FLASHOVER PERFORMANCE OF 330kV ICE-COVERED COMPOSITE INSULATORS OF DIFFERENT SHED PROFILES

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***Abstract*:** The study explores the effects of shed profile on icing condition of insulators and 50% icing flashover voltage through a large number of tests on five types of composite insulators with different shed profiles in the artificial climate chamber. The results indicate that under the same icing condition, the states of ice on insulators of different shed profiles are obviously different and 50% icing flashover voltage can be significantly increased by optimizing insulator shed profiles and reasonably placing big sheds.

1 INTRODUCTION

Composite insulators have been developing rapidly worldwide currently. It is significant theoretically and practically to conduct the research on flashover performance of insulators under the complicated environment.

2 RESULTS AND DISCUSSIION

A B C D E

Figure 1： Icing state of insulators of different shed profiles

Under the same ice thickness being 13 mm, for basic profile type A insulator, the sheds were completely bridged by icicles; for the rest four types of insulators，with different numbers of big sheds added at intervals, the middle- sized and small-sized sheds were bridged by icicles, but there was no or few icicles totally bridged the big sheds.

Under the condition of *SDD*=0.08mg/cm^2, the results are expressed in Table 1.

Table 1 Test results with *SDD* of 0.08mg/cm^2

U_{50}，σ%	Type				
	A	B	C	D	E
U_{50}	267.5	307.5	294.5	282.5	294.5
σ%	2.96	4.15	3.44	2.8	4.83

From Table 1, the 50% flashover voltage of type A insulator(basic profile) with only middle and small-sized sheds is the lowest, 14.95%、10.09%、5.61% and 10.09% lower than that of other four types of insulators respectively.

Figure 2 shows the relationship between the 50% icing flashover voltage of type A and type B insulator and *SDD*. Apply the regression method to results of the 50% flashover voltage, The *SDD* exponent for type A insulator is 0.3289 and that for type B insulator is 0.2775.

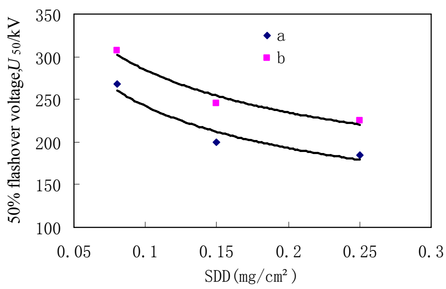

Figure 2： the relationship between the 50% icing flashover voltage and SDD

3 CONCLUSIONS

(1) Under the same icing condition, the icing states for composite insulators of different shed profiles are significantly different.

(2) The icing flashover voltage can be raised by reasonably placing big and small sheds. In the study, the 50% icing flashover voltages of composite insulators with five, six, seven and nine ultra big sheds are respectively 14.95%, 10.09%, 5.61% and 10.09% higher than that of the basic profile insulator.

(3) Among the five types of composite insulators, the icing flashover voltage of the composite insulator with five big sheds is the highest, 15% higher than the common insulator.

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Abstract: **The study explores the effects of shed profile on icing condition of insulators and 50% icing flashover voltage through a large number of tests on five types of composite insulators of different shed profiles in the artificial climate chamber. The results indicate that under the same icing condition, the states of ice on insulators of different shed profiles are obviously different and 50% icing flashover voltage can be significantly increased by optimizing insulator shed profiles and reasonably placing big sheds.**

Key word: composite insulators; shed profile; flashover performance; icing;

1 Introduction

Composite insulators which have the virtue of light weight, high mechanical strength, excellent pollution-resistance properties and convenient operation and maintenance in comparison with the traditional porcelain and glass insulators, have been developing rapidly worldwide currently [1,14]. In China, over two million composite insulators have been applied to transmission lines nowadays [2]. Due to the unbalanced distribution of energy centers and load centers, “west-to-east power transmission and south-north power transaction” has become the strategic option of China’s power industry. Thus, it is unavoidable for transmission lines to pass through high latitude and extreme frigidity areas. In view of the fact revealed by the operation experience and tests, the electrical performance of insulators will degraded apparently under the combined effects of low atmospheric pressure, contamination and icing [1,3,4,10,13,16], it is significant theoretically and practically to conduct the research on flashover performance of insulators under the complicated environment. In addition, although many studies at home and abroad have investigated icing flashover performance of composite insulators, most of them mainly focus on short string composite insulators and few studies compare flashover performance of composite insulators of different shed profiles.

Based on large numbers of icing flashover tests in the artificial climate chamber, this study aims to explore effects of shed profile on icing state of composite insulators and compare icing flashover performances of five types of 330kV composite insulators of different shed profiles as test specimens.

2 Test facilities and procedure

2.1 *Test facilities*

All the tests are carried out in the multi-function artificial climate chamber of State Key Laboratory of Power Transmission Equipment & System Security and New Technology of Chongqing University. The chamber has a diameter of 7.8 m and a height of 11.6 m, with the minimum temperature of -45℃±1℃ and the minimum atmospheric pressure of 30kPa which can simulate the atmospheric environment of the high latitude of 9000m and below. More details can be found in [4] .

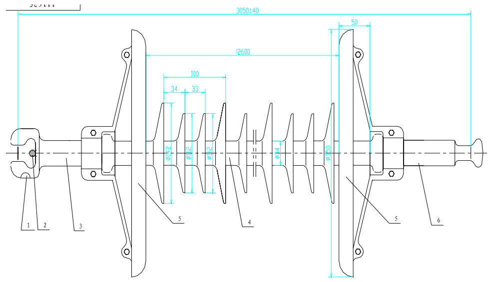
According to IEEE Std.4[7], the DC and AC power source parameters[8] for tests on ice-covered insulators are recommended by IEEE Task Force on insulator icing test method. The power used in this study is applied by test transformer used in pollution flashover test, which meets the requirements above，with rated capacity of 2000kVA, rated current of 4A, input voltage of 0-10.5kV, output voltage of 0-500kV, and short circuit impedance less than 6%.

2.2 *Specimens*

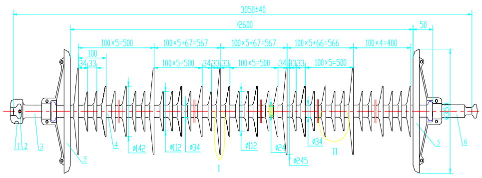
The specimens are five types of composite insulators of different shed profiles, made of the same material and with the same parameter for the grading ring attached. Each specimen’s profile parameter and contour are presented in Table 1 and Fig.1. In the table, *D* is shed diameter of each insulator, mm; h_d dry arc distance, mm; *L* leakage distance, mm; D_1 shank diameter of the insulator, mm.

Table 1 Profile Parameters for each specimen

Type	**Profile Parameters**				**Configuration**
	D **(mm)**	h_d **(mm)**	***L*** **(mm)**	D_1 **(mm)**	
A		3050	8930	34	1a
B	245(big)	3050	9500	34	1b
C	142(middle)	3050	9430	34	1c
D	112(small)	3050	9697	34	1d
E		3050	9798	34	1e



(a)



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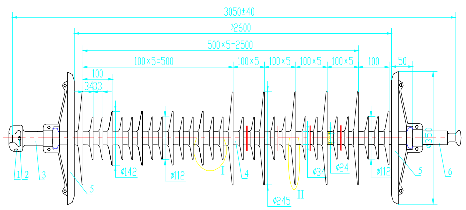

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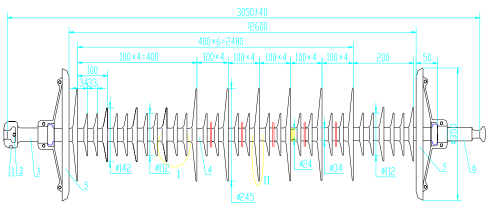

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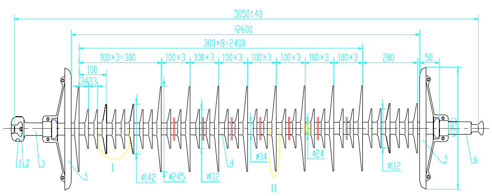


(e)

Fig. 1 Profiles for each specimen

2.3 *Procedure*

The test procedure consists of four steps shown as follows:

(1) *Pre-contamination*: Before tests, all the specimens were carefully cleaned to ensure the removal of all traces of dirt and grease and then dried naturally[11,12]. On account of hydrophobicity of the composite insulator surface, a layer of hydrophilic material should be attached to the surface by means of coating insulators with a very thin layer of dry kieselguhr with dry cotton balls and removing excess kieselguhr using a rubber suction bulb。 Because the layer of kieselguhr was very thin, the effects of the kieselguhr on non-soluble deposit density *NSDD* (in mg/cm^2) could be ignored. In addition, the contamination must be finished within 1 hour.

(2) *Artificial polluting*: There exist two polluting methods, solid-layer method and icing-water-conductivity method. The former is employed in this study to simulate the condition that insulators had been polluted before icing. The surfaces of insulators were contaminated to a condition of certain *SDD* and *NSDD*, then deionized water being 100μS/cm in conductivity is used for accreting ice on insulators.

(3) *Ice deposit*: The specimens are suspended vertically from the hoist at the center of the chamber, rotating at one r.p.m.. With all test equipments prepared, temperature in climate chamber is decreased to predetermined value for icing. Before automatic spraying, the surface of the insulators is wetted by the sprayer manually and covered with a 1-2mm layer of ice to make sure the pollution layer not to be cleared away. In the icing procedure, the droplet diameter is 80~120μm, the spraying flow 60±20l/h•m^2 , wind speed fixed 3~5 m/s, and temperature is stabilized in -7℃~-5℃. Icing on insulator is mainly glaze with the density value of 0.8~0.9 g/cm^3. Conductivity of the test water is 100μS/cm(20℃), which was cooled to 4℃ in the climate chamber before entering the spray system to simulate natural icing condition. Extracted by a pump, the water flowed into the spray system to form spraying. Insulators were iced without operation voltage.

The amount of ice accumulated on insulators was characterized by the thickness *d* of the ice on a monitoring cylinder. The monitoring cylinder is a 600 mm copper pipe rotates one r.p.m uniformly , being 28 mm in diameter[8]. Three monitoring cylinders is placed uniformly in the top, middle, bottom part of the insulator string respectively, the average of whose ice thickness value is used for representing the ice thickness on insulators. icing thickness of all the test in This study is fixed at 13mm.

(4) *Flashover test for ice-covered insulators*: The method of constant voltage under up-down is adopted to attain 50% flashover voltage U_{50}, the procedure of which is as follows:

(i) Stop spraying steam fog when ice thickness reaches target value, and remove the monitoring cylinder;

(ii) Lift the iced insulator by the hoist above the wall bushing, and connect the conductor between wall bushing and the bottom of insulator;

(iii) Keep the air temperature at -12 °C for 15 min. to guarantee complete hardening of the ice and equalization of insulator and ice temperature [9];

(iv) Open the door of the climate chamber to raise the temperature rapidly to -3 °C, and then close the door to recover the temperature to -1.0--0.5 °C at a speed of 2 °C/h -3 °C/h;

(v) The method of constant voltage under up-down(Figure 2) is employed to attain 50% flashover voltage. The voltage applied is decided by the previous test result: if flashover occurred in the last test, the voltage applied next will be reduced ΔU. Otherwise, the voltage applied next will be increased ΔU. The value of ΔU is 5% of the voltage last time used. Every test samples could only be used once. If flashover did not occur, the samples should stand the voltage at least 20 minutes. On each test condition, at least 10 validate tests had to be carried out. Validate tests starts from the test the result of which is different with that of the previous test [10].

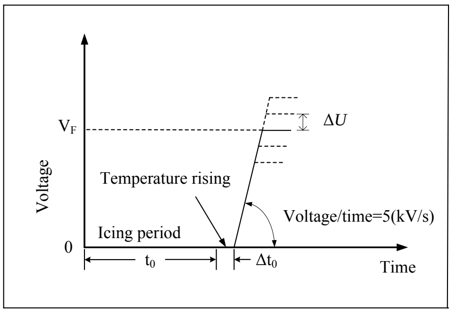
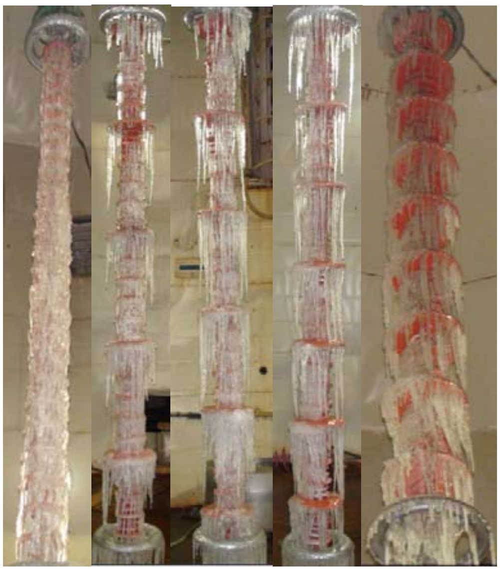


Fig .2 The test method of 50% icing flashover voltage

3 Test results and analysis

3.1 *Icing conditions of composite insulators of different shed profiles*

The fixed ice thickness (ice accretion degree) is applied during the whole artificial icing process for consideration of eliminating the effects of ice thickness on flashover voltage. With the ice thickness of 13mm, i.e., d=13mm, the icing state of five types of insulators are shown in Fig 3.



A B C D E

Fig. 3 Icing state of insulators of different shed profiles

From the figure above, it is known that under the same ice accretion degree, for basic profile type A insulator, the sheds were completely bridged by icicles; for type B insulator, the middle- sized and small-sized sheds were bridged by icicles, but there was big gap between the icicle end along the upper big shed and the lower big shed; for type C and D insulators, the middle-sized and small-sized sheds were also bridged by icicles, but there was no or few icicles bridged among the big sheds; for type E insulator, the middle- sized and small-sized sheds were bridged by icicles and parts of big sheds were bridged.

Under the condition of ice thickness being 13mm, the weights of ice on the five types of composite insulators are shown in Table 2. The ice weight for the corresponding type of insulator is the mean value of ice weights from the valid samples.

Table 2 Ice weight of insulators of different shed profiles

	Type				
	A	**B**	**C**	**D**	**E**

M(kg)	11.92	14.28	16.23	14.9	15.15

Based on the table, Type A insulator without big shed has the smallest ice accretion amount. When different numbers of big sheds are added at intervals, ice weight increases obviously, while ice amount does not increase regularly with the increase of the number of the big shed. In the study, Type C insulator with six big sheds added at intervals has the biggest ice accretion amount.

The results above indicate that despite the same ice accretion degree, icing condition and ice weight of each composite insulator are different owning to different shed profiles.

3.2 *Comparison of 50% flashover voltage of composite insulators of different shed profiles*

Under the condition of *SDD*=0.08mg/cm^2, the 50% flashover voltages of composite insulators of different shed profiles and their standard deviations are expressed in Table 3.

Table 3 Test results with SDD of 0.08mg/cm^2

U_{50}, σ%	Type				
	A	B	C	D	E
U_{50}	267.5	307.5	294.5	282.5	294.5
σ %	2.96	4.15	3.44	2.8	4.83

From the table 3, the 50% flashover voltage of type A insulator(basic profile) with only middle and small-sized sheds is the lowest, 14.95%、10.09%、5.61% and 10.09% lower than that of other four types of insulators respectively.

The flashover process of ice-covered insulators is as follows: when the water film appeared on the ice surface, the high conductivity of the water film caused most of the voltage applied to insulators to be burdened by air gap between icicles and sheds, resulting in the first appearance of the partial arcs at the pointed end of icicles due to the comparatively high electric field there. Under the effects of arcs, the icicles melted gradually and at the same time arcs appeared in the rest gaps. Then with the air gaps elongate, partial arcs further propagated and arcs also appeared on the ice surface. Later with the increasing voltage, the arc length reached the threshold flashover distance and accordingly partial arcs propagated till flashover.

As stated earlier, the reasons for the different flashover voltages of composite insulators of different shed profiles are concluded as follows: for type A insulator, its sheds were completely bridged by icicles and partial arcs could easily develop to flashover with the increase of the voltage; for type B-E insulators, on account of the existence of big sheds, sheds were not completely bridged by icicles, different degrees of air gap occurred between icicles stretching along the edge of the big shed and the neighboring big shed, which greatly increased the flashover voltage.

3.3 *Effects of SDD on 50% flashover voltages of Type A and B specimens*

It is known from 3.2 that with *SDD* of 0.08mg/cm^2, the icing flashover voltage for Type A insulator and that for Type B insulator are the lowest and the highest respectively. For the better-targeted purpose, further studies were conducted to investigate effects of *SDD* on flashover voltages of type A and type B insulators and the results are presented in Table 4.

Table 4 Effects of SDD on flashover voltages of Type A and Type B insulators

SDD(mg/cm^2)	A		B	
	U_{50}	σ %	U_{50}	σ %
0.15	200	4.24	245	2.15
0.25	185	4.59	225	2.34

From Tables 3-4, under the three levels of *SDD*, the 50% icing flashover voltages for Type A insulator are higher than those for Type B insulator.

The relationship between the 50% icing flashover voltage and *SDD* can be expressed as [1,4, 5,15-18],

$$U_{50} = A \times SDD^{-c} \qquad (1)$$

where U_{50} is the 50% icing flashover voltage, kV and c is the characteristic exponent indicating the effects of contamination.

Apply the regression method to results in Tables 3-4 according to Equation 1. See results in Fig. 4 and Table 5.

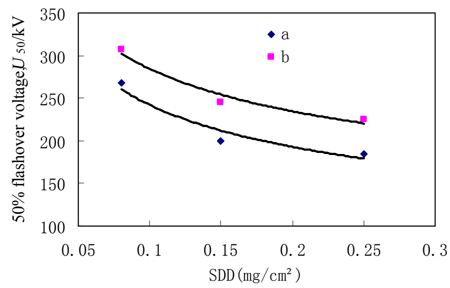


Fig. 5 the relationship between the 50% icing flashover voltage and *SDD*

Table 3 The values of *A*, *c*, and R^2 for different types of insulators

Type	***Profit coefficient***		
	A	*c*	R^2
A	113.57	0.3289	0.9329
B	150.11	0.2775	0.9616

According to the regression results, it is known that: for two types of composite insulators of different shed profiles, the 50% icing flashover voltage decreases with increasing *SDD* and they are in a relationship of negative power function similar to pollution flashover test.

The *SDD* exponent for type A insulator is 0.3289 and that for type B insulator is 0.2775, which shows the effects of contamination on the 50% flashover voltage for type A insulator are more notable than those for type B insulator. Thus, it can be inferred that under the icing condition, the characteristic exponent characterizing contamination effect is related to the shed profile of insulators.

4 Conclusions

Based on the icing flashover experiments on five types of composite insulators of different shed profiles, the following conclusions can be drawn:

(1) Under the same icing condition, the icing states for composite insulators of different shed profiles are significantly different.

(2)The icing flashover voltage can be raised by reasonably placing big and small sheds. In the study, the 50% icing flashover voltages of composite insulators with five, six, seven and nine ultra big sheds are respectively 14.95%, 10.09%, 5.61% and 10.09% higher than that of the basic profile insulator.

(3)Among the five types of composite insulators, the icing flashover voltage of the composite insulator with five big sheds is the highest, 15% higher than the common insulator.

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