EXTERNAL INSULATION CHARACTERISTIC OF LONG ROD PORCELAIN INSULATOR IN HVDC TRANSMISSION LINE

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Abstract: Comparing to cap and pin insulator, long rod porcelain insulator has some advantages, such as no breakdown possibility, good self-cleaning and corrosion resistance, to be used in HVDC transmission lines. This paper describes the external insulation characteristic of long rod porcelain insulator in HVDC transmission line. The DC artificial contamination tests were carried out in high altitude area to study influences of shed profile, insulator arrangement and un-uniform pollution on pollution flashover voltage. The impulse discharge tests were carried out to analyze the relationship between impulse discharge voltage and dry arcing distance of test insulators string, and the effect of parallel double insulator string on voltage. These results provide references to external insulation design and operation in extra and ultra high voltage direct current transmission line.

Key words: long rod porcelain insulator, external insulation characteristic, pollution flashover voltage, impulse discharge voltage, HVDC transmission line

1 INTRODUCTION

External insulation design is one of the critical issues of overhead transmission lines, and it mainly depends on the external insulation characteristics and contamination performance of insulators [1].

Much research of disc-type porcelain insulators, glass insulators and composite insulators have already been done, arriving at a range of experimental data and insulators selection experiences [1].

Long rod porcelain insulator with the similar shape as composite insulator, has advantages of non-breakdown, good self-cleaning, low breakage, etc. [2], mainly used in Germany, Austria, Switzerland and other European countries [3], Japan [4], and Eastern, Central, North and other regions in China [2]. At present, the related studies on external insulation characteristics of long rod porcelain insulator are not sufficient, and concentrate in artificial pollution flashover characteristics of not large tonnage specimens [5, 6].

In the Ultra high voltage direct current (HVDC) (minimum voltage is ± 800 kV) transmission lines, 300 kN and above large tonnage insulators need to be widely used. Long rod porcelain insulator is one of the choices of those projects, and it is urgent to carry out the systematic research on external insulation characteristics of large tonnage specimens.

In this paper, the external insulation characteristics of long rod porcelain insulator were studied in natural high altitude areas. DC artificial contamination tests were carried out to study influences of shed profile, insulator arrangement and un-uniform pollution on pollution flashover voltage. The switching and lighting impulse discharge tests were carried out to analyze the relationship between impulse discharge voltage and dry arcing distance of test insulators string, and the effect of parallel double insulator string on voltage.

2 DC ARTIFICIAL POLLUTION FLASHOVER CHARACTERISTIC

2.1 Test condition and test methods

DC artificial pollution tests of long rod porcelain insulator were carried out in the ultra high voltage test station of Yunnan Electric Power Grid Co., Ltd (1970 m above sea level).

The test circuit was shown in Figure 1. DC generator provided ± 250 kV. A short circuit current higher than 10 A was provided while flashover occurred. In tests, the voltage polarity was negative for lower flashover voltage than that of positive polarity test voltage. The dimension of fog chamber was 10m * 10m * 10m. The steam fog was sprayed into the fog chamber within the range (50 ± 10) kg/h, and forty nozzles with a diameter of 12 mm were used and fixed on the ground in the fog chamber.

The artificial pollution test used the solid layer method, which was performed in accordance with IEC 61245-1993 [7]. The contaminants deposited on surfaces of specimen insulators were simulated by NaCl and Kaolin powder. The amount of NaCl and Kaolin was adjusted to obtain the specified salt deposit density (SDD) and nonsoluble deposit density (NSDD), and the ratio between NSDD and SDD was 6:1 for all the tests. The test procedure was shown in Figure 2. The 50% DC pollution flashover voltage ($U_{50\%}$) of the specimen was acquired by the up and down method and the voltage step was 5% of the expected $U_{50\%}$. The $U_{50\%}$ was calculated using the following formula

$$U_{50\%} = \Sigma(U_i * n_i)/N \qquad (1)$$

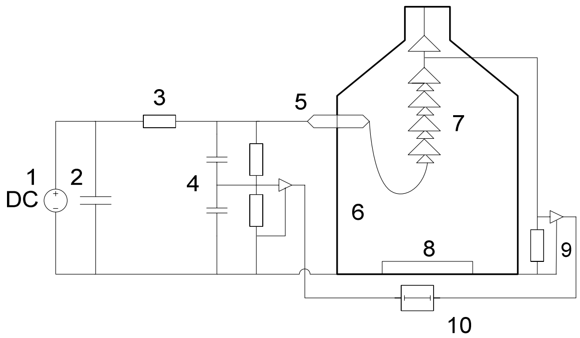
Where

U_i is an applied voltage level;

n_i is the number of tests at the same U_i;

N is the number of useful tests. N is no less than 10.

In tests, the development process of electric arc and flashover process on insulator surface was studied by high speed photography, while the leakage current was recorded in PC.



1- DC voltage generator, 2 - Power capacitor, 3 – Protection resistance, 4 - Voltage divider, 5 - Wall bushing, 6 - Fog chamber, 7 - Specimen, 8 - Nozzles, 9 - Measurement resistance for leakage current, 10 - Waveform recorder

Figure 1 DC artificial contamination test circuit

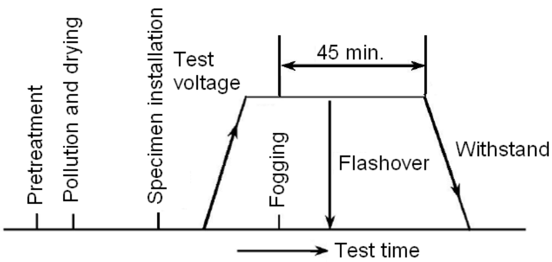


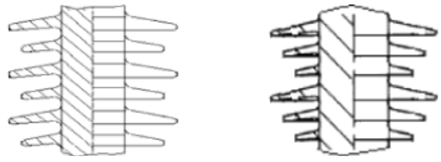
Figure 2 Test procedure

2.2 Specimen

Specimens included three long rod porcelain insulators, and Table 1 listed the parameters of specimens and Figure 3 showd the profile. The core diameter of all three specimens was 115 mm, in which the mechanical failing load is 400 kN.

Table 1 Parameters of specimens

Type	Leakage distance /mm	Insulation distance /mm	Diameter of shed /mm	Space between sheds/mm	Creepage factor
A	5833	1450	255/225	68/34	4.02
B	5400	1450	265/235	76/34	3.73
C	5643	1470	275/235/195	106/65/34	3.84



(a) A and B (b) C

Figure 3 Profiles of specimens

2.3 Test Results and Analysis

2.3.1 Flashover characteristic

The comparison of the $U_{50\%}$ for insulators is shown in Figure 4. These results in Figure 4 indicate the following,

1) The pollution flashover voltage of three long rod porcelain insulators gradually decreased with SDD, and the relationship between the flashover voltage and the SDD could be expressed by following equation:

$$E_H = a(\mathrm{SDD})^n \qquad (2)$$

Where, E_H is the $U_{50\%}$ per unit insulation distance; a is constant and n is pollution characteristic index which shows the decreasing trend of the flashover voltage with the increase of the SDD.

2) The E_H of for type A was higher than that for both type B and C when the SDD was no more than 0.1 mg/cm^2, and the difference on E_H of three types of insulators decreased gradually after 0.1 mg/cm^2. The reason for that was the leakage distance of type A was longer than that of others.

Therefore, the pollution flashover characteristic for type A insulator was better than those for both type B and type C insulators. And type A was chose for subsequent tests items.

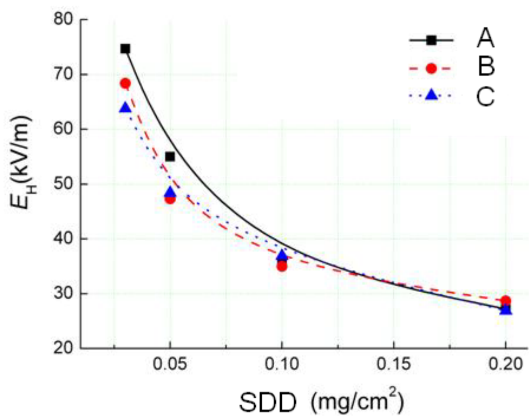


Figure 3 DC artificial pollution flashover voltage characteristic curve of long rod insulator

2.3.2 Effect of parallel clearance distance

Multi-string insulators were arranged in parallel to improve the reliability of operation in current HVDC transmission line. In the Π string insulator test, the parallel clearance distance (the centre distance of insulator strings) at 50cm and 70cm was chose in the same condition with an SDD of 0.5 mg/cm^2 and an NSDD of 0.3 mg/cm^2 in this paper.

The test result was shown in Table 2. Compared to the pollution flashover voltage of I string insulator, it decreased by about 9% of the pollution flashover voltage of the Π string insulators. This was because the distortion of insulator surface electric field and more local arc and flashover paths were provided in the Π string insulators.

Table 2 DC artificial pollution flashover voltage of parallel arrangement insulator

Parallel clearance distance (cm)	I string	50	70
E_H(kV/m)	55.0	49.9	50.5

In addition, it was not observed that the flashover arc bridged between two insulator strings. And the difference on pollution flashover voltage between distance of 50 cm and 70 cm could be ignored.

2.3.3 Effect of tension string insulator arrangement

The comparison of the $U_{50\%}$ for tension string insulator and I string insulator is shown in Figure 4. These results indicate the following,

1) The pollution flashover voltage of tension string insulator was higher than that of I string insulator.

2) The difference on E_H of both tension string insulator and I string insulator gradually increased with SDD at the range of 0.03 mg/cm^2 to 0.1 mg/cm^2.

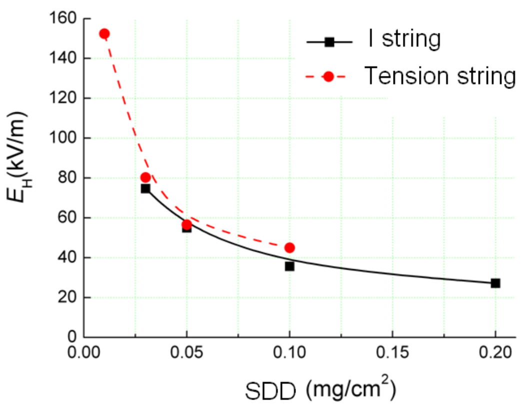


Figure 4 DC artificial pollution flashover voltage characteristic curve of tension string insulator

2.3.4 Effect of un-uniform pollution

As mentioned in field experience, the contamination accumulated on the top surface of insulator is less than that on the bottom surface due to the nature cleaning effect. In DC artificial pollution tests, the top / bottom surface contamination uniformity ratio is listed in Table 3.

Table 3 Top / bottom contamination uniformity ratio of DC line insulator

Salt deposit density (mg/cm^2)	0.03	0.05	0.08	0.10
Ratio	1/3	1/5	1/8	1/10

Figure 5 shows the DC artificial pollution flashover voltage characteristic of un-uniform pollution insulator. The pollution flashover voltage of un-uniform pollution insulator was higher than that of uniform pollution insulator, and the difference on E_H gradually increased with SDD.

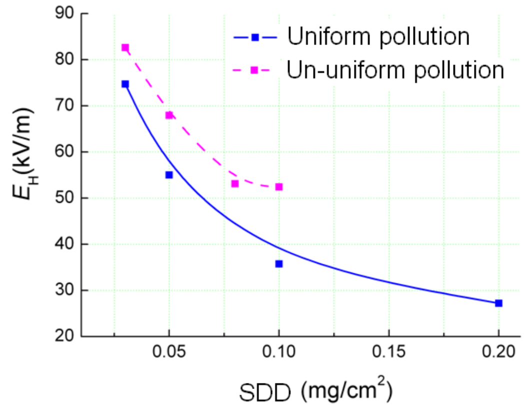


Figure 5 DC artificial pollution flashover voltage characteristic curve of un-uniform pollution insulator

The relationship between the difference on E_H and the contamination uniformity ratio of the top / bottom surface could be expressed by following equation:

$$K_2 = 1 - M\lg(T/B) \qquad (2)$$

Where, k_2 is the ratio of E_H of un-uniform pollution insulator to that of uniform pollution insulator; M is a constant and T/B is contamination uniformity ratio.

According to test results, M was calculated in this paper, as shown in Table 4.

Table 4 Parameter value of *M*

Salt deposit density (mg/cm2)	0.03	0.05	0.08	0.10
T/B	1/3	1/5	1/8	1/10
M	0.24	0.30	0.34	0.35

3 IMPULSE VOLTAGE DISCHARGE CHARACTERISTICS

3.1 Test condition and test methods

The impulse voltage tests of long rod porcelain insulator were carried out in extra High Voltage test station of China Southern Power Grid Co., Ltd (2100 m above sea level).

Impulse voltage generator was rated at 7200 kV / 720 kJ. Type A insulator was chose as the specimen in all of the tests, the test arrangement was as shown in Figure 6.

Figure 6 Impulse voltage discharge experiment arrangement

In this paper, one valid U_{50} (50% discharge voltage) is obtained with at least 30 and 20 valid shots for switching impulse and lighting impulse voltage discharge respectively, by applying the up and down methods. The “g” parameter method recommended by IEC Publication 60.1 (1989) was used to correct test results for the standard atmosphere condition. The polarity of test voltage for both switching impulse (SI) and lighting impulse (LI) were positive.

3.2 SI Voltage Discharge Characteristics

The waveform of SI voltage discharge test was 250/2500 μs, and the environment of tested insulator was at the dry state. The SI 50% discharge voltage curve of long rod porcelain insulator is shown in Figure 7. It was shown that, the SI U_{50} increased more and more slowly with the increase of length of insulator string, which indicated there was a non-linear relationship between SI discharge voltage and dry arcing distance of test insulators string.

Figure 7 also showd that the difference on U_{50} of insulator string with and without setup of arcing ring and grading ring could be ignored. The main reason was that uniformity of electric field on the surface of insulator was improved to offset the reduction of dry arc distance.

3.3 LI Voltage Discharge Characteristics

The waveform of LI voltage discharge test was 1.2/50 μs. The LI 50% discharge voltage curve of long rod porcelain insulator is shown in Figure 8. It was shown that, the LI U_{50} increased linearly with the increase of length of insulator string, which indicated there was a linear relationship between LI discharge voltage and dry arcing distance of test insulators string.

LI discharge voltage was mainly affected by the dry arc distance. In Figure8, LI discharge voltage of 4 units insulators (dry arcing distance is 5800 mm) decreased by about 12% because of the setup of arcing ring and grading ring which resulted in the reduction of dry arc distance.

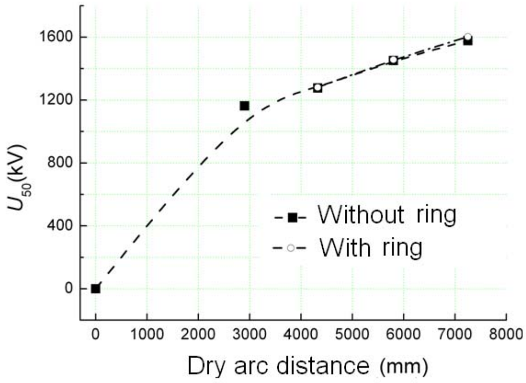


Figure 7 SI 50% discharge voltage curve of long rod insulator

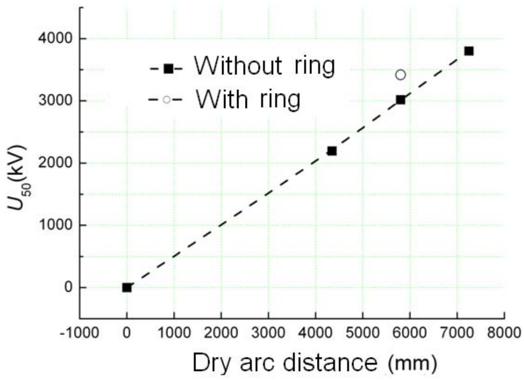


Figure 8 LI 50% discharge voltage curve of long rod insulator

3.4 Effect of parallel clearance distance on Impulse Discharge Voltage

In the impulse voltage test of Π string insulators, the parallel clearance distance (the centre distance of insulator strings) at 50cm and 60cm was chose at the same length of 4 units insulators with setup of arcing ring and grading ring.

Table 5 lists the test results. It was shown that the SI U_{50} of Π string insulators was almost equal to that of I string insulators, and it was same for LI U_{50} of Π string insulators. Therefore, there was no difference on both SI and LI discharge voltage between single and parallel double insulator string at a 50 or 60cm distance.

Table 5 Parallel arrangement affection to the impulse discharge voltage of long rod insulator

Parallel spacing/cm	I string	50	60
SI U_{50}	1457	1441	1429
LI U_{50}	3018	3003	3096

4 CONCLUSIONS

From the test results of long rod porcelain insulator in natural high altitude areas, the following conclusions can be drawn.

1) The DC pollution flashover characteristic for type A insulator was better than those for both type B and type C.

2) For Π string insulator, the pollution flashover voltage at the range of 50 to 70cm on parallel clearance distance was decreased by about 9% compared to I string insulator. The pollution flashover characteristic of tension string insulator was better than that of I string insulator.

3) Under un-uniform pollution, the pollution flashover characteristic of insulator was much better than that of uniform pollution insulator, and the constant M was proposed.

4) The relationship between switching impulse discharge voltage and total dry arc distance was nonlinear;

5) Setup of arcing ring and grading ring had little effect on switching impulse discharge voltage, but a significant effect on lightning impulse;

6) There was no difference on impulse discharge voltage between single string and parallel double string at a 50 or 60cm string distance.

Those results in this paper can be used as references to external insulation design of extra high voltage direct current transmission line.

REFERENCES

[1] Z. Y. Su, X. D. Liang, Y. Yin et al. Outdoor Insulation Selection Method of HVDC Lines. Proceedings of the 14th International Symposium on High Voltage Engineering, Beijing, China, 2005, D-25:1-4.

[2] G. Y. Wu, W. Cai, R. Zhang, et al. Analysis of the Characteristics for Porcelain Long Rod Insulators in Transmission Lines [J]. High Voltage Engineering, Vol. 27, No. 2, pp. 36-38, 2001(in Chinese).

[3] K.L. Chrzan, J. Vokalek, V. Sklenicka, et al. Pollution Flashover of Long Rod Insulators with Different Profiles. Proceedings of the 8th International Symposium on High Voltage Engineering, Netherlands, 2003: 1-4.

[4] T. Fujimura. The Evolution of Porcelain Insulator Technology in Japan [J]. IEEE Electrical Insulation Magazine, Vol. 11, No. 3, pp. 26-36, 1995.

[5] K. Yamada, A. Hayashi, C. Saka. Improvement of Contamination Flashover Voltage Performance of Cylindrical Porcelain Insulators. ISEI 2008 : 69-72.

[6] J. M. Seifert, W. Petrusch and H. Janssen. A Comparison of the Pollution Performance of Long Rod and Disc Type HVDC Insulators [J]. IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 14, No. 1, pp. 125-129, 2007.

[7] IEC. IEC 61245—1993 Artificial Pollution Tests on High-voltage Insulators to Be Used on DC System[S]. Geneva：IEC，1993.