COMPARATIVE STUDY ON ICING STATE AND AC FLASHOVER PERFORMANCE BETWEEN COMPOSITE INSULAORS UNDER ENERGIZED AND NON-ENERGIZED ICING CONDITION

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Abstract: To find out the difference of icing states and flashover performance between energized and non-energized icing of composite insulators, icing tests with and without voltage applied on two kinds of composite insulators were accomplished in the artificial climate chamber. It was found that, compared to non-energized icing, less ice accreted on energized insulator with smaller density which could be altered by icing water conductivity, and considerable difference of flashover performance existed between the iced insulators under energized and non-energized icing conditions. Thus, icing tests with composite insulators energized is preferred.

1. INTRODUCTION

Limited by test condition, when studying insulator icing and its external insulation performance, most icing tests are conducted with non-energized insulators [1].

To simulates the real icing states of overhead line insulator in actual working condition, and analyze the difference of icing states, density, and external insulation performance between energized and non-energize icing condition, artificial icing tests were carried out for composite insulators of FXBW-10/70 and FXBW-35/70.

2. RESULTS AND DISCUSSION

Results of ice state, ice density and ice flashover performance of insulators energized or non-energized were recorded within the tests.

Observations illustrates that under energized condition, more ice deposits on the sheds marginal to the two terminal and adjacent sheds are harder to be bridged by icicles, while under non-energized condition all sheds are the same in ice amount and bridged easily.

The ice density (average density value of ice on all sheds) of different icing water conductivity under both energized and non-energized conditions had been measured as listed in Table 1.

Table 1. Compare of glaze density on composite insulators

γ_{20}/μS/cm		80	330	405	600	1024
FXBW-10/70	Energized	0.75	0.79	0.81	0.83	0.86
	Non-energized	0.88	0.87	0.88	0.89	0.88
FXBW-35/70	Energized	0.74	0.78	0.81	0.83	0.85
	Non-energized	0.88	0.88	0.89	0.89	0.87

Up and down method was employed to attain the 50% flashover voltage in each test, as listed in Table 2.

Table 2: Flashover voltage of iced insulators energized and non-energized

γ_{20}/μS/cm		80	330	330	600	1024
FXBW-10/70	Energized	52.7	35.5	33.2	29.6	25.2
	Non-energized	43.8	29.6	28.0	25.1	21.6
FXBW-35/70	Energized	88.0	60.7	57.2	51.1	44.5
	Non-energized	74.1	51.6	49.0	44.1	38.4

Values of 50% flashover voltage were fitted by power-law function. The difference between the energized and non-energized tests is shown in Figure 1.

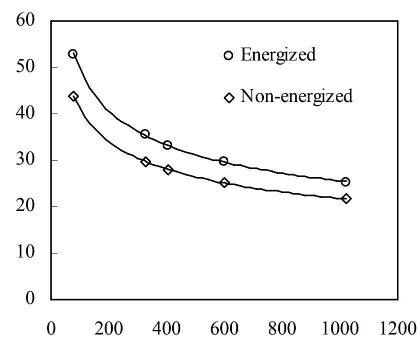

Figure1. The relation between the 50% flashover voltage and conductivity of freezing water (FXBW-10/70 insulator)

3. CONCLUSION

(1) In the icing process of energized composite insulators, the Joule heating from leakage current and the corona discharge reduces the ice amount apparently. Meanwhile it makes sheds more difficult to be bridged by icicles.

(2) Density of ice on energized composite insulators is lower than that on non-energized composite insulators. The difference relates to icing water conductivity. The lower conductivity the icing water is, the more apparent the difference will be.

(3) For the ice flashover character of energized composite insulator is different from that under non-energized condition considerably, energized icing is recommended for the insulator icing test.

4. REFERENCES

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Abstract: **Most of the tests studying the icing state and flashover performance of composite insulators are carried out with non-energized insulator, which is different from the icing condition on actual overhead transmission lines. To find out the difference of icing states and flashover performance between energized and non-energized composite insulators, icing tests with and without voltage applied on two kinds of composite insulators were accomplished in artificial climate chamber. It was found that, compared to non-energized icing, less ice accreted on energized insulator with smaller density which could be altered by icing water conductivity, and considerable difference of flashover character existed between the energized and non-energized icing conditions. Thus, icing tests with composite insulators energized is preferred.**

Keywords-energized icing; composite insulator;icing state; flashover performance

I. INTRODUCTION

Ice accretion on insulators could be serious threatens to the security of power system. Lots of power system failures caused by icing flashover of insulators has been reported at home and aboard [1-3].It is significant to deeply investigate the icing states and discharge characters of insulators. Limited by test condition, when studying insulator icing and its external insulation performance, most icing tests are conducted with non-energized insulators. Even if voltage is applied on insulators tested, the value is much lower than the insulator in service. Therefore, test results obtained under non-energized icing could not precisely reveal the icing states and electrical performance of iced insulator in practical transmission lines.

To simulate the real icing states of overhead line insulator in actual working condition, and analyze the difference of icing states, density, and external insulation performance between energized and non-energize icing condition, artificial icing tests were carried out for FXBW-10/70 and FXBW-35/70 composite insulators.

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II. TEST SAMPLES, FACILITIES AND TEST METHODS

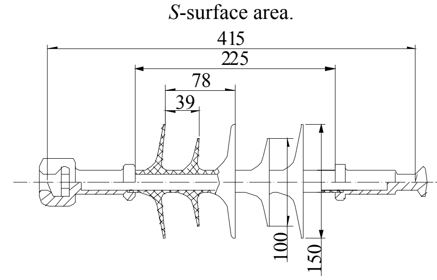
A. Test Samples

Two kinds of Composite insulators, FXBW-10/70 and FXBW-35/70 were selected in this study, the parameters and sketch of which are shown in Table 1 and Figure 1 respectively.

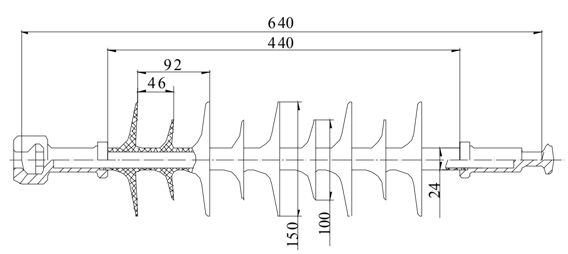
Table 1. The parameters of the tested insulators

TYPE	*H*/mm	*D*/mm	*L*/mm	*S*/mm^2
FXBW-10/70	415	225	590	122107
FXBW-35/70	640	440	1100	207658

H-structure height, *D*-dry arcing distance, *L*-creepage distance, *S*-surface area.



(a) FXBW-10/70



(b) FXBW-35/70

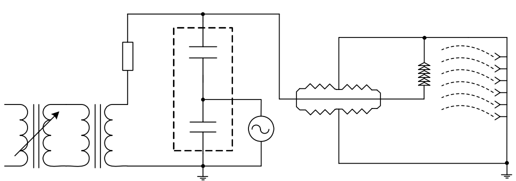
Figure 1. Sketch maps of the tested composite insulators

B. Facilities

The tests were conducted in the artificial climate chamber with diameter of 2 m and length of 3.8 m. Refrigeration system, spraying system and wind speed controlling system have been built up in the chamber. The lowest temperature in the chamber can reach -36±1 ℃ being able to fulfill icing requirement. Standard nozzles recommended by IEC are installed to spray the icing water. For the aim of assuring the uniform distribution of temperature and droplets, a wind controlling system is equipped. The test power source is leaded into the chamber through a 110 kV ceramic bushing.

Test power is supplied by AC test transformer with rated current of 6 A and rated voltage 150 kV, the largest short circuit current is 30 A which can satisfy the power source requirement of icing test. The voltage is leaded into the chamber through a 110 kV ceramic bushing, and is measured by the 200 kV/200 V capacitor divider and an oscilloscope.

The test circuit is shown in Figure 2.



T—Voltage Regulator, B—Test Transformer, R_0—Protect Resister, F—Divider, Osc—Oscillation, H—High voltage bushing, K—Artificial climate chamber, S—Insulator Sample, N—Nozzles.

Figure 2. Test circuit

C. Test Methods

(1) Artificial icing method: Icing-water-conductivity method was employed as the pollution method. The procedure was as follows: remove the oil and dust deposited on the insulator surface with deionized water which got conductivity less than 10 μS/cm. After dried naturally, the insulator was suspended in the chamber, icing with the droplets drawn to it by spray system [4-5]. The temperature in the chamber is attained at -5 ℃, and icing water had been cooled to 3~4 ℃ before tests. The droplet diameter and the wind speed were also set 40~120 μm and *3* m/s respectively for the test condition in which the ice form would be glaze. Five different icing water conductivity were set as 80, 330, 405, 600, 1024 μS/cm(measured at 20 ℃). Either energized or non-energized icing tests were carried out. When energized icing tests were conducted, the voltages applied on the two kinds of insulators were 5.8 kV and 20.2 kV, which correspond to the phase voltages of 10 kV and 35 kV systems. The icing states were taken pictures and recorded with voltage retreated within test process.

(2) Measurement of ice weight and density: the ice thickness (*d*, in mm) on 25 mm diameter monitoring cylinders was used as the icing characteristic parameter, and the actual ice weight on each test was recorded. When *d* reached 10 mm, icing was stopped and insulators were in the medium degree of icing. The ice density was measured by drainage method [3].

(3) 50% flashover voltage: When icing was finished, stopped icing and insulators were frizzed for 15 min, after which the temperature was raised to -2～-1 ℃. Up-and-down method was employed for the flashover or standing tests, and 50% flashover voltage under different conditions were obtained.

III. ICING STATES UNDER ENERGIZED AND NON-ENERGIZED CONDITION

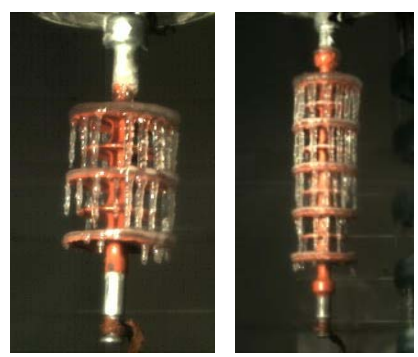
A. Difference in Icing States and Ice Weights

Icing states and ice weights of composite insulators under non-energized condition (γ_{20}=330 μS/cm) are described in *Figure 3* and *Table 2* respectively. From the figure and the table it can be found that:

(1) When icing thickness d was 10 mm, all adjacent big sheds on the two kinds of insulators were bridged by icicles.

(2) The ice on composite insulators was smooth and limpid, and little ice existed on the lower surface. Most of the icicles elongated vertically due to the gravity.

(3) More ice accreted on the top sheds of composite insulators than on the rest sheds on which ice magnitude were all most the same. When no electric field exists, the process that insulator capture super cooled droplets is mainly influenced by gravity and air viscous force, thus more super cooled droplets impact and freeze on the top sheds than that deposit on the lower sheds.



(a) FXBW-10/70 (b) FXBW-35/70

Figure 3. The ice shape of non-energized composite insulators

Table 2. Ice weights on different sheds of non-energized composite insulators

FXBW-10/70		FXBW-35/70	
Shed	***Ice weight /g***	***Shed***	***Ice weight /g***
A	95	A	100
B	85	B	85
C	85	C	90
/	/	D	85

/	/	E	75

Icing states and ice weights of composite insulators under energized condition (γ_{20}=330 μS/cm) are shown in Figure 4 and Table 3 respectively. From the figure and the table it can be found that:

(a) FXBW-10/70 (b) FXBW-35/70

Figure 4. The ice shape of energized composite insulators

Table 3. Ice amount on different sheds of energized composite insulators

FXBW-10/70		FXBW-35/70	
Shed	***Ice weight /g***	***Shed***	***Ice weight /g***
A	35	A	40
B	35	B	25
C	40	C	35
/	/	D	35
/	/	E	40

(1) When icing thickness *d* was 10 mm, the condition that icicles bridge the sheds is less serious than that of non-energized icing.

(2) Compared to the non-energized icing, the ice on energize insulator is more loose and granular ice deposits on the lower side of sheds, which should be owned to the attraction effect of electric field on super cooled droplets. Also, the icicles bent to insulator rod due to the attract effect of electric field.

(3) From the mount of ice on each shed of *FXBW-35/70* insulator in *Table 3*, it is shown that more ice deposits on the sheds at both ends of the insulator, while least ice exist in the second shed. The reason is that the electric field distribution of iced composite insulator is extremely un-uniform and the larger field strength exists near the two ends of insulators attracting more droplets than the middle part.

(4) *Table 3* and *Table 4* reveal that the ice weights of the energized insulators are smaller than that of the non-energized insulators. This is because that the partial arcs and corona discharges at the surface of ice layer, together with the Joule heating created by leakage current, can melt the ice and increase the temperature of ice surface that decelerate droplet freezing.

B. Difference in Ice Density

This study measured the ice density (average density value of ice on all sheds) of different icing water conductivity under both energized and non-energized conditions as listed in *Table 4*.

Table 4. Comparison of glaze density on composite insulators

γ_{20}/μS/cm		80	330	405	600	1024
FXBW-10/70	***Energized***	0.75	0.79	0.81	0.83	0.86
	Non-energized	0.88	0.87	0.88	0.89	0.88
FXBW-35/70	***Energized***	0.74	0.78	0.81	0.83	0.85
	Non-energized	0.88	0.88	0.89	0.89	0.87

Table 4 indicates that:

(1) Under energized condition, the ice on insulator is lower in density and more porous in appearance than that under non-energized condition.

(2) The difference of ice density is influenced by icing water conductivity. The lower conductivity the icing water is, the more apparent the difference will be. This is because lift of icing water conductivity causes larger leakage current, the heat effect of which will melt ice and increase ice density close to the value under non-energized condition.

IV. ICE FLASHOVER PERFORMANCE OF COMPOSITE INSULATOR UNDER ENERGIZED AND NON-ENERGIZED CONDITION

Table 5 lists the 50% ice flashover voltage of the two kinds of insulators under energized and non-energized condition.

Table 5. Flashover voltage of iced insulators

γ_{20}/μS/cm		80	330	330	600	1024
FXBW-10/70	***Energized***	52.7	35.5	33.2	29.6	25.2
	Non-energized	43.8	29.6	28.0	25.1	21.6
FXBW-35/70	***Energized***	88.0	60.7	57.2	51.1	44.5
	Non-energized	74.1	51.6	49.0	44.1	38.4

The relationship between 50% ice flashover voltage and γ_{20} can be expressed as [6]:

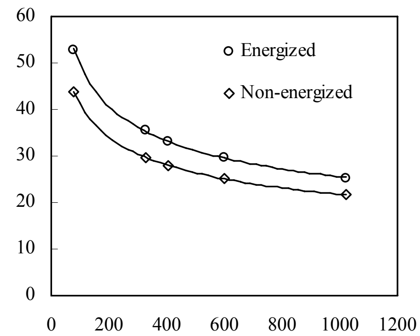
$$U_{50\%} = B\gamma_{20}^{-b} \qquad (1$$

In the equation, *B* is a constant related to ice state, insulator structure and materials, and *b* is the character exponent represents the effect of γ_{20} on $U_{50\%}$. Fitting the test result in *Table 5* by equation (1), values of *B* and *b* under different test conditions can be attained, as shown in Table 6. The curves of fitting are shown in *Figure 5* and the correlation coefficient R^2 exceeds 0.95.

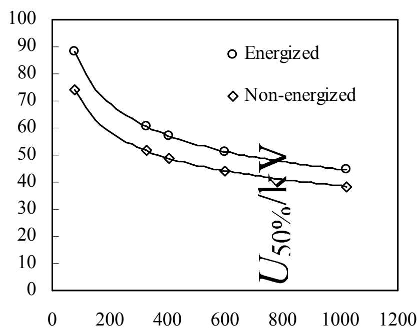
Table 6. Values of *B*, *b* under different conditions

Type		*B*	*b*
FXBW-10/70	***Energized***	187.7	0.2888
	Non-energized	147.5	0.277

FXBW-35/70	***Energized***	285.7	0.2682
	Non-energized	229.6	0.2577



(a) FXBW-10/70 insulator



(b) FXBW-35/70 insulator

Figure 5. The relation between the 50% flashover voltage and conductivity of freezing water

Table 5, *Table 6* and *Figure 5* show that:

(1) Both in the energized and non-energized icing conditions, the relation between 50% flashover voltage and icing water conductivity follow a power law.

(2) The flashover voltage of insulators iced under non-energized condition is lower than that of energized icing tests. The difference for *FXBW-10/70* insulator is 14.3%~16.9% and for *FXBW-35/70* insulator is 13.7%~15.8%. Reasons for above results are that ice on energized insulator is lower in amount and more porous in appearance than that on non-energized insulators, which lead to the less leakage current and bigger arc-start voltage contributing to the increase of flashover voltage.

V. CONCULSION

(1) In the icing process of energized composite insulators, the Joule heating from leakage current and the corona discharge reduces the ice amount apparently. Meanwhile it makes sheds more difficult to be bridged by icicles.

(2) Density of ice on energized composite insulators is lower than that on non-energized composite insulators. The difference relates to icing water conductivity. The lower conductivity the icing water is, the more apparent the difference will be.

(3) For the ice flashover performance of energized composite insulator is much different from that under non-energized condition, energized icing is recommended for the insulator icing test.

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