Study on Effect of AC Electrical Field on Rime-icing Process of Composite Insulators

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***Abstract*— Icing on the insulators is one of the severe problems for external insulation of transmission lines and the influence of AC electrical field on the icing process of the transmission line insulators can't be neglected. As a result, experiment investigations are carried out on the FXBW-35/100 composite insulators in the artificial climate chamber of Chongqing University. The influence of AC electrical field on process of composite insulators covered-with rime is studied. Based on the test results, it can be concluded that the influence of AC electrical field appears mainly as the attractive action to water droplet, the leakage current and the corona discharge on the insulator. The attractive action to water droplet will cause the increment of the weight of the rime ice. However, the leakage current and the corona discharge on the insulator will cause the decrease of the rime ice. When the insulator is energized, the amount of rime is great at the edge of the sheds. The rime at the upwind will droop. The rime on the insulator tends to grow along the direction of the electric field. The amount of rime will increase at first and then reduce with the increase of the applied voltage.**

***Key words*—Rime ice, Composite Insulators, AC Electrical field, Icing process**

I. Introduction

In recent years, China suffered the frequent occurrence of severe icing accidents. Following the nationwide icing accidents in 2005, most provinces and cities in southern China have been encountered the severe snow and ice weather since January 2008. Icing on transmission lines caused a widespread power blackout, which brought huge losses to the national economy. Although a lot of researches have been done on the electrical characteristics of iced insulators [1-11], these studies are almost carried out under the non-energized condition. Due to insulators energized in actual transmission lines, the influence of electrical field on the icing process of the transmission line insulators can't be neglected. The influence of electrical field presents the effects on icing type, icing shape, icing weight, ice density and speed rate of ice accretion, which affects the flashover performances of iced insulators.

Up till now, many researches about energized conductors under icing condition have been carried out. Researches on energized insulators under icing condition are relatively less. The research of reference [12] on three types of insulators indicates that the icing process of insulators grows loosely and presents the form of pine needle with the small ice density. The high-voltage end of insulators can not be easily bridged by icicles. Experiment investigations carried out on 7 units of insulator string show that the density of ice accretion on energized insulators surface is smaller than that of the non-energized ones. Reference [13] points that differences of ice weight and density on 5 units of porcelain insulator string are not apparent under the conditions of positive DC, negative DC and AC. Ice crystal structure and moisture content also have no difference in the microscope. Reference [14] indicates that glaze icicles on the energized insulators are hollowed, which can turn into the arc flashover paths. Comparing icicles shaped regularly in the case of no wind,

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the glaze icicles at the upwind are heavier. Icing is influenced by the thermal effect of leakage current and the cooling effect of ionic wind, but the former's effect is greater. Reference [15] shows that the Joule heat produced by the leakage current and corona discharge will melt the ice layer, which cause the weight of the energized is lighter than that of the non-energized. Based on the artificial glaze icing test results carried out on composite insulators under the energized and non-energized conditions, Reference [16] discusses that at the area of the insulator, with low electric field intensity, the effect of attractive action to water droplet is obvious, while at the area with high electric field intensity the thermal effect produced by the leakage current is distinct. During the process of energized icing, bubbles in icicles will increase and bend to the core rod of the composite insulator.

At present it has been rarely reported the difference of the process of rime accretion of composite insulators under energized and non-energized conditions. In this paper, experimental investigations are carried out on FXBW-35/100 composite insulators under the conditions of non-energized and with applied AC voltages of 10kV, 20kV, 30kV respectively in the artificial climate chamber. This paper mainly studied and analyzed the relationships between AC electrical field, shape of rime ice and the amount of rime ice.

II. TEST FACILITIES, SPECIMENS AND PROCEDURES

A. Test Facilities

Tests are carried out in the artificial climate chamber (showed in Fig. 1), 2.0 meters in diameter and 4.0 meters in height, which can provide the lowest temperature of −36±1℃. Spray system is composed of two spray nozzles recommended by IEC and the droplet diameter, which can be changed by adjusting the air inflow and water inflow of the spray nozzles, is in the range of 10~120μm. The applied voltage is supplied by a TDJC-20/100 transformer and a TDJA-20/0.5 induction voltage regulator. The test circuit is illustrated in Fig. 2.

B. Test Specimens and Arrangements

Test specimens are FXBW-35/100 composite insulators. The technical parameters are displayed in Table I.

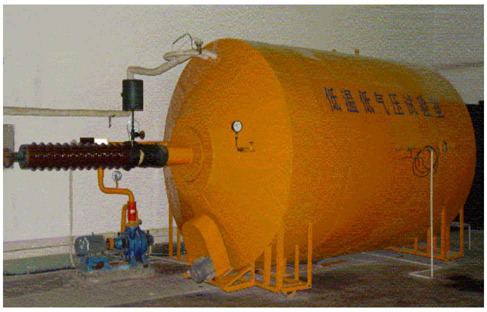
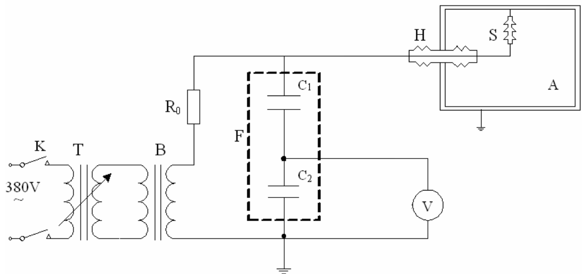


Fig.1. Artificial climate chamber of Chongqing University

Test specimens are suspended in the artificial climate chamber. The distances between test object and the chamber top, bottom, and sidewall are respectively 480, 800mm and 1000mm (showed in Fig. 3).



K: power switch; T: voltage regulator; B: testing transformer; C: voltage divider; H: high voltage wall bushing; A: artificial climate chamber; S: test specimen; R0: protection resistor; V: voltmeter

Fig. 2. Test circuit

TABLE I THE CHARACTERISTICS OF THE TESTED INSULATOR

Type	Structural height (mm)	Dry arc distance (mm)	Creepage distance (mm)	Superficial area (mm^2)
FXBW-35/70	640	440	1100	207658

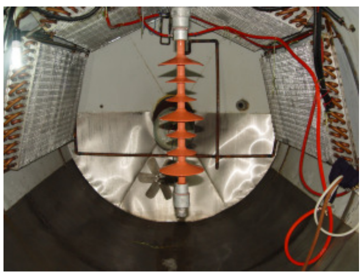


Fig. 3. Test arrangements

C. Test Procedure

Voltage between the two ends of the FXBW-35/100 composite insulator is almost 20kV in engineering practices. In order to study the influence of electrical field on the icing process of insulators, the condition of icing is remained basically the same and tests are carried out under the conditions of non-energized and with applied AC voltages of 10kV, 20kV, 30kV respectively. The electrical conductivity of freezing water is 350μS/cm (corrected to 20 ℃). The droplet diameter is about 20μm. The environment temperature is -8 ~ -4℃ and the wind speed is 0.5~0.7m/s.

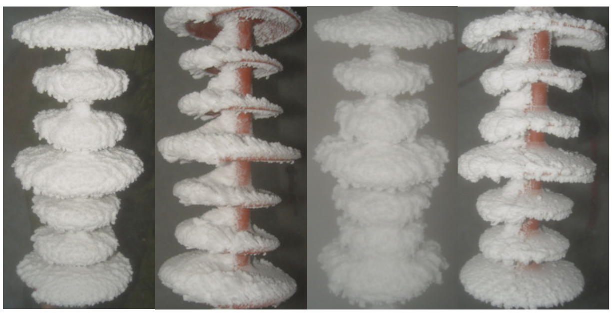
III. TEST RESULTS AND ANALYSIS

A. Effect of AC Electrical Field on Rime Shape of the insulators

Fig. 4 shows the shape of rime accreted on composite insulator when energized and non-energized. When icing is not energized, fog-droplets emitted from spray nozzles only move under the common action of the inertia, air resistance and gravity. The rime shape on each shed of the insulator reflects the influence of the airflow. There is no significant difference among them. The rimes at the upwind all increase on the top of the insulator shed without droop, while there is almost no rime on the bottom-surface of the upwind and the lee face of the core rod.

When icing is energized, the shape of rime is not only affected by the airflow, but also reflects the effect of electrical field. The effect of electrical field gives rise to the greatest amount of rime at the edge of the sheds, which is also the loosest. And the rimes tend to grow along the direction of the electrical field. The rimes on energized at the upwind side will droop. There are rimes, along the direction of the electric field, on the bottom-surface of the upwind side and the lee face of the core rod.

upwind side   the side   upwind side   the side



(a) Non-energized   (b) 10kV

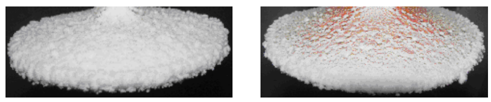
upwind side   the side   upwind side   the side

(c) 20kV   (d) 30kV

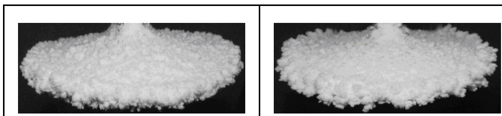
Fig.4. Shape of rime accreted on composite insulator

B. Effect of AC Electrical Field on the shape of rime accreted on the first shed's surface at high-voltage end

Fig. 5 shows the shape of rime accreted on the shed of the high voltage end under the conditions of energized and non-energized after 25 minutes. When icing is not energized, rimes on the sheds surface at the high-voltage end grow averagely, which only reflect the effect of the airflow. When icing is energized, rimes at the sheds edge of the high-voltage end grow greater and the rime shape is looser. The amount of rime is greater at the edge of the sheds as the voltage rises and tends to grow along the direction of the electric field.



(a) Non-energized   (b) 10kV



(c) 20kV   (d) 30kV

Fig.5. Shape of rime accreted on the shed at the high voltage end

C. Effect of AC Electrical Field on the Shape of rime accreted on the lee face

Fig. 6 shows the shape of rime on the lee face of insulators under the conditions of energized and non-energized. In the figure shed1~shed3 successively represent three big sheds counted from the low-voltage end.

As it is showed in Fig. 6, when icing is not energized, the rime shape on each shed of the insulator reflects the influence of the airflow. There is no significant difference among three sheds. When icing is energized, rimes on the lee face of insulators start to present a distribution from the core rod to the shed face. The bottom edge appears outward floccus rimes. This phenomenon becomes obvious as the voltage rise. The above-mentioned characteristic is more obvious on the shed3 for the reason that shed3 is closest to the high-voltage end and ambient electrical field strength is greater than that of shed1 and shed2. Due to the reason effect on shed3 is heavier, which is clearly illustrated in Fig. 6(d).

D. Effect of AC Electrical Field on the Shape of rime accreted on the pins

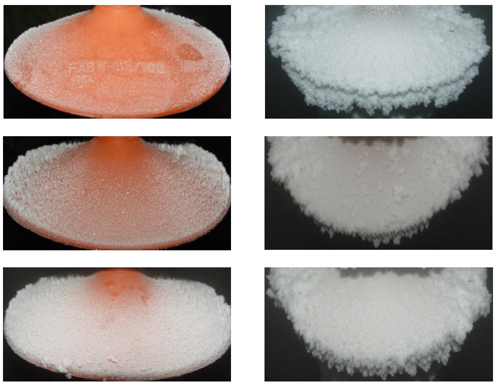
Fig. 7 shows the shape of rime accreted on the surface of the pins under the conditions of energized and non-energized after 25 minutes. As it is showed in Fig. 7, electrical field strength on the pins is greatest, so the effect of the field is also the most obvious. When icing is not energized, rimes on the surface of the pins grow closely without any burr. When icing is energized, burrs appear on the rimes. The surface roughness increases, burrs grow dispersedly and tend to develop along the direction of the electric field as the voltage rises.

Icing after 15min Icing after 25min

shed1

shed2

shed3



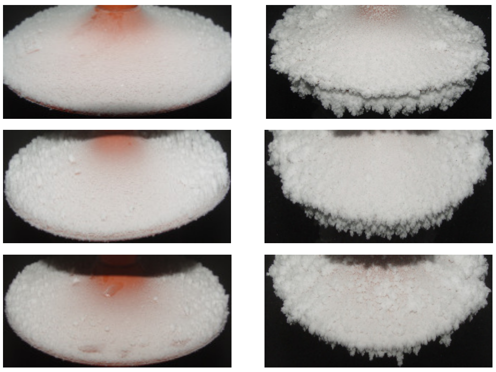
(a) Icing with non-energized

Icing after 15min Icing after 25min

shed1

shed2

shed3



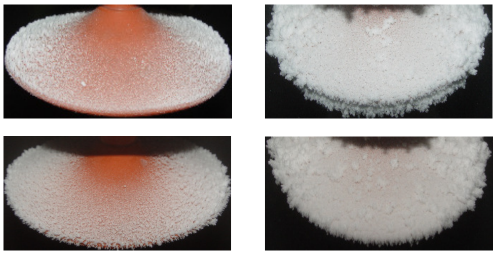
(b) Icing with energized on 10kV

Icing after 15min Icing after 25min

shed1

shed2

shed3



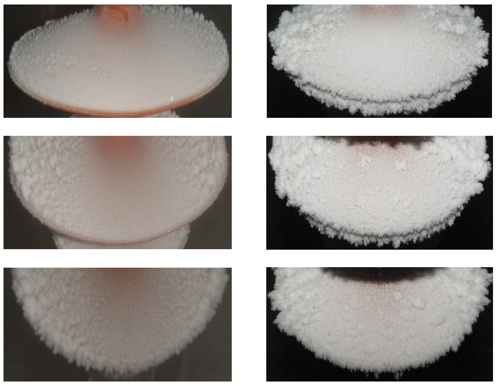
(c) Icing with energized on 20kV

Icing after 15min Icing after 25min

shed1

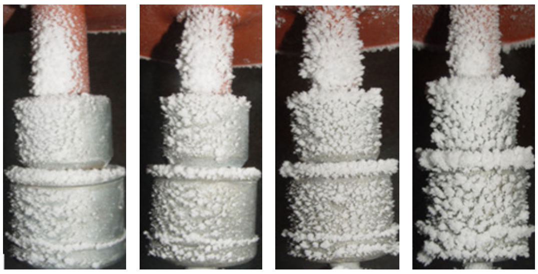
shed2

shed3



(d) Icing with energized on 30kV

Fig.6. Shape of rime accreted on the lee face of the big sheds



(a) Non-energized (b)10kV (c)20kV (d)30kV

Fig.7. Shape of rime accreted on the pins

E. Effect of AC Electrical Field on the Weight of Rime

In order to analyze the influence of electrical field on the ice weight, four comparison tests of different ice weight are carried out. The data of the rime weight are showed in Table Ⅱ.

TABLE Ⅱ WEIGHT OF RIME ON THE COMPOSITE INSULATOR

Applied Voltage	Non- voltage	10kV	20kV	30kV
Test result(1)	0.100	0.125	0.150	0.115
Test result (2)	0.200	0.240	0.265	0.215
Test result (3)	0.350	0.420	0.475	0.370
Test result (4)	0.250	0.300	0.405	0.275

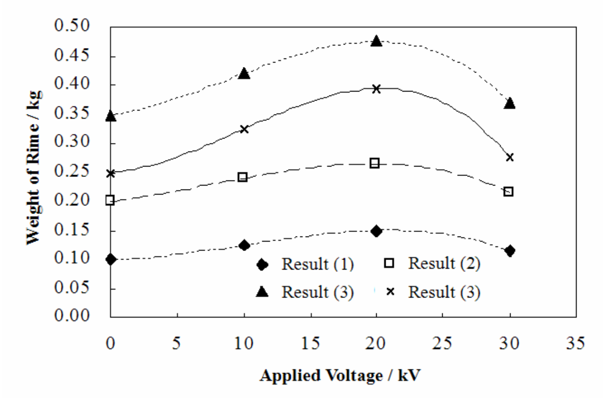


Fig. 8 Comparison of weight of rime at different voltage

Results from comparison tests of weight are plotted in Fig. 8. Fig. 8 shows that as the voltage rises form 0kV to 20kV, the weight of rime on the insulator increase with the increment of applied voltage. While the voltage increases from 20kV to 30kV, the weight of rime on the surface reduces with the increment of applied voltage.

The effect of the electrical field on the rime of composite insulator mainly behaves in two aspects:

(1) In the electrical field, droplets are subjected to the polarization. The attractive action to water droplet intensifies as the electrical field strength strengthens. For super-cooled water droplets with the same radius, the greater the electrical field strength, the stronger electrical field force suffers.

(2)With the increment of the applied voltage, due to the corona discharge and local arc caused by the local electric field strength on the insulator and the Joule heat of leakage current, the ice layer is melted and the temperature on the ice surface increases. Thus the freezing process of super-cooled water droplets on the ice is retarded, which leads to the decrement of ice weight.

In this paper, when the applied voltage is less than 20kV, the effect of attractive action to water droplet is stronger than the effect of leak current and discharge, so the rime weight increases with the increment of voltage. While the applied voltage is higher than 20kV, the effect of leak current and discharge is stronger than that of attractive action to water droplet. Accordingly with the increment of voltage the rime weight decreases. In a word, when icing is energized, the weight of rime on the surface of the insulator is heavier than that of the non-energized.

IV. Calculations

Through AC tests carried out on FXBW-35/100 composite insulators in the artificial climate chamber, it is concluded as following:

(1) When icing is not energized, the rime shape on each shed of the insulator reflects the influence of the airflow. When icing is energized, the shape of rime not only is affected by the airflow, but also reflects the effect of electric field. The amount of rime is greatest at the edge of the sheds. The rimes on energized at the upwind will droop and tend to grow along the direction of the electric field as the voltage rise.

(2) The attractive action to water droplet is the reason of the weight of the ice increasing on the insulators, which causes that the weight of rime increases as the voltage rises when it is less than 20kV. The Joule heat, produced by the leakage current, corona discharge and local arc resulted from local electrical field on the insulators will melt the ice layer, which make the amount of rime increase at first and then reduce with the increment of the voltage which is beyond 20kV.

(3) Generally speaking, when icing is energized, the weight of rime on the surface of the insulator is heavier than that of the non-energized. Since the weight of ice has a sharp effect on the flashover of ice surface, the influence of AC electrical field on the icing process of the transmission line insulators can't be neglected.

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