# AC FLASHOVER PERFOMANCE OF ICE-COVERED INSULATOR STRINGS ADOPTED IN 500KV TRANSMISSION LINES BASED ON UP-AND-DOWN METHOD

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**Abstract**: Based on up-and-down method, a new approach and procedure to perform icing flashover test for insulator strings are proposed, through which 50% flashover voltage of iced insulators can be evaluated. Test is carried out in the artificial climate chamber (diameter 22m, height 34m) of Pollution and Environment Lab at China Electric Power Research Institute (CEPRI). Under full scale conditions, icing flashover characteristics of long insulator strings adopted in 500kV AC transmission lines are obtained with the method mentioned above. Comparison between rising voltage to flashover method and up-and-down method is made, which shows advantages of the latter. Under operating voltage, the distribution of icicles and air gaps along insulator string was relatively fixed. Besides, leakage current is analysed to explain the process of ice flashover and withstand.

## 1 INTRODUCTION

Phenomena of ice deposited on insulators in transmission lines often appear in winter or in cold regions worldwide, which may lead to flashover of insulator strings sometimes. In order to prevent icing flashover, characteristics of it have been studied by many institute and researchers [1-6]. Mechanism and performance of icing flashover on models and short samples have been put forward. Several different test methods have been proposed to find out flashover voltage of insulator strings [7-8]. However, these methods were mostly based on rising voltage to flashover method, which could not accord to real operation conditions of transmission lines.

There are many 500kV AC transmission lines operating in China. According to rough statistics, during the ice disaster happened in China in 2008, line tripping caused by icing flashover were 58% of the total. Seventy-three tripping operations of 500kV lines were recorded from January 20th to 29th, 2008, which has caused huge economic losses.

In order to determine external insulation of 500kV AC lines in ice region, based on up-and-down withstanding method, 50% icing flashover voltage of 30 units double sheds porcelain insulators string was obtained. Meanwhile, leakage current during the withstanding course was also analysed.

## 2 TEST FACILITIES AND TEST METHODS

### 2.1 Test facilities

*2.1.1 Artificial Climate Chamber*

Artificial climate chamber of pollution and environment lab in UHVDC Test Base, China, as shown in Figure 1, was used to simulate the environment of icing in this research. The chamber was made of steel, with the size of Φ22m×34m and test space of Φ20m×25m, in which 0℃ to -20 ℃ ambient temperature and 0-6000m air pressure can be simulated. Under conditions above, various high external insulation tests such as icing, raining as well as pollution tests, etc. can be performed in the chamber.

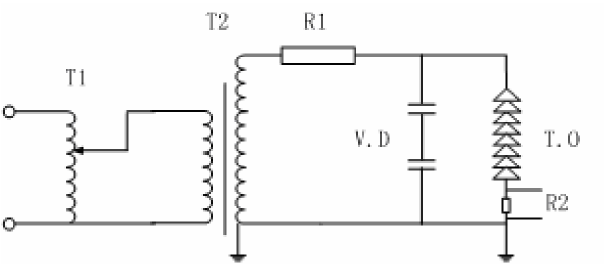
**Figure 1:** Artificial climate chamber

*2.1.2 Environment Simulation System*

Refrigerating system was adopted to ensure that the ambient temperature around specimens be kept at -10℃±1℃. Nozzles set vertically on wall of the chamber sprayed towards insulator string at the angle of 45°. The freezing water sprayed was pre-cooling by a refrigerator. In order to make ice melt, lamp banks arranged on wall turned on to heat ice surface when needed.

*2.1.3 Test System*

As shown in Figure 2, insulator string was energized by a test transformer. The test system meets the requirement of pollution and icing flashover tests [9].




Where: T1-voltage regulator (4800kVA);
T2-test transformer (800kV, 4800kVA);
R1-protective resister;
V.D - voltage divider (800kV);
T.O-test object (insulator string)
R2- resister for measurement of leakage current

**.Figure 2:** 800kV test system

### 2.2 Specimens and installation

*2.2.1* Specimens

Double sheds porcelain insulators XWP-300 were used in the research. Parameters of insulator are shown in Table 1 and the profile in Figure 2.

**Table 1:** Parameters of insulator XWP-300

| Type | Structure Height (mm) | Creepage Distance (mm) | Diameter (mm) | Mechanical Load (kN) |
|---|---|---|---|---|
| XWP-300 | 195 | 495 | 330 | 300 |

**Figure 3:** Profile of insulator XWP-300

*2.2.2 Test Layout*

Thirty units insulator string, pre-contaminated, was hung vertically at the centre of climate chamber, and energized by wall bushing, as shown in Figure 3.

**Figure 3:** Test layout

### 2.3 Test method

Method adopted in this research was based on up-and-down method, which accords real operating conditions of transmission line.

### 2.4 Test procedures

*2.4.1 Pre-contamination*

Insulators to be test were pre-contaminated following solid-layer method in IEC 60507:1991 [9]. Sodium chloride and kaolin were mixed by deionized water, and then brushed uniformly onto insulators (in this research ESDD=0.05mg/cm$^2$, NSDD=1.0 mg/cm$^2$).

*2.4.2 Icing under Operating Voltage*

Water (100μs/cm at 20℃) pre-cooled to 0℃-3℃, was sprayed towards insulator string by nozzles from about 11m distance at high pressure to make sure it can deposit on insulator surface. To prevent water dropping from insulator, after ten-second spaying, there was about 5min freezing time to ensure that no contamination was washed away. In climate chamber, -10℃±2℃ ambient temperature was maintained in order to freeze the water at wetting grown type (glaze) [ref]. Air velocity around test sample at any directions in chamber was no more than 0.1m/s to ensure the uniform icing on insulators. In this research, icing was formed by spaying from only one direction.

In order to acquire the worst meteorological condition, heavy ice (thickness>20mm) was simulated on insulators. The highest operating phase-to-earth voltage 318kV ( $500\text{kV}\times1.1/\sqrt{3}$ ) was applied on insulator string during the whole icing course.

Due to the nonuniform distribution of electric field along insulator string, ice on insulators at different positions of the string showed obvious different shape, as shown in Figure 4. At earth end and high-voltage end, the icicles barely bridged insulators due to the arc burning effect. However, insulators in middle part of the string were much easier to be bridged by icicles. According to individual tests in this research, the total numbers of unbridged air gaps were about 14-16.

(a) earth end (b) middle part (c) high-voltage end

**Figure 4:** Icing shape of insulator string

*2.4.3 Hardening at Operating Voltage*

After icing, at least 30min hardening time was needed to ensure there was no liquid content on insulator. Leakage current was monitored in this phase.

*2.4.4 Voltage Rising*

Voltage should be rose at a very slow average speed (about 5kV per 3min) to test voltage. Each time 5kV was added with an interval of 3min. Leakage current should be always monitored to avoid ice broken or shedding caused by discharge. If larger than 20mA current appeared, longer time should be waited after spaying.

*2.4.5 Hardening under Test Voltage*

After voltage rising phase, there should be another at least 30min hardening course to guarantee no liquid content on insulator.

*2.4.6 Melting at Test Voltage*

In this phase, refrigerating system was turned off and air temperature in chamber quickly rose from -10℃ to about -3℃.

Lamp banks were turned on to heat the ice surface along insulator string, whose heating power can be controlled to let ice melt slowly. During melting phase, to prevent air flow, doors of climate chamber should be closed

At this phase, large current may occur due to ice melting. If flashover occurred, which almost happened at about 1 hour after lamps turned on, according to experience of tests performed before, the individual test finished. Otherwise 2 hours should be waited for and then withstand would be confirmed.

*2.4.7 Result Evaluation*

Up-and-down method was adopted in this research [9]. For each individual test, iced insulator string was tested only once. If flashover occurred, test voltage would be 5%-10% lower than before. If withstood, test voltage would be 5%-10% higher than before (In this research, 30kV voltage step was adopted). At least 10 “useful” tests should be carried out in one given pollution and icing condition. The calculation of 50% withstand voltage of iced insulator string should be calculated with the following formula:

$$U_{50} = \frac{\sum (n_i \times U_i)}{N} \quad (1)$$

Where: $U_i$ is a test voltage level. $N_i$ is the number of test groups carried out at the same $U_i$. $N$ is the number of “useful” tests.

## 3 RESULTS AND DISCUSSION

### 3.1 Test results

When Salt Deposit Density (SDD) equalled to 0.05mg/cm$^2$ and Non-Soluble Deposit Density (NSDD) 1.0mg/cm$^2$, under heavy ice condition, the 50% withstand voltage of the 30 units XWP-300 insulators string was calculated from 10 “useful” tests following equation (1). Test result ,the value of $U_{50}$, is shown in figure 5:

### 3.2 Discussion

*3.2.1 Result Comparison of Different Methods*

Another research on 500kV ice flashover was carried out in 2010 at the same laboratory of CEPRI, but with different method. In that research, 30 units XWP-210 insulator string was energized at 80% of operating voltage $V_o$ in icing and melting phase. When the “critical moment” [7] occurred, voltage was rose until flashover. Comparison of test condition in two methods can be seen in table 3.

**Table 2:** Test conditions of two different methods

| Year | Insulator Type | SDD/NSDD | Units | Test Method |
|---|---|---|---|---|
| 2010 | XWP-210 | 0.05 /1.0 | 30 | Icing and melting at 80% $V_o$ then rise voltage to flashover. |
| 2011 | XWP-300 | 0.05 /1.0 | 30 | Icing and melting at Vo then withstand at $V_t$. |

Test results and comparison between two methods can be seen from Figure 5. In same laboratory, according to six individual tests results shown in figure 5, the average flashover voltage can be calculated, which is 22.33% higher than $U_{50}$ in up-and-down withstand method in this research (The value of $U_{50}$ are modified to the structure height of XWP-210 with the correction factor K=170/195). Meanwhile, the average flashover voltage in rising voltage to flashover method was 2.97% higher than $U_{50}$ of pollution flashover voltage. From the results above, it is apparent that flashover value obtained in up-and-down withstand method is more accordant with field operating condition rather than in rising voltage to flashover method.

Moreover, the standard deviation of this research was 4.2% of $U_{50}$. However, the standard deviation with rising voltage to flashover method was 13.33% of the average flashover voltage. It is obvious that results dispersion in rise-voltage method is much higher than in up-and-down withstand method.

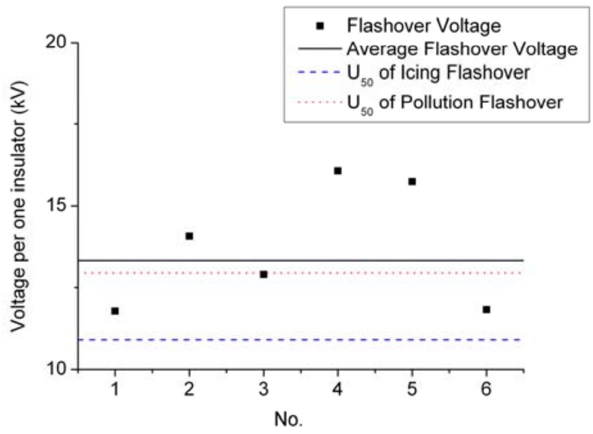



**Figure 5:** Comparison of test results with two test methods

*3.2.2 Statistics of Icicles and Air Gap Length*

Under icing condition, both icicles and air gaps may exist together or separately between two insulators. In this research, for each individual test, the total length of air gaps and fully bridged insulator gaps were recorded. Analysis of the results showed that for 500kV energized insulators the total length of air gaps and total number of fully bridged insulator gaps were within a definite range, which could be seen from table 4. That is to say, for 30-unit insulators string energized at operating voltage in heavy ice condition, the distribution of icicles and air gaps were relatively fixed. Consequently, once parameters reached the values within the range, a heavy ice condition could be confirmed.

**Table 3:** Statistics of Icicles and air gaps distributed along Insulator String

| Total insulator gaps | Fully bridged insulator gaps | Percentage of air gaps taken up in distance between insulators along the whole string | | |
|---|---|---|---|---|
| | | Min. | Max. | Average |
| 29 | 14-16 | 33.8% | 41.38% | 36.67% |

*3.2.3 Leakage Current at Melting Phase*

Figure 6 shows a typical leakage current tendency chart of flashover. The first large current (80mA) occurred at about 30 minutes after melting phase began. Then about 20minutes later, flashover appeared.

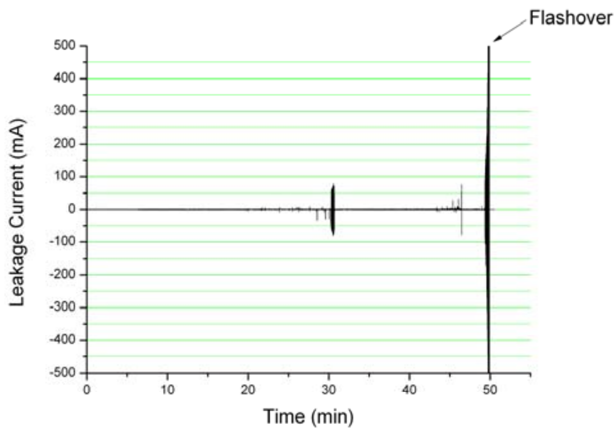



**Figure 6:** Typical tendency chart of flashover case

A typical leakage current tendency chart of withstand is shown in figure 7. The first large current (50mA) also occurred at about 30 minutes after melting phase began. Then about 20 minutes later, the largest leakage current (198mA) appeared. After that, leakage current was no larger than 80mA.

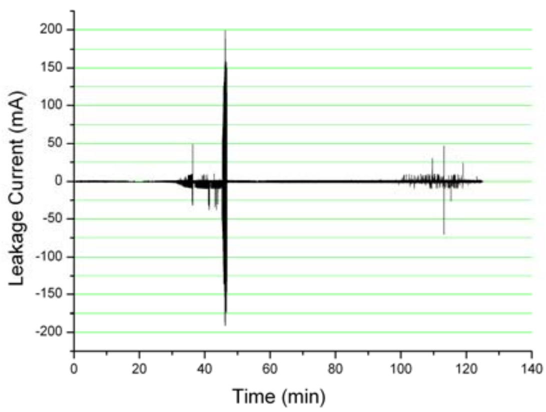



**Figure 7:** Typical tendency chart of withstand case

When melting phase began, ice started to transform into water, which led arc to appear. However, due to the burn away caused by arc, icicles were shortened, leading to extinguishment of arc. With the continuous ice melting and arc burning, a water film formed on the surface of insulators. And then the arc developed at a very high speed, accompanied by fast ice melting. At that moment, flashover would occur or arc would extinguish to withstand.

#### *3.2.4 Insulation Selection for 500kV AC Transmission Line under Heavy Icing Conditions*

Based on the results obtained by up-and-down withstand method, recommendation of external insulation for 500kV AC transmission line under heavy icing condition could be carried out. Besides, according to site severity of pollution and ice, icing flashover probability of insulator strings can be calculated from test results as well.

## 4 CONCLUSION

(1) Icing flashover test methods and procedures for insulator strings based on up-and-down method are proposed, which accords real operation conditions better than other methods.

(2) 50% flashover voltage of 30 units XWP-300 iced insulators were acquired by up-and-down method.

(3) Comparison between rise voltage to flashover method and up-and-down method are made, which shows advantages of the latter.

(4) For insulator string energized at operating voltage in heavy ice condition, the fully bridged icicles are within the rage of 14-16. Air gaps between insulators along the string are within definite range.

(5) The first large current occurred at about 30 minutes after melting phase began. Then about 20minutes later, the maximum leakage current occurred, which may lead to flashover.

## 5 ACKNOWLEDGMENTS

Authors wish to acknowledge National Basic Research Program of China (973 Program).

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