VALIDATION OF THE EQUIVALENT EFFECT OF POLLUTION SIMULATION METHODS ON DC ICING FLASHOVER VOLTAGE OF INSULATORS

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***Abstract**:* The influence of two pollution methods, solid-layer method and icing-water-conductivity method, on the icing flashover voltage is equivalent. In this paper, the dc icing flashover performances of three different types of proclaim and composite insulators, respectively polluted by these two pollution method, are studied. The research results show that the equivalent relationship of the two different pollution methods is linear. So the experimental results can be compared by translation using the equivalent equation.

1. INTRODUCTION

The icing flashover character is one of the key factors in external insulation design in high altitude and heavy icing regions. Solid-layer method and icing-water-conductivity method are the two common pollution simulation methods for iced insulators in icing flashover test. For the aim of comparing test results from tests with different pollution methods, study on equivalent effect of pollution simulation methods on flashover voltage of insulators is of significant for engineering and academic.

2. RESULTS AND DISCUSSION

According to the principal of pollution equivalence, equivalent relationship of the two pollution simulation methods is drown as:

$$\begin{cases} \gamma_{20} = \left(\dfrac{Dh}{0.725W} SDD_g \times 10^4 + \gamma_s^{1.0301} \right)^{1/1.0301} \\ SDD_g = \dfrac{0.725W}{Dh} \left(\gamma_{20}^{1.030} - \gamma_s^{1.0301} \right) \times 10^{-4} \end{cases}$$

(1)

In the formula, γ_{20} is icing water conductivity conversed to the condition of 20℃. SDD_g and γ_s stand for the salt density and conductivity of icing water used in solid-layer method respectively.

Inserted with data of insulator structure and tests, formula (1) is transformed to:

$$U_{50}(f) = B\gamma_{20}^{-b} = \begin{cases} 597.58\,\gamma_{20}^{-0.259} & \text{(TYPE A)} \\ 573.15\gamma_{20}^{-0.2659} & \text{(TYPE B)} \\ 557.33\gamma_{20}^{-0.2716} & \text{(TYPE C)} \end{cases} \quad (2)$$

The equivalence of the two pollution methods act as a linear function as illustrated in Fig.1.

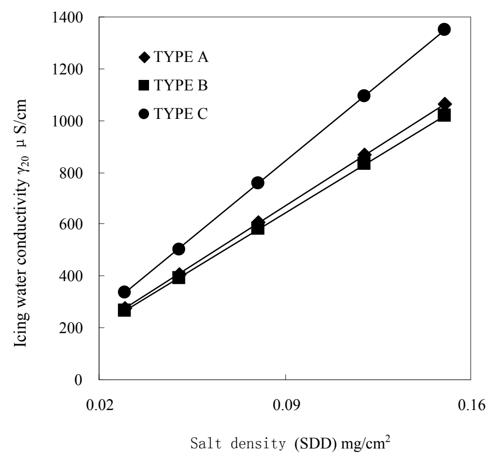

Figure 1. The relation curve between SDD_g and γ_{20}

SDD value in solid-layer method can be converted to a equivalent conductivity of icing water used in icing-water-conductivity method. Also equivalent flashover voltage of solid-layer method can be attained from the test result from icing-water-conductivity.

3. CONCLUSION

Equivalent relationship of the effects from SDD of solid-layer method and water conductivity of icing-water-conductivity method on DC icing flashover voltage is the same as that in AC flashover voltage, which is influenced by structure type and ice amount of iced insulators. This study carry out further verification on the equivalence between icing water conductivity and SDD. The equivalent relationship proposed in [1] is a wide adaptive formula, supplying a useful path to the comparison of test results using different pollution methods. Meanwhile, study on the equivalent effect of test methods on test results can supply valuable help for formulating icing test method standards.

4. REFERENCES

[1] JIANG Xing-liang, ZHANG, Zhi-jin, HU Jian-lin, YANG, Jian-lan. Equivalence of Pollution Simulation Methods for AC Flashover Performance of Iced Composite Insulator[J]. Proceedings of the CSEE, 2010, 30(13): 115-120.

Validation of the Equivalent Effect of Pollution Simulation Methods on DC Icing Flashover Voltage of Insulators

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Abstract—The icing flashover performance is a key factor in designing the external insulation of transmission lines passing through the high altitude and heavy icing regions. In icing experiments, there are two methods, solid-layer method and icing-water-conductivity method, to simulate the pollution of iced insulators. The icing flashover voltages of insulator polluted by these two methods are different, so it is difficult to compare the experimental results obtained by these two different pollution methods. But the influence of these two methods on the icing flashover voltage is equivalent. In this paper, the dc icing flashover performances of three different types of proclaim and composite insulators, respectively polluted by these two pollution method, are studied. According to the dc experiments with different pollution methods, the equivalent equation, proposed by our laboratory and based on AC icing flashover experiments, are checked. The research results show that the equivalent relationship of the two different pollution methods is linear. So the experimental results can be compared by translation using the equivalent equation.

Keywords- icing; flashover performance;insulator, pollution method,;equivalence; dc.

I. INTRODUCTION

China is one of the countries that face plenty of transmission line icing accidents. The icing of insulator and its flashover has been a critical problem for the safety and design of transmission lines [1-4]. The electric performance of iced insulators can be weakened seriously, even in operational voltage flashovers happening, which is related mainly to parameters such as ice type, ice weight, pollution and altitude [5-10].

The icing flashover character is one of the key factors in external insulation design in high altitude and heavy icing regions. In recent years large amount of investigation has been carried out on icing flashover of insulators [5-15]. While, no IEC criterion for icing test has been formulated thus different laboratories often use different test methods. Solid-layer method and icing-water-conductivity method are the two common pollution simulation methods for iced insulators. The former can simulates the stained condition before icing, while the latter can attain a less Dispersion of test results compared to solid-layer method[16,17]. In abroad icing-water-conductivity method is the often chosen for insulator icing[18,19], while in China solid-layer method is usually employed to simulates the contamination before ice deposited[20,21]. The results occupied from different test methods could hardly been put in comparison. Thus study on equivalent effect of pollution simulation methods on flashover voltage of insulators is of significant for engineering and academic.

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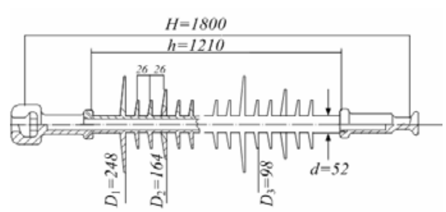
Paper[16] carried out artificial icing test for composite insulators of FXBW-10/70 and FXBW-35/70, which investigated the equivalent effect of pre-contamination methods on flashover voltage and demonstrated the equivalent relationship of the two pollution methods in theory.

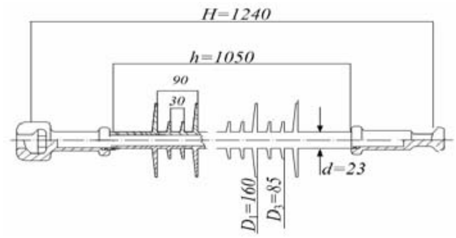
II. TEST SAMPLES AND METHODS

A. Test samples

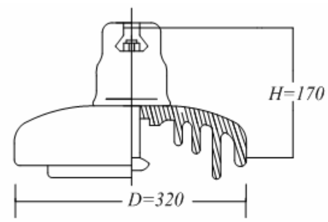
Test samples used in this paper are short-cut of FXBW-±800/530 ±800kV DC ultrahigh voltage composite insulator (Type A, with shed profile of "large- middle-small"), 110kV composite insulator of FXBW4-110/100 (Type B, with shed profile of "large-small") and ceramic insulator string of 7 XZP-210 (Type C). Structure and technical parameters are shown in Fig.1 and Tab.1 respectively, H refers to structural height, h arc distance, D insulator diameter, L leakage distance, d rod diameter of composite insulators.



(a) Type A: FXBW-±800/530



(b) Type B: FXBW$_4$-110/100



(c) Type C: XZP-210

Figure 1. Sketch maps of the test insulators

Table 1. Parameters of insulators

Insulator	Structure height *H*/mm	Dry arc distance *h*/mm	Leakage distance *L*/mm	Rod diameter *D*/mm
A	1800	1210	4260	248(D_1)/164(D_2)/98(D_3)
B	1240	1050	3350	160(D_1)/85(D_3)
C	170	/	540	320

B. *Test facilities*

Tests were carried out in large multifunctional artificial climate chamber with diameter of 7.8 m and height of 11.6 m, the lowest air pressure could be 30kPa and temperature could be decreased to -45°C, which satisfies the requirements of insulator icing test[18].

Test voltage was supplied by a current-voltage dual-feedback controlling ±600 kV/ 0.5 A DC power source, the dynamic voltage drop when leakage current being 0.5 A is less than 5 % and fluctuation coefficient is less than 3 % when flashover occurs[22].

(a) artificial climate chamber   (b) DC power source

Figure 2. Testing equipment

C. *Test Methods*

(1)Pollution method: both solid-layer method and icing-water-conductivity method were used.

Solid-layer method is carried out by quantitative brushing, and the value of SDD in test is: 0.03, 0.05, 0.08, 0.12 mg/cm2 and 0.15 mg/cm2.The ratio of SDD and NSDD is 1:6.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[11,16]. Pollution is finished within one hour after pretreatment of test samples.

As is to icing-water-conductivity method, test samples were cleaned first by tap water than by deionized water with conductivity less than 10 μS/cm, after which test samples were dried suspended in artificial climate chamber before icing. The icing-water-conductivity（γ_{20}） adopted were: 80, 200,360,630 and 1000μ S/cm.

(2)A thin ice layer would be formed manually by spraying droplets on the samples polluted by solid-layer method before automatic spraying, so that the loss of pollution could be avoided[11,16].

The flashover voltage of iced insulators is related to ice amount besides pollution. To assure the ice amount in tests of the two pollution methods being the same, icing parameters were controlled strictly within each test as shown in Tab.2. In test procedure a rotating copper cylinder of 25mm in diameter was employed to monitor the icing state.

After iced under the icing condition listed in Tab.2, the insulators were totally bridged by glaze, as shown in Fig.2. Ice amount on samples of each icing test were shown in Tab.3.

Table 2. Icing Parameters

Droplet diameter μm	Spray velocity (mm/h)	Temperature °C	Wind speed (m/s)	Icing time /h
40~120	10	-5~-7	5	8.0

(a) Type A   (b) Type B   (c) Type C

Figure 3. the icing state of insulators

Table 3. Ice amount Covered on The Test Insulators

Insulator	Ice amount *W* g/string	Ice thickness upper surface / lower surface (mm)
A	3500±200	8.0/1.5
B	2300±160	8.0/1.5
C	5000±300	5.0/1.5

III. TEST RESULTS AND ANALYSIS

The 50% flashover voltage and standard deviation of different types of insulator under different contaminate methods are listed in Tab.4 and Tab.5.

Tab.4 50% Flashover Voltage of Iced Insulators with Solid-Layer Method

		Slat density(SDD) mg/cm^2				
		0.03	0.05	0.08	0.12	0.15
A	U_{50}/kV	143.2	126.7	113.9	103.7	97.9
	σ%	4.4	5.8	6.4	7.4	8.1
B	U_{50}/kV	130.9	115.4	107.4	93.4	88.9
	σ%	3.9	5.6	6.5	7.3	7.6
C	U_{50}/kV	105.7	102.2	93.8	85.8	/
	σ%	6.6	7.2	6.8	7.1	/

Tab.5 50% Flashover Voltage of Iced Insulators with Icing- Water-Conductivity Method

		Icing water conductivity γ_{20} μS/cm				
		80	200	360	630	1000
A	U_{50}/kV	187.3	157.0	130.7	113.0	98.0
	σ%	4.9	5.9	5.4	4.3	2.1
B	U_{50}/kV	172.3	146.2	121.8	104.9	87.9
	σ%	3.3%	4.5	5.7	4.2	3.8
C	U_{50}/kV	/	130.2	113.1	101.2	82.6
	σ%	/	3.1	3.7	4.0	3.5

Based on Tab.4 and Tab.5 the relationship between icing flashover voltage and SDD or icing water conductivity are shown in Fig.4 and Fig.5, which is in formula of power function. Fitting the data of icing flashover voltage and SDD or icing water conductivity according to Fig.4 and Fig.5, empirical formulas are obtained as follows:

$$U_{50}(s) = A(SDD)^{-a} = \begin{cases} 62.92\,(SDD_g)^{-0.2344} & \text{(TYPE A)} \\ 56.89\,(SDD_g)^{-0.2390} & \text{(TYPE B)} \\ 63.21\,(SDD_g)^{-0.152} & \text{(TYPE C)} \end{cases} \quad (1)$$

In this formula, A is a constant affected by insulator type, material and ice amount; a is the character stand for the influence from SDD on 50% icing flashover voltage.

$$U_{50}(f) = B\gamma_{20}^{-b} = \begin{cases} 597.58\,\gamma_{20}^{-0.259} & \text{(TYPE A)} \\ 573.15\gamma_{20}^{-0.2659} & \text{(TYPE B)} \\ 557.33\gamma_{20}^{-0.2716} & \text{(TYPE C)} \end{cases} \quad (2)$$

B is a constant related to insulator structure and material; b represents the influence from γ_{20} on U_{50}.

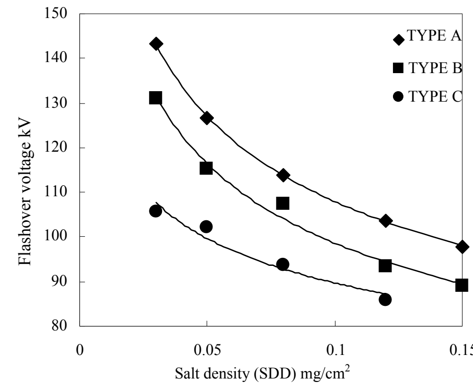


Fig.4 U_{50} versus SDD in Solid-layer method

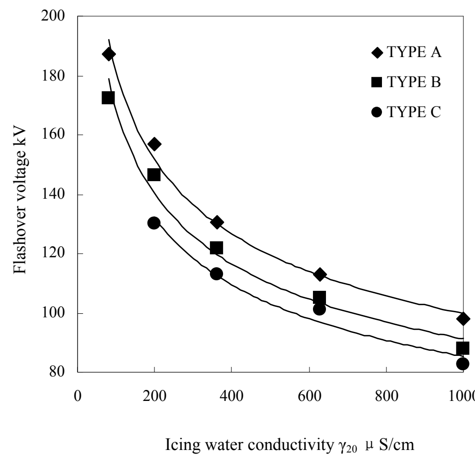


Fig.5 U_{50} versus γ_{20} in icing-water-conductivity method

IV. VALIDATION OF EQUIVALENT RELATIONSHIP

Literature[16] attains the equivalent relationship of the two pollution simulation methods according to the principal of pollution equivalence.

$$\begin{cases} \gamma_{20} = \left(\dfrac{Dh}{0.725W} SDD_g \times 10^4 + \gamma_s^{1.0301}\right)^{1/1.0301} \\ SDD_g = \dfrac{0.725W}{Dh}\left(\gamma_{20}^{1.030} - \gamma_s^{1.0301}\right) \times 10^{-4} \end{cases} \quad (3)$$

In the formula, γ_{20} is icing water conductivity conversed to the condition of 20℃. SDDg and γ_s stand for the salt density and conductivity of icing water used in solid-layer method respectively.

In the article[16] AC icing flashover voltage of composite insulators of FXBW-10/70 and FXBW-35/70 were obtained for the validation of formula (3), showing that error between calculated voltage from formula (3) and test results were less than 7%. This study takes a further verification of formula (3) with DC icing flashover test results of 3 kinds of insulators. Inserted with data in Tab.1 and Tab.3, formula (3) is transformed to:

$$\gamma_{20}=\begin{cases}6573.0SDD_g+80 \ \text{TYPE A}\\ 6261.3SDD_g+80 \ \text{TYPE B}\\ 8468.0SDD_g+80 \ \text{TYPE C}\end{cases} \quad (4)$$

In this formula 80 is the icing water conductivity when using solid-layer method (γ_s). Based on formula (4) the equivalence of the two pollution methods act as a linear function as illustrated in Fig.6.

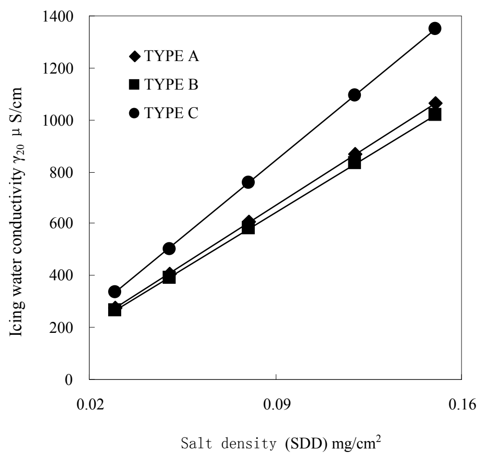


Fig.6 The relation curve between SDD_g and γ_{20}

According to formula (4), SDD value in solid-layer method can be converted to a equivalent conductivity of icing water used in icing-water-conductivity method, which inserted to formula (2) can give out the equivalent flashover voltage of icing-water-conductivity method converted from solid-layer method. Also equivalent flashover voltage of solid-layer method can be attained from the test result from icing-water-conductivity. Comparison of equivalent flashover voltage and test results is shown in Tab.6 and Tab.7.

It is indicated by Tables that the largest error between test results and icing flashover voltage from equivalent conversion is 8.8%, thus the equivalent relationship represented by formula (4) reveals the equivalence of the two test methods well.

Tab.6 Validating test results for solid layer method translating to the equivalent icing-water-conductivity method

Insulator	SDD_g	$U_{50}(s)$	γ_{20}(c)	$U_{50}(fc)$	Δ%
Type A	0.03	143.2	277.19	139.2	-2.79%
	0.05	126.7	408.65	125.9	-0.63%
	0.08	113.9	605.84	113.7	-0.18%
	0.12	103.7	868.76	103.6	-0.10%
	0.15	97.9	1065.95	98.2	0.31%
Type B	0.03	130.9	267.84	129.6	-0.99%
	0.05	115.4	393.07	117.1	1.47%
	0.08	107.4	580.90	105.5	-1.77%
	0.12	93.4	831.36	95.9	2.68%
	0.15	88.9	1019.20	90.9	2.25%
Type C	0.03	105.7	334.04	115.0	8.80%
	0.05	102.2	503.40	102.9	0.68%
	0.08	93.8	757.44	92.1	-1.81%
	0.12	85.8	1096.16	83.3	-2.91%

note: Δ%=100%*[$U_{50\%}(c)-U_{50\%}(s)$]/$U_{50\%}(s)$; $U_{50\%}(s)$—results from insulators polluted with solid-layer method and iced by water of 80μS/cm converted to condition of 20℃; γ_{20}(c)—icing water conductivity(μS/cm) calculated by formula (4) equivalent to test salt density; $U_{50\%}(fc)$—the 50% flashover voltage(kV) attained by formula (2) with γ_{20}(c); SDD_g—the salt density(mg/cm^2) in tests employing solid-layer method

Tab.7 Validating test results for icing-water-conductivity method translating to the equivalent solid layer method

Insulator	γ_{20}	$U_{50\%}(f)$	$SDD_g(c)$	$U_{50\%}(sc)$	Δ%
Type A	80	187.3	0	/	/
	200	157	0.0183	160.7	2.37%
	340	130.7	0.0396	134.1	2.62%
	640	113	0.0852	112.1	-0.82%
	1000	98	0.14	99.8	1.79%
Type B	80	172.3	0	/	
	200	146.2	0.0192	146.3	0.09%
	340	121.8	0.0415	121.7	-0.07%
	640	104.9	0.0894	101.3	-3.42%
	1000	87.9	0.1469	90.0	2.36%
Type C	200	130.2	0.0142	120.7	-7.31%
	340	113.1	0.0307	107.3	-5.10%
	640	101.2	0.0661	95.5	-5.61%
	1000	82.6	0.1086	88.6	7.24%

note: Δ%=100%*[$U_{50\%}(c)-U_{50\%}(s)$]/$U_{50\%}(s)$; $U_{50\%}(f)$—test results from insulators polluted by icing-water-conductivity method; $SDD_g(c)$ — salt density(mg/cm^2) calculated by formula (4) equivalent to icing water conductivity set in tests; $U_{50\%}(sc)$—the 50% flashover voltage/kV calculated by formula (1) with $SDD_g(c)$; γ_{20}—conductivity of the water(μS/cm) used in tests employing icing-water-conductivity method

V. CONCLUSION

Equivalent relationship of the effects from SDD of solid-layer method and water conductivity of icing-water-conductivity method on DC icing flashover voltage is the same as that in AC flashover voltage, which is influenced by structure type and ice amount of iced insulators. This study carry out further verification on the equivalence between icing water conductivity and SDD. The equivalent relationship proposed in [16] is a wide adaptive formula, supplying a useful path to the comparison of test results using different pollution methods. Meanwhile, study on the equivalent effect of test methods on test results can supply valuable help for formulating icing test method standards.

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