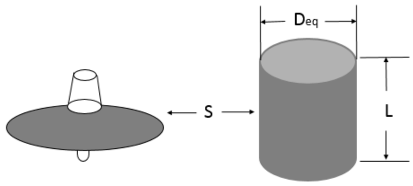


Figure 4. The equivalent diameter of the tested insulators

According to Equation (2), the equivalent diameters of two types of insulators are calculated and shown in Table 2.Compared to insulator structure parameters, it is concluded that the equivalent diameter of insulator increases with its surface area and shed diameter.

Table 2. Equivalent diameter of different insulators

Type	Equivalent diameter D_{eq}/mm
XP-300	203.0
LXY-300	205.9

C. *Ice Thickness of Equivalent Diameter of Insulators*

The insulator has been equivalent to a cylinder with the same surface area and the height of the creepage distance. Since icing of the cylinder is similar with conductor icing and both are icing around the column, the ice thickness of the equivalent diameter of insulator is defined as the thickness of ice with equivalent weight to insulator icing amount evenly distributing on the cylinder body. According to its definition, the equation of ice thickness of the equivalent diameter of the insulator is derived as:

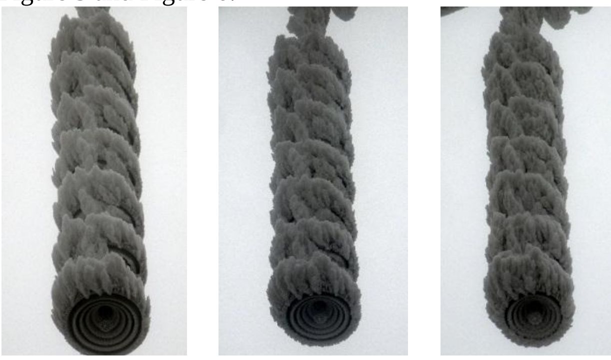
$$d = \frac{1}{2}\left(\sqrt{\frac{4V}{L\pi} + D_{eq}^2} - D_{eq}\right) \quad (3)$$

Where V is the volume of coated ice, L is the creepage distance of the insulator and D_{eq} is the equivalent diameter.

III. Test Result and Analysis

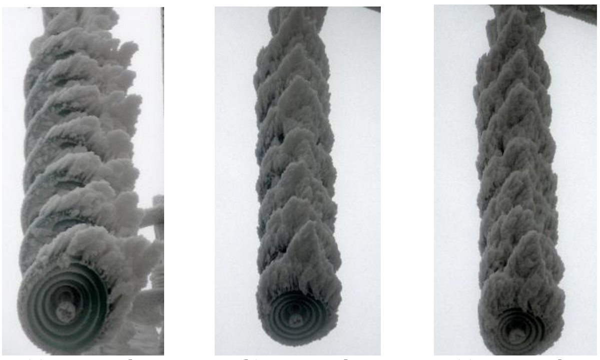
A. *Performance of Icing Accretion on Insulators*

Ice accretion on two type of insulators is shown in Figure 5 and Figure 6.



(a) time: 21 h (b) time: 40 h (c) time: 88 h

Figure 5. Ice shape of XP-300 porcelain insulators



(a) time: 21 h (b) time: 40 h (c) time: 88 h

Figure 6. Ice shape of LXY-300 glass insulators

Figure 5 and Figure 6 show that, ice shapes on two types of insulators are similar. There are big differences in ice shape and accretion process between windward side and leeward side. Moreover, icing on windward side is much more serious than that on leeward side. Icing on the windward side grew against the wind and formed ice bridge connection gradually, while icing on the leeward side was well-distributed and would not form ice bridge connection. There are also some ice in the flute of insulators. The reasons for these are: the flow fields in windward side and leeward side are disparate, which contribute to differences in the way and amount of capturing over cooling water droplets on both sides. Inflow in the air impinged the surface of windward side directly, so windward side of insulators could capture a lot of over cooling water droplets. However, over cooling water droplets captured by leeward side mostly came from air flow around surface of insulator and vortex backflow. And only part of droplets in the air flow would impinge on the surface of leeward side. Furthermore, ice bridge connection on the windward side would make it hard for air flow around the insulators. So the leeward side would capture little over cooling water droplets.

Average ice mass variations of one insulator of two types are presented in Figure 7. It is known from Figure 7 that: ice mass of insulator grew nonlinearly with the time and growth rate is high at first and then slow down. The increased ice mass of XP-300 porcelain insulator every 30 hours is respectively about 1946，788，1243，326 g and that of LXY-300 glass insulator every 30 hours is respectively about 3489，500，1317，488 g。

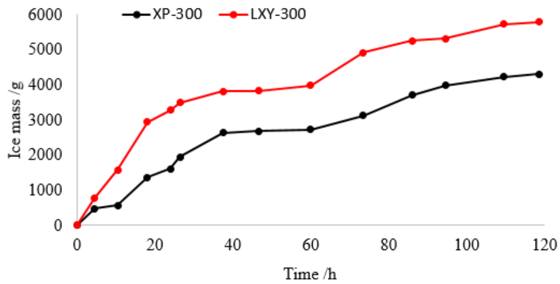
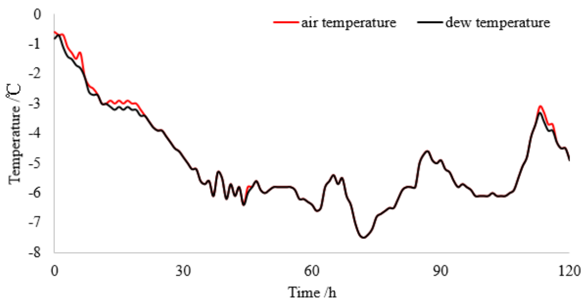
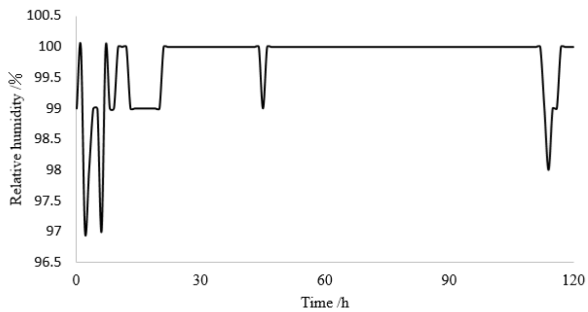


Figure 7. Average ice mass of one insulator vs. time

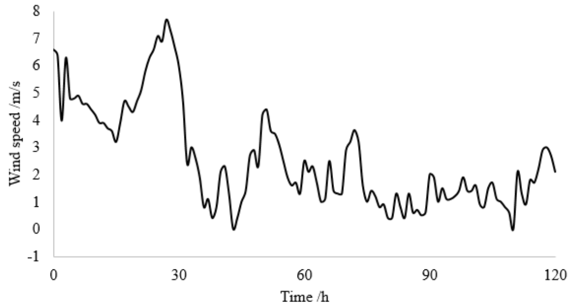
The PortLog weather station recorded data of weather parameters in 120h icing period. Figure 8 shows variation of environment temperature, dew temperature, relative humidity, wind speed, and wind direction.



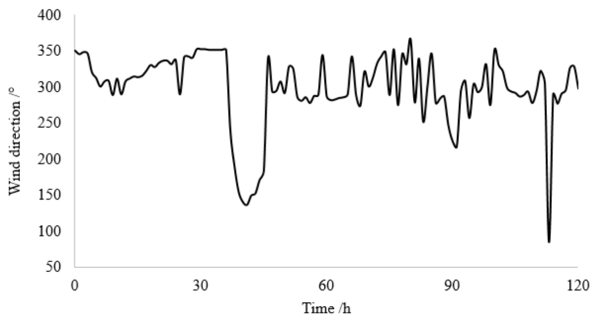
(a) Environment temperature and dew temperature



(b)Relative humidity



(c) Wind speed



(d) Wind direction

Figure 8. Variation of weather parameters

The whole icing period could be divided into three phases. In the first phase, ice mass of insulators grows heavily. The environment temperature started falling gradually and remain under -3℃ in a long time. The average wind speed in this phase is higher than1 m/s and the maximum wind speed is 7.6 m/s. The relative humidity is above 97%. In the middle phase, growth of ice mass of insulators slows down. The environment temperature declined till it reaches the lowest point and then increased a little. The relative humidity is still above 98%. Wind speed in this phase is obviously lower than that in the first phase. Moreover, wind speed fluctuated severely with the time and is under 2 m/s in most of time. In the last phase, ice mass of insulators still grows a little. Environment temperature at night declines again and varies from -4.6 to -6℃. Wind speed is less than 2 m/s but still higher than 1 m/s, which is beneficial to ice accretion. In the day time, environment temperature rises a lot but is less than -2℃. The average wind speed is about 1 m/s and relative humidity is almost 100% in most of this period.

In the whole icing period, wind speed and environment temperature have great influences on ice accretion. The larger wind speed is, the bigger collision coefficient and freezing coefficient are. On the one hand, large wind speed increased droplets' momentum, which make it easier for droplets impinging the surface of insulator. On the other hand, large wind speed intense heat interchange of droplets and would be helpful to freezing of droplets on insulator surface. When environment temperature is high, the latent heat of droplets released slowly. It takes more time for droplets to be frozen on the surface of insulators. In the first icing phase, environment temperature is low and wind speed is high, so ice accretion is fast. In the middle icing phase, wind speed declines seriously and is not good to impingement and frozen of droplets. Therefore, ice growth slows down and is not as much as that in the first phase. In the last icing phase, although wind speed and environment temperature is not as high as those in the first phase, they would still promote impingement and frozen of droplets. And ice mass on insulators still grows a little.

B. *Icing Thickness of the Equivalent Diameter of Insulator*

Ice density was measured several times during icing period. It did not change a lot. The average ice density is 0.725 g/cm^3. Ice volume could be derived from ice mass and ice density. Assuming that ice is equally distributed around the equivalent cylinder, based on equal volume method, icing thickness of equivalent diameter of insulator could be calculated from Equation (3). Figure 9 shows variation of icing thickness of equivalent diameter of different insulator.

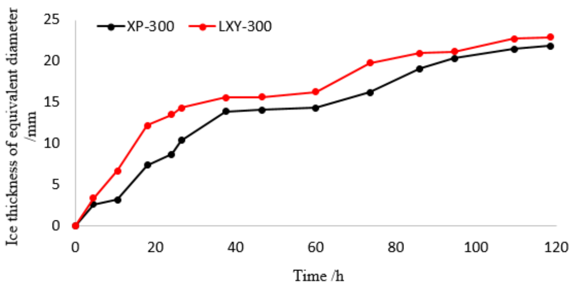


Figure 9. Ice thickness of equivalent diameter of different insulators

It could be concluded from Figure 8 that: with time varying, more serious the icing degree is, the thicker icing thickness of equivalent diameter of insulator is. For XP-300 porcelain insulator and LXY-300 glass insulator, their equivalent diameter are pretty much the same and variation of icing thickness of equivalent diameter of insulator are similar. In the first icing phase, icing thickness of equivalent diameter of both insulators have larger dispersion degree and fluctuation while they become more stable in the middle and last icing phase. This is because: ice mass is far smaller than the mass of insulator in the first icing phase, and wind speed is high (the maximum wind speed reached 7.6 m/s). Wind load has to some extent influence on ice mass so icing thickness of equivalent diameter have large dispersion degree. While wind speed reduced a lot in the middle and last phase, effects of wind load on ice mass is little. Ice accretion on insulators make the measurement results steadier. And variation tendency of icing thickness of equivalent diameter of both insulators looks alike.

IV. CONCLUSIONS

(1) Based on equation of the equivalent diameter of insulators deduced by equal-area method, the equivalent diameter of insulators is related to configuration parameters. The larger the sheds and areas of insulators are, the bigger the equivalent diameter of insulators is.

(2)There are obvious windward side and leeside on the surface of icing insulators in natural icing environment. Meanwhile, the icing of insulator is related to icing time, meteorological parameters and its structure. The greater the wind speed is and the lower the temperature is, the faster the insulator icing accretion is.

(3)The icing thickness of the equivalent diameter of insulators is obtained from equal icing volume. More serious the icing on insulator surface is, the thicker the icing thickness of the equivalent diameter of insulator is.

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