DC FLASHOVER PERFORMANCE OF ICED INSULATOR STRINGS WITH INSULATOR VARIETY STRUCTURES

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Abstract: The prevention of icing flashover of insulator strings is significant for the secure operation of transmission lines located in ice-covered regions. The icing condition was generated in the artificial climate chamber, then glass insulator (FC210D) and normal porcelain insulators (XZP-210 and XZP-300) were selected to take as test samples. Five types of iced insulator strings consisted of insulator variety structures were considered and compared in the ice flashover test under d.c. test condition. The results show that the variety structure of the insulator sheds in the string, accomplished by aerodynamic insulator with big diameter, can effectively increase the ice flashover voltage of the insulator string, and the variety structure with three small sheds and one large shed shows the best performance on improve the ice flashover voltage.

Keywords: insulator string; ice flashover; variety structure; d.c.

1. INTRODUCTION

In the past few years, a number of flashover accidents or outages have been caused by of iced insulator strings on transmission lines in China, and especially in January 2008, a rare ice disaster caused a great of loss to the power grid of China. From January 10, 2008, some regions of the Central China Power Grid, the East China Power Grid and South China Power Grid suffered a wicked snow and freezing rain weather with high intensity and large-scale, which led to the tower fallen down, wire broken, galloping, ice flashover, and other accidents.

The constructions of ± 800kV HVDC transmission projects follow the UHV backbone grid development idea of the State Grid Corporation of China with the development of the west China and the implementation of the west-east power transmission strategy. According to the special geographic and environmental conditions of China, ice peoblems will keep effecting on the transmission lines, especially through and round the canyons, rivers, microclimate and glaze areas [1-2].

Under the same ice condition, the gaps between the sheds of the insulator determine the iced degree. The larger gaps, the more time are required to realize the heavy degree of ice-coating. Therefore, insulators with special configuration will perform better anti-ice flashover performance under operating conditions.

In some places, the cross-connections of norm insulator and aerodynamic insulator are used to prevent ice bridging of the insulator string, and reduce the probability of flashover events happening consequently. At present, this type of insulator sting has successful experiences in some flashover frequently occurred areas of China [3]. According to the experience of Canadian Hydro-One, the insulators with cross-connections can not only be adopted on I-type insulators of 500kV transmission line, but also be used on V-type insulators, as shown in Figure 1.

(a) vertical string (b) V string

Figure 1: Anti-ice insulator string with cross-connection configurarion of Canadian Hydro's 500kV line.

Alternate structure of insulators have important practical significance and engineering value to the reliable operation of the power grid. In the present paper, the iced flashover performance of DC insulator strings with alternate structures are studied, and an optimized alternate structure is recommanded to improve the anti-iced flashover ability of the vertical insulator string.

2 TEST EQUIPMENT, SAMPLE AND METHODS

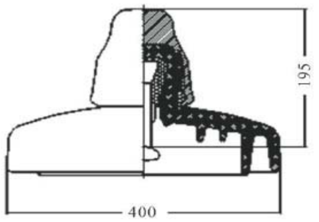
2.1 Test samples

The mechanical strength of insulators commonly used on ±500kV DC transmission lines in China was 210kN, while on ±800 UHV DC transmission lines, 300kN and above insulators were mostly used. To represent the performance of these kinds of insulators, XZP-300 insulator and XZP-210 insulator were employed in the present study. The geometric parameters of the test samples were listed in Table 1, and the structure charts of the test samples are shown in Figure 2.

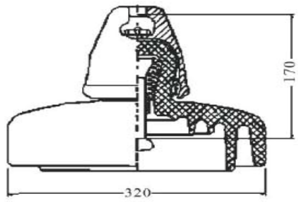
Based on the domestic and the international research results and operation investigations, 5 typical string structures were used and compared with the conventional insulator string in the present study.

Table 1: Geometric parameters of test insulators.

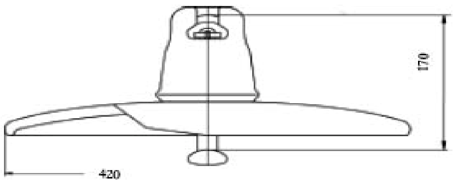
Test Samples	Diameter (mm)	Structure Height (mm)	Creepage Distance (mm)	Mechanical Strength (kN)
XZP- 300	400	195	635	300
XZP- 210	320	170	545	210
FC 210D	420	170	380	210



(a) Normal d.c. insulator, XZP-300



(b) Normal d.c. insulator, XZP-210



(c) Aerodynamic insulator, FC210D

Figure 2: Test product structure diagram

The string types were described as follow:

- Type (a): One large shed and one small shed, as shown in Figure 3(a).

- Type (b): One large shed and two small sheds, as shown in Figure 3(b).

- Type (c): One large shed and three small sheds, as shown in Figure 3(c).

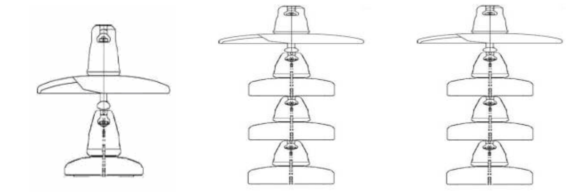
- Type (d): One large shed and four small sheds, as shown in Figure 3(d).

- Type (e): One large shed and five small sheds, as shown in Figure 3(e).

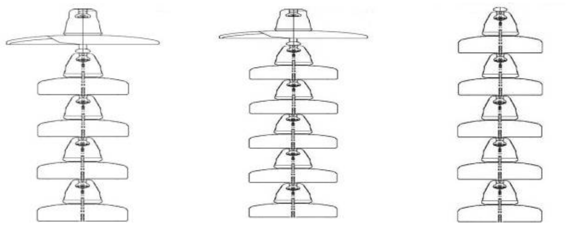
- Type (f): Conventional type, as shown in Figure 3(f).

Due to the manufacturing capacity limitation, the maximum diameter of the aerodynamic insulators was only 420mm, and the mechanical strength was 210kN or 240kN only.

During the test, the aerodynamic insulator, FC210D, was connected with normal d.c. insulator, XZP-210. And the aerodynamic insulator, FC210D, was connected with normal d.c. insulator, XZP-300. Although there was a connection difference between the FC210D insulator and the XZP-300 insulator, this kind of test structure was still used to in the study to analyse the influence of shed structures on the ice bridge shape and the iced flashover voltage.



(a) (b) (c)



(d) (e) (f)

Figure 3: Test strings with different insulator structures.

2.2 Test Equipment

The experiment was carried out in an artificial climate chamber, as shown in Figure 4, in the *China Electric Power Research Institute*.

The diameter and the height of test space in the artificial climate chamber was 4m and 7m respectively. The environmental parameters could be generated by the test chamber were listed in Table 2.

Figure 4: Appearance of the artificial climate chamber.

Table2: Environmental parameters of the test chamber.

Environmental parameters	**Test parameters**
Types of ice	glaze
Thickness of ice	0~30 mm
Diameter of water droplets	100~300 μm
Flow rate of cooling water	60±20 $l/h/m^2$
Conductivity of ice freezing water	100±10 μS/cm（20℃）
Air temperature	-5 ~ -10 ℃

A thyristor-controlled d.c. source was used as the power supply, and the voltage drop of the the power supply was less than 5% when the leakage current was 0.5A. The output voltage is dc 0~±600 kV. The output voltage can be regulated automatically and manually [4].

A set of thickness measurement device was used to determine the ice thickness with the same test condition. The device is shown in Figure 5. The measurement device consisted of a rotating cylinder with 30mm in diameter and 600mm in length, which can ratate in a constant rate(about 1r/min). The ice thickness on the cylinder was regarded as the thickness in the present study.

Figure 5: Ice thickness measurement device**.**

2.3 Test Methods

Lots of tests have indicated that the degree of contaminant before the ice flashover is an important factor to influence the flashover voltage [5-8]. The operation experience shows that ice flashover incidents seldom occurred in the clean areas. Therefore, the pollution level of the test insulators was set on heavy level. Before the ice flashover test, the test insulators were contaminated with artificial pollution according to the solid layer method, referred to GB/T 22707-3008 [9]. The quality of NaCl and kaoline were calculated by the test salt deposit density and the surface area of the test insulators. The NaCl and kaoline were mixed well with the deionized water, of which the conductivity was 10 μS/cm at 20℃. And then the contaminated water was brushed on the insulator surface uniformly. Before the ice flashover test, the test sample should be dried naturally.

According to the field investigation, most of ice flashover incidents occured in ice-melting period. So the present study mainly focused on the characteristics of ice flashover in ice-melting period. After the thickness of ice reached the prescriptive level, the temperture of the chamber would be raised to melt the coated ice. When the melting water dropped off from the insulator surface, the test voltage would be raised up to flashover.

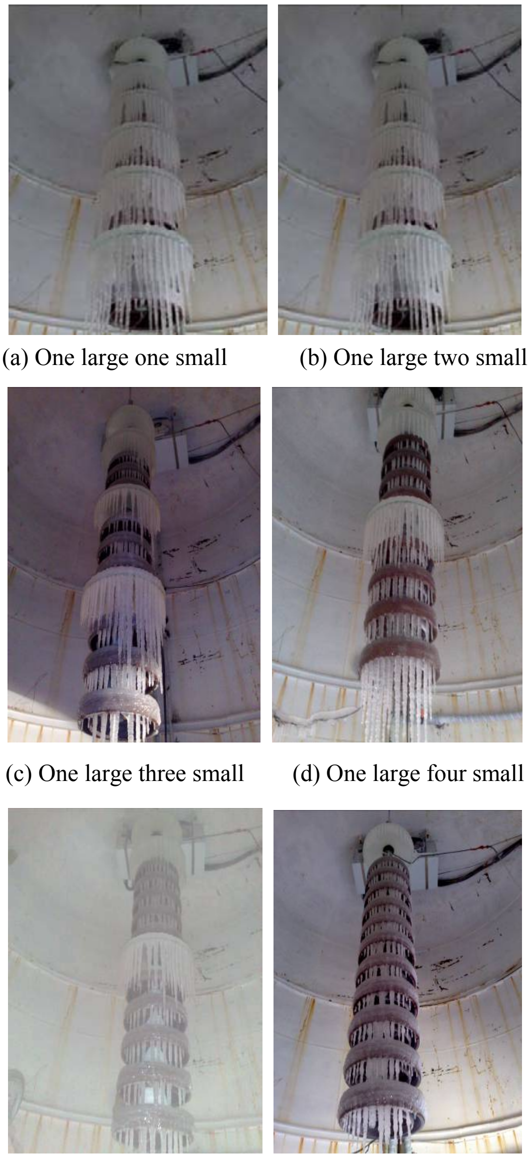
In all tests, the 15mm ice thickness was defined as the prescriptive level, the salt density of NaCl was 0.05 mg/cm^2 and the dust density of kaoline was 0.3 mg/cm^2. The conductivity of ice freezing water was 100 μ s/cm.

Five typical structures were adopted on both XZP-300 insulator and XZP-210 insulator, as shown in Figure 3. The ice flashover voltage would be compared with conventional insulators which consisted of 8 pieces of XZP-300 insulators and 11 pieces of XZP-210 insulators respectively.

3 Test Results and Anlysis

3.1 Test Results

The Figure 6 shows the XZP-210 and FC210D connected strings under the same ice condition.



(a) One large one small (b) One large two small

(c) One large three small (d) One large four small

(e) One large five small (f) conventional string

Figure 6: XZP-210 and FC210D connected strings.

Due to the differece of string length, the test results were compared with the flashover voltage gradient *G*, which was defined in formula (1):

$$G = U / (n \times d) \quad (1)$$

In formula (1), *U* presented the flashover voltage, *n* presented the number of the test insulators, and *d* presented the structure height of the test insulator.

The flashover voltage gradient of various XZP-210 and FC210D conneted strings, and the conventional string are shown in Figure 7. In Figure 7, the iced flashover voltage gradient of the test string was represented by the p.u. value, of which the standard value came from the iced flashover gradient of the *Type (f)*: the conventional string with 11 pieces of XZP-210 insulators.

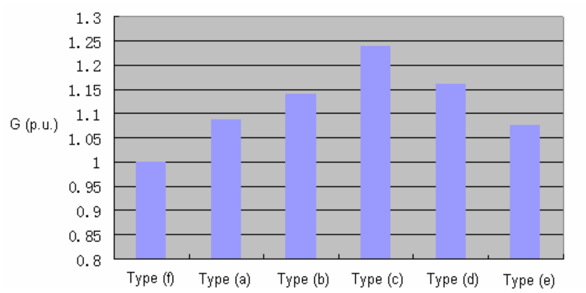


Figure 7: Ice flashover voltage gradient of various string types (XZP-210 series).

Figure 8 shows the XZP-300 and FC210D connected strings under the same ice condition.

(a) One large one small. (b) One large two small.

(c) One large three small. (d) One large four small.

(e) One large five small. (f) Conventional type.

Figure 8: XZP-300 and FC210D connected strings.

The flashover voltage gradient of various XZP-300 and FC210D conneted strings, and the conventional string are shown in Figure 9. In Figure 9, the iced flashover voltage gradient of the test string was represented by the p.u. value, of which the standard value came from the iced flashover gradient of the *Type (f)*: the conventional string 11 pieces of XZP-210 insulators.

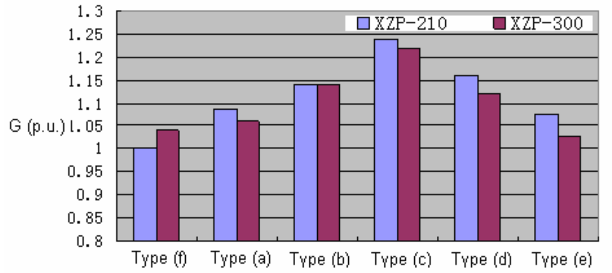


Figure 9: Ice flashover voltage gradient of various string types (XZP-210 series and XZP-300 series).

3.2 Influence of variety structures to icing flashover characteristic

Normally, the icicles reduced the insulation resistance; the longer the icicle is, the more the reduced result appeared.

From Figure 6 and Figure 8, it could be found that the conventional strings were more easier to be bridged by icicles under the same test condition. When the variety structure appeared, the icicles bridge between big sheds became hard.

However, the Figure 7 and the Figure 9 all indicated that the variety structures have influence on increasing the ice flashover voltage gradient, especially to the variety structure with three small sheds and one large shed.

From Figure 9, The XZP-210 and FC210D connected strings was found to show the better effect to improve the ice flashover voltage gradient than the XZP-300 and FC210D connected strings.

4 CONCLUSIONS

Under same ice condition, the ice flashover voltage gradient of variety structures were higher than the conventional string, which could enhance the ice flashover resistant ability of the insulator string.

The structure of one big shed and three small sheds showed better anti-ice flashover performance than other types.

For the insulators with small difference on the diameter between the big shed and the small shed, such as the XZP-300 and FC210D connected strings, the improvement effect of string structure varietied became weak.

The present paper focused on the short insulator strings, the test proceeded on the long insulator strings will be considered in the future to verify the conclusions of above.

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