TESTING METHOD ON DC ARTIFICIALLY ICED DISK-SHAPED AND SUSPENSION INSULATORS

Yang Jianlan[1, 2], Shu Lichun[1], Zhou Tianchun*[1], Jiang Xingliang[1], Hu Jianlin[1], Zhang Zhijin[1]

1. State Key Laboratory of Power Transmission Equipment & System Security and New Technology, Chongqing University, P. R. China, 400044;
2. Chongqing Jiang-bei Power Supply Bureau, Chongqing, P. R. China, 401147.

*Email: ztccqu@163.com

Abstract: Adopting mathematical statistical methods, by comparing the differences and equivalent relationship of test result under 3 kinds of test methods, this paper has bring forward the DC icing test methods of disk-shaped suspension insulator. Results have been shown that: Firstly, iced flashover voltages obtained by different test methods at the same salt concentration (SDD) or ice water conductivity (γ 20) differ from each other significantly, among which, voltage obtained by equably boosting voltage method is the highest , the U50% obtained by constant voltage under up-down manner follows by, and the minimum flashover voltage obtained by "U"-shaped curve is the lowest; Secondly, there is equivalent relationship between the average flashover voltage Uave obtained by t equably boosting voltage method and the U50% obtained by constant voltage under up-down manner, and the same relationship between the minimum flashover Ufmin voltage obtained by "U"-shaped curve and the U50% obtained by the constant voltage under up-down manner is also found.

1. INTRODUCTION

Artificial icing test has been used for icing insulating experimental for a long time. It can be obtained in the artificial climate chamber which can simulate the natural icing condition and get the electrical characteristics of the insulators in a short period. In this paper, a number of experimental were carried out to put forward the DC icing procedure, DC test method and schedule [1, 2].

2. RESULTS AND DISCUSSION

The test result of XZP-210 insulator is shown in Fig. 1 and Fig. 2. Equivalence of the experimental results between method of "U"-shaped curve way and up-down manner is shown in Tab. 1.

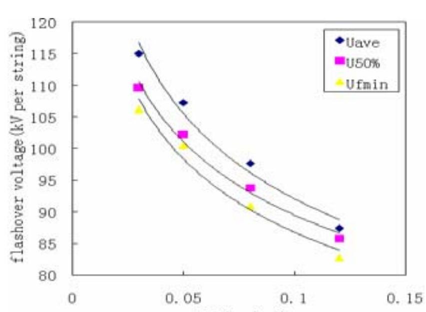


Figure.1 The relations between flashover voltage of XZP-210 insulators string and salt deposit density (SDD) by different electrical test methods

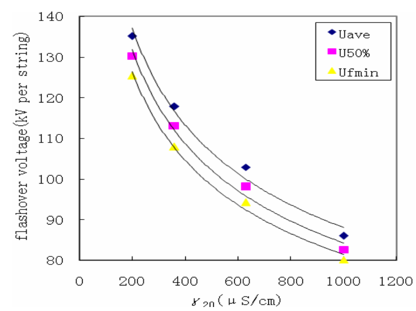


Figure.2 The relations between flashover voltage of XZP-210 insulators string and ice water conductivity by different electrical test methods

Table 1 The equivalence of the experimental results between method of "U"-shaped curve way and up-down manner.

SDD (mg/cm²)	R(%) XZP-210	R(%) LXZY-210	γ_{20} (μS/cm)	R(%) XZP-210	R(%) LXZY-210
0.03	3.2	4.5	200	3.7	2.7
0.05	1.6	3.6	360	5	11
0.08	3	4.4	630	3.9	3.5
0.12	3.5	4	1000	3	2.9

$R = \left(\left|U_{f\min} - U_{50\%}\right| \div U_{50\%}\right) \times 100\%$; $\overline{R}$ =4%

3. CONCLUSION

The DC icing test method is studied in this paper, and it can be concluded that the flashover voltage for the same salt deposit density (SDD) or ice water conductivity (γ 20) is different by three kinds of electrical tests. The DC icing flashover voltage has a power function relation with the SDD or γ 20 under all the three kinds of the electrical tests. There are equivalence of the experimental results among method of equably boosting voltage, "U"-shaped curve way and up-down manner.

4. REFERENCES

[1] Sun Caixin, Sima Wenxia, Shu Lichun. Atmospheric environment and electrcial outdoor insulation [M]. Beijing: China Electric Power Press, 2002 (in chinese).

[2] Yang Jianlan. Testing method on DC Artificially Iced disk-shaped and suspension Insulators [Master's thesis]. Chongqing University, 2009 (in chinese).

Testing Method on DC Artificially Iced Disk-shaped and Suspension Insulators

Yang Jianlan
Jiang-bei Power Supply Bureau
Chongqing Power Company
Chongqing, P. R. China
boyyjl@yahoo.com.cn

Shu Lichun, Zhou Tianchun, Jiang Xingliang, Hu Jianlin, Zhang Zhijin
State Key Laboratory of Power Transmission Equipment & System Security and New Technology
Chongqing University
Chongqing, P. R. China
ztccqu@163.com

***Abstract*—Artificial icing test has been employed as an important approach to evaluate icing insulation for long. However, there is no uniform standard for testing method concerning the study on characteristics of external insulation of porcelain and glass insulators, and iced DC transmission lines. In this paper, based on experiments carried out in a large, multifunctional artificial climate chamber with diameter of 7.6 meters and height of 11.6 meters and in a low temperature and low pressure test chamber with diameter of 2 meters and length of 3.8 meters, the flashover performance of the iced insulators strings is investigated. Adopting mathematical statistical methods, by comparing the differences and equivalent relationship of test result under 3 kinds of test methods, this paper has bring forward the DC icing test methods of disk-shaped suspension insulator. Results have been shown that: Firstly, iced flashover voltages obtained by different test methods at the same salt concentration (SDD) or ice water conductivity (γ 20) differ from each other significantly, among which, voltage obtained by equably boosting voltage method is the highest , the $U_{50\%}$ obtained by constant voltage under up-down manner follows by, and the minimum flashover voltage obtained by "U"-shaped curve is the lowest; Secondly, there is equivalent relationship between the average flashover voltage U_{ave} obtained by t equably boosting voltage method and the $U_{50\%}$ obtained by constant voltage under up-down manner, and the same relationship between the minimum flashover U_{fmin} voltage obtained by "U"-shaped curve and the $U_{50\%}$ obtained by the constant voltage under up-down manner is also found.**

Keywords-component; Icing insulators; DC voltage; electrical test method; outdoor insulation

I. INTRODUCTION

Artificial icing test has been used for icing insulating experimental for a long time. It can be obtained in the artificial climate chamber which can simulate the natural icing condition and get the electrical characteristics of the insulators in a short period. In this paper, a number of experimental were carried out to put forward the DC icing procedure, DC test method and schedule [1, 2].

There are natural icing and artificial icing respectively for the icing test method. The natural icing test is carried out by establishing a testing station in the icing area or by testing in the practical transmission lines in the icing area. The natural icing test can reflect the real condition of the icing insulators, but it is time consuming and difficult to do the test, besides, it is also difficult to control the testing factors of the natural icing testing and has poor repetition because of the changing of the testing time or position even at the same site. To avoid the limit of the natural icing test, the artificial icing technique can be used to substitute for the natural icing test as one kind of icing insulating test. But currently, there isn't a uniform standard for the testing method to DC artificially iced disk-shaped and suspension insulator, and different methods have different testing results. Accordingly, it is necessary to study the DC icing method of the iced disk-shaped and suspension insulators [3].

II. EXPERIMENTAL DEVICES AND METHOD

A. Experimental devices

The experimental is carried out in the a large, multifunctional artificial climate chamber with diameter of 7.6 meters and height of 11.6 meters and the lowest temperature to -45℃ and lowest pressure to 30kPa, to meet the need of the testing icing insulators. The test voltage is supplied by a ±600kV/0.5A dual feedback control current and voltage DC power supply, its dynamic voltage drop is less than 5% when the Current leakage is 0.5A, and the ripple coefficient of voltage is less than 3% when flashover happens. All these parameters can meet the need of power supply of the DC polluting test.

B. Samples

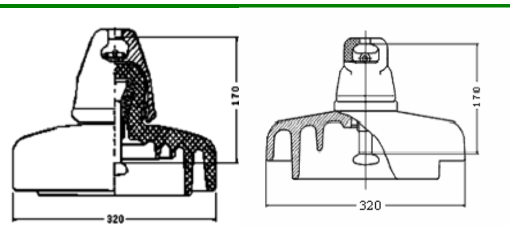
The samples used in the test are type XZP-210 porcelain insulator and type LXZY-210 glass insulator respectively, and the structure and parameters are shown in Figure 1 and Table I.

C. Test method

(1) Samples cleaning. Insulators are carefully cleaned to remove the contaminant and oil with water and then dried to be used.

TABLE I. PARAMETERS OF TESTED INSULATORS

Type	Structure height H(mm)	Nominal diameter D(mm)	Leakage distance L(mm)	Surface area A(cm^2)
XZP-210	170	320	540	3860
LXZY-210	170	320	545	3671



(a) XZP-210 (b)LXZY-210

Figure.1 Sketch maps of the tested insulators

(2) Polluting simulation of the iced insulator. There are solid layer pollution method and ice water conductivity method to simulate polluting.
(3) Control of the icing. The weight and state of the ice can be obtained by controlling the icing condition and time. The icing of the insulator is named glaze. The icing thickness of the top surface of the insulator is about 5 to 7 mm, with the density between 0.84 and 0.89 g/cm^3 and weight from 3.8 to 4.5 kg/string. The insulators are bridged by the icing sleet when heavily iced.
(4) Flashover experiment. The equably boosting voltage, constant voltage under up-down and "U"-shaped curve method were used to test the electrical performance after icing finished.

The negative DC voltage was applied for the electrical test since the flashover voltage when positive voltage applied is high than that when applied negative voltage [4].

III. RESULTS AND DISCUSSION

A. Results

The test result is shown in Figure 2 and Figure 3.

TABLE II. THE RESULTS UNDER DIFFERENT SALT DEPOSIT DENSITY BY THREE ELECTRICAL TEST METHODS

SDD (mg/cm^2)	XZP-210 U_{ave}	σ%	$U_{50\%}$	σ%	$U_{f\min}$
0.03	115.1	8.1	109.7	6.6	106.2
0.05	107.3	7	102.2	7.2	100.5
0.08	97.7	8.2	93.8	6.8	91.
0.12	87.4	7.8	85.8	7.1	82.8

U_{ave} is the average flashover voltage; ,kV; $U_{50\%}$ is the 50% tolerance voltage or 50% flashover voltage ,kV; $U_{f\min}$ is the minimum flashover voltage, kV

SDD (mg/cm^2)	LXZY -210 U_{ave}	σ%	$U_{50\%}$	σ%	$U_{f\min}$
0.03	120.1	9.1	116.9	7.3	111.6
0.05	118.2	8	112.6	6.1	108.5
0.08	103.7	7.8	99.7	6.4	95.3.
0.12	94.4	8.1	90.9	6.8	87.3

U_{ave} is the average flashover voltage; ,kV; $U_{50\%}$ is the 50% tolerance voltage or 50% flashover voltage ,kV; $U_{f\min}$ is the minimum flashover voltage, kV

TABLE III. THE RESULTS UNDER DIFFERENT CONDUCTIVITY BY THREE ELECTRICAL TEST METHODS

γ_{20}(μS/cm)	XZP-210 U_{ave}	σ%	$U_{50\%}$	σ%	$U_{f\min}$
200	135.1	6.3	130.2	3.1	125.4
360	117.8	6.6	113.1	3.7	107.9
630	102.9	7.2	98	4.0	94.2
1000	86	6.1	82.6	3.5	80.1

U_{ave} is the average flashover voltage; ,kV; $U_{50\%}$ is the 50% tolerance voltage or 50% flashover voltage ,kV; $U_{f\min}$ is the minimum flashover voltage, kV

γ_{20}(μS/cm)	LXZY -210 U_{ave}	σ%	$U_{50\%}$	σ%	$U_{f\min}$
200	140	7.2	135.3	4.3	131.6
360	127.3	7.8	122.4	3.8	108.7
630	109.3	6.5	104.1	3.2	100.5
1000	91.2	7.7	87.6	4.1	85.1

U_{ave} is the average flashover voltage; ,kV; $U_{50\%}$ is the 50% tolerance voltage or 50% flashover voltage ,kV; $U_{f\min}$ is the minimum flashover voltage, kV

B. Analysis and discussion

The relationship of the flashover voltage, salt deposit density (SDD) and ice water conductivity for porcelain and glass insulators using different testing methods can be achieved by fitting equations (1) and (2) [5-10], and the results are shown in Figure 2 to Figure 5, Table IV and Table V.

$$U_{50\%} = AS^{-a} \tag{1}$$

Where S is the SDD of the pre-polluting insulators, A is constant relevant to the state of the icing and structure of the insulators, and a is the characteristic index reflecting how SDD influence the flashover voltage of the iced insulators.
The connection of the flashover voltage and ice water conductivity (γ_{20} under 20℃) can be shown as follow.

$$U_{50\%} = B\gamma_{20}^{-b} \tag{2}$$

Where γ_{20} is ice water conductivity, B is constant regard to the state of the icing and structure of the insulators, and b is the characteristic index reflecting how γ_{20} influence the flashover voltage of the iced insulators.

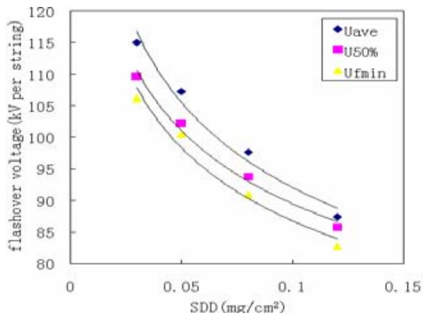


Figure.2 The relations between flashover voltage of XZP-210 insulators string and salt deposit density (SDD) by different electrical test methods

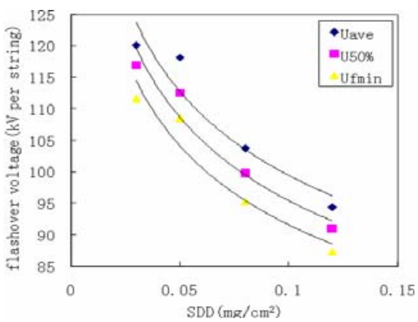


Figure.3 The relations between flashover voltage of LXZY-210 insulators string and salt deposit density (SDD) by different electrical test methods

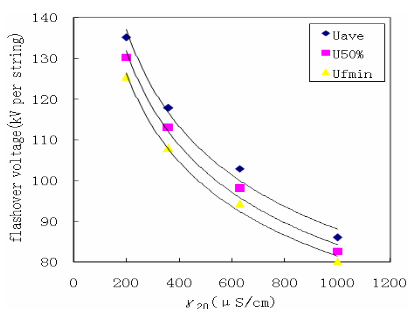


Figure.4 The relations between flashover voltage of XZP-210 insulators string and ice water conductivity by different electrical test methods

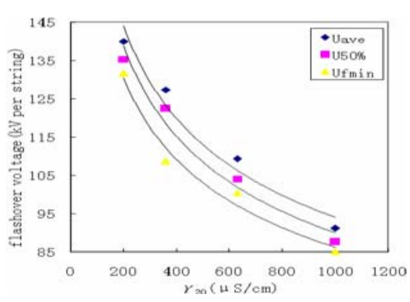


Figure.5 The relations between flashover voltage of LXZY-210 insulators string and ice water conductivity by different electrical test methods

It can be concluded from Figure 2 to Figure 5, Table IV and Table V that, With the same type of the insulator and the same state of the icing,

TABLE IV. THE VALUE OF A AND A WITHIN DIFFERENT ELECTRICAL TEST METHODS

Electrical test method	XZP-210		LXZY-210	
	A	*a*	*A*	*a*
equably boosting voltage method	58.50	0.1972	65.36	0.1821
constant voltage under up-down manner	59.53	0.1769	61.96	0.1806
"U"-shaped curve method	57.12	1.1814	59.76	0.1854

TABLE V. THE VALUE OF B AND B WITHIN DIFFERENT ELECTRICAL TEST METHODS

Electrical test method	XZP-210		LXZY-210	
	B	*b*	*B*	*b*
equably boosting voltage method	587.76	0.2748	584.43	0.2644
constant voltage under up-down manner	576.67	0.2785	580.45	0.2699
"U"-shaped curve method	538.59	0.2736	507.62	0.2566

(1) Different electrical testing methods have nothing to do with the relationship of SDD, γ_{20} and the flashover voltage. The DC icing flashover voltage has a power function relation with the SDD or γ_{20} under all the three kinds of the electrical tests.

(2) The flashover voltage for the same SDD or γ_{20} is different under three kinds of electrical tests, where U_{ave}> $U_{50\%}$>U_{fmin} shown in Table 5.

The characteristic index in the equation (1) and (2) shows little change under different electrical tests, that is to say different testing method have nothing to do with the value a or b. But the constant A and B show obvious changes when different testing methods applied, leading to the different values of the flashover voltage under different testing methods.

C. Equivalence of the experimental results using different test methods

According to the result of section 2.1, it can be concluded the Equivalence of the experimental results using different test methods.

(1) Equivalence of the experimental results between equably boosting voltage method and constant voltage under up-down manner.

The equably boosting voltage method is not the standard test method but a common method used in the scientific research. It can be shown from the results of section 2.2 that, the average flashover voltage (U_{ave}) using the equably boosting voltage method is high than that using the up-down manner ($U_{50\%}$). Results from Table II and Table III show the relationship between U_{ave} and $U_{50\%}$ as in Table VI.

TABLE VI. THE CORRESPONDING RELATION OF TEST RESULT BETWEEN METHOD OF EQUABLY BOOSTING VOLTAGE AND UP-DOWN MANNER

SDD (mg/cm²)	*R*(%)		γ_{20} (μS/cm)	*R*(%)	
	XZP	LXZY		XZP	LXZY

	-210	-210		-210	-210
0.03	4.9	2.7	200	3.8	3.5
0.05	5	5	360	4.2	4
0.08	4.2	4	630	5	5
0.12	2	3.9	1000	4.1	4.1
R=[($U_{ave}-U_{50\%}$)/ $U_{50\%}$]×100%; $\overline{R}$ =4%					

From Table VI, it can be seen that, with the same condition, U_{ave} is about 4% higher than $U_{50\%}$, and we propose R=4% when using the equably boosting voltage method.

$$R=\frac{U_{ave}-U_{50\%}}{U_{50\%}}\times 100\% \qquad (3)$$

$$U'_{50\%}=0.96U_{ave} \qquad (4)$$

Considering the minimum number of samples for equably boosting voltage method in [2], we choose the confidence level ($1-\alpha$) as 0.95, statistical error (e) as 0.03 and sample capacity not less than 20, and U_{ave} multiplied by 0.95 equals in value of $U_{50\%}$.

(2) Equivalence of the experimental results between method of "U"-shaped curve way and up-down manner

The method of "U"-shaped curve way is also not the standard IEC testing method, but using the test method, it is easy to get the relation between the flashover voltage of the iced insulator string and the time when ice melting, furthermore the minimum flashover voltage when ice melting can be obtained in a short time.

From section 2.2, the minimum flashover voltage of the insulator using the "U"-shaped curve way (U_{fmin}) is different from the result using the up-down manner ($U_{50\%}$), and to get the relationship of them we choose the same method when comparing U_{ave} and $U_{50\%}$ shown in Table VII.

TABLE VII. THE CORRESPONDING RELATION OF TEST RESULT BETWEEN METHOD OF "U"-SHAPED CURVE WAY AND UP-DOWN MANNER

SDD	R(%)		γ_{20}	R(%)	
(mg/cm^2)	XZP	LXZY	(μS/cm)	XZP	LXZY
	-210	-210		-210	-210
0.03	3.2	4.5	200	3.7	2.7
0.05	1.6	3.6	360	5	11
0.08	3	4.4	630	3.9	3.5
0.12	3.5	4	1000	3	2.9
$R=\left(\left\|U_{f\min}-U_{50\%}\right\|\div U_{50\%}\right)\times 100\%$; $\overline{R}$ =4%					

From Table VII, it can be seen that, with the same condition U_{fmin} is 4% lower than $U_{50\%}$. We propose R=4%, and,

$$R=\frac{\left|U_{f\min}-U_{50\%}\right|}{U_{50\%}}\times 100\% \qquad (5)$$

$$U'_{50\%}=1.04U_{fmin} \qquad (6)$$

In conclusion, the equivalence of the experimental results between method of "U"-shaped curve way and up-down manner is that the minimum flashover voltage (U_{fmin}) multiplied by 1.04 is the $U_{50\%}$.

IV. CONCLUSION

The DC icing test method is studied in this paper, and it can be concluded as follow:

(1) The flashover voltage for the same salt deposit density (SDD) or ice water conductivity (γ_{20}) is different under three kinds of electrical tests, where $U_{ave} > U_{50\%} > U_{fmin}$. The DC icing flashover voltage has a power function relation with the SDD or γ_{20} under all the three kinds of the electrical tests.

(2) The equivalence of the experimental results among method of equably boosting voltage, "U"-shaped curve way and up-down manner is, the average flashover voltage U_{ave} multiplied by 0.95 equals in value of $U_{50\%}$, and the minimum flashover voltage U_{fmin} multiplied by 1.04 is the $U_{50\%}$.

REFERENCES

[3] Sun Caixin, Sima Wenxia, Shu Lichun. Atmospheric environment and electrcial outdoor insulation [M]. Beijing: China Electric Power Press, 2002 (in chinese).

[4] Yang Jianlan. Testing method on DC Artificially Iced disk-shaped and suspension Insulators [Master’s thesis]. Chongqing University, 2009 (in chinese).

[5] Jiang Xingliang, Yuan Jihe, etc. Insulators Icing and Electrical Tests Methods. High Voltage Engineering, 2005, 31 (5): 4-6 (in chinese).

[6] Jiang Xingliang, Wang Bo, etc. Influence of Units and Assemble on DC Flashover Voltage of Iced Insulator Strings at High Altitude Districts [J]. Journal of Chongqing University (Natural Science Edition). 2007,30 (7): 37-41 (in chinese).

[7] Jiang Xingliang, Shu Lichun. Chinese transmission lines’ icing characteristics and analysis of severe ice accidents [J]. International Journal of Offshore and Polar Engineering, 2004, 14 (3): 196-201.

[8] Farzaneh M, Zhang J, Behavior of DC arc on ice surfaces [C]. Proceedings of 8th IWAIS. 1998: 193-197.

[9] Farzaneh M, Drapeau J.F. AC flashover performance of insulators covered with artificial ice [J]. IEEE Transactions on Power Delivery, 1995, 10(2): 1038-1046.

[10] Xie Shujiao, Jiang Xingliang, etc. State-of-the-Art of DC Flashover Characteristics of Iced Insulators. High Voltage Engineering, 2004, 30 (1): 16-18 (in chinese).

[11] Li Peng, Fan Jianbin, etc. Icing Flashover Performance of HVDC Transmission lines. Power System Technology, 2006, 30 (19): 74-78 (in chinese).

[12] Farzaneh M, Volat C. Three-dimensional modeling of potential and electric field distributions along an EHV ceramic post insulator covered with ice [J]. IEEE Transactions on Power Delivery. 2005, 20 (3): 2006-2013.