A Comparative Study on Contamination Deposited Characteristics of ±800kV DC Line Insulators

Fangcheng Lv[1], Chunxu Qin[1], Yunpeng Liu[1], Wenyi Guo[2], Ruihai Li[2]

[1] **Hebei Provincial Key Laboratory of Power Transmission Equipment Security Defense, North China Electric Power University
Baoding, 071003, China**

[2] **Electric Power Research Institute, China Southern Power Grid Corporation Limited
Guangzhou, 510000, China**

Abstract

This report describes the natural contamination test results of ±800kV line insulators at high altitudes. Natural exposure tests with -816kV DC voltage energization were carried out at National Engineering Laboratory for UHV Engineering Technology (Kunming).The results showed that the strain type and V-type insulator strings show a lighter pollution and the insulators with a better aerodynamic shed shape show a better contamination deposited characteristic. Also the ratios of contamination on top surface to that on bottom surface in terms of the equivalent salt deposit density (ESDD) and the nonsoluble deposit density (NSDD) were influenced by the insulator shed shapes and the string types. The ESDD and the NSDD along the insulator strings presented decreasing trend from the earth side to the line side.

Keywords: *±800kV, Comparison, ESDD, NSDD.*

1. Introduction

Due to the economy development, energy demand and resource distribution in China, the ultra-high-voltage direct current (UHVDC) transmission lines have been built since 2006. The ±800kV Yunnan-Guangdong Line built by the China Southern Power Grid Corporation (CSG), has been in bipolar operation since June 2010. Several UHVDC transmission lines will be constructed in China during the Twelfth Five-Year Plan Period (2011-2015). Most of these lines will cross over high altitude regions, for example, the partial Nuozhadu-Guangdong ±800kV UHVDC transmission line will be situated in areas over 2000 meters above sea level[1-4].

A series of studies about the natural contamination deposited characteristics of the HVDC insulators have been studied in the USA, Japan, Sweden, France, and China since 1980s [5-13]. Several investigations have indicated that more contamination accumulated on DC insulators is more than on AC insulators. The amount of contamination collected is not uniformly distributed along a string. Insulators near the line and earth sides of a string accumulate more contaminant than those of middle part when DC voltage is applied. However, some measured the highest (ESDD) values measured in some researches occurred at the earth sides while the highest ESDD values measured in others occurred at the line sides. The investigations have showed that Estimations of contamination severity for inland areas should be made using data obtained from insulators with exposure periods of at least one year. And some investigations about the contamination deposited characteristics of ± 500kV transmission line have been reported in China [14-16].

However, in these researches, the range of the tested voltage levels was from 20kV to ±600kV, such as ±250kV, ±400kV and ±500kV, the voltage level is much lower than ± 800kV. The tested sites usually located in low altitudes, and also the insulators of ± 800kV are different from before. To ensure the safe and reliable operation of UHVDC transmission lines, the insulators with mechanical failing load of no less than 300kN are proposed to satisfy the electrical requirements [17-21]. However, there is no study on the DC natural contamination deposited characteristics of all the kinds of insulators with the minimum mechanical failing load of 300kN.

So, in order to provide important reference to the outdoor insulation design of the UHVDC transmission line at high altitudes, in this paper, the natural contamination deposited characteristics of all the kinds of ±800kV full scale insulators under -816kV energized for one year exposure are investigated and compared in high altitude areas.

2. Test Site and Specimen Insulators

2.1 Test Site

Exposure test was conducted at the National Engineering Laboratory for UHV Engineering Technology (Kunming), which is located in the Songming Town, Kunming City, Yunnan Province of China, where at an altitude of 2100 meters. The insulators were energized with -816kV DC voltages, the highest operating voltage of the Yunnan-Guangdong ±800 kV DC transmission project in China. The power supply for the test came from the ±1200kV/500mA bipolar DC voltage generator with ripple factor less than 3%, in the National Engineering Laboratory.

2.2 Specimen Insulators

The specimen insulators consisted of nine insulator strings, which include seven shed shapes (type A~G) insulators as shown in Fig. 1 and Fig. 2. And the more detail of the insulators are listed in Table1.

Fig. 1 The tested insulators

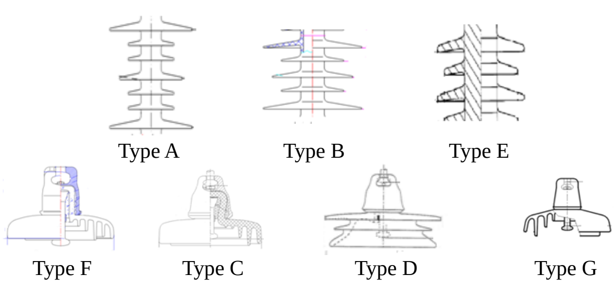

Fig. 2 Shed shapes of specimen insulators. The type A, B, E is long rod insulators. The type C, F, G is DC fog disc insulators. The type D is 3 outer-rib type insulators.

3. Exposure Test Periods and Contamination Test

3.1 Test Period

Located at an area of 2,100 meters above sea level on the Yungui Plateau with low latitude and high elevation, Somgming has one of the mildest climates in China, characterized by short, cool and dry winters with mild days and crisp nights, and long, warm and humid summers, but much cooler than the lowlands. The period from May to October is the rainy season and the rest of the year is dry. The rainfall in the rainy season is about 85% of annual precipitation. The exposure test period extended for one year from April 2011 to April 2012. So there were twice contamination measurement tests for the insulators in this study. The first test was in October 2011 before the dry season, and the second test was in the beginning of April 2012 before the rainy season.

3.2 Contamination Test

The test of contamination was referred to DL/T374-2010, GB/T16434-1996, Q/GDW152-2006 and other papers [22-27]. Test unit was defined as follows: one piece of insulator disc as one test unit for the type C, D, F and G insulators, and one group of sheds as one test unit for the type A, B and E insulators. In this study, the contamination on the top surface and the bottom surface of the insulator disc was tested respectively for the type C E F and G insulators, and the contamination on the top, the middle and the bottom surface of the insulator disc was tested separately for the type D insulator. There was not separately test on the top and bottom surfaces of the sheds for the type A and B insulators, however, a supplementary test was carried out for getting the contamination difference on the top and bottom surfaces of the sheds of the type A and B insulators. In order to get the contamination distribution along the insulator, three test units including one near the line side, the other in the middle and another near the earth side, were selected in every tested insulator string.

Table 1.Dimensions of insulators

Insulator String No.	*Materials*	*Shape*	*Shed Diameter (mm)*	*String Length (mm)*	*String Type*	*Insulator Type*	*MFL (kN)*
#1	SIR	A	218/166/121	8160	I	FXBZ-800/400	400
#2	SIR	A	218/166/121	12000	V	FXBZ-800/400	400
#3	SIR	B	218/178/138	8160	I	FXBWZ-800/400	400

#4	SIR	B	218/178/138	12000	V	FXBWZ-800/400	400
#5	porcelain	C	400	58×205	I	XZP-400	400
#6	porcelain	D	400	53×240	I	CA-779EX	550
#7	porcelain	E	265/235	8×1790	I	LG115/21+20/1790	400
#8	glass	F	390	52×240	I	LXZY3-550	550
#9	glass	G	380	47×195	strain	FC300P/195DC	300

Note:*MFL stands for mechanical failing load MFL

Table 2. Ratios of contamination on bottom surface to that on top surface in terms of the ESDD and the NSDD and the ratio of the NSDD to the ESDD after one year exposure period.

No.	***Shed shape***	***String type***	R_{ESDD}		R_{NSDD}		***NSDD/ESDD***	
			1^{st}	2^{nd}	1^{st}	2^{nd}	1^{st}	2^{nd}
#1	A	I	/	2.56:1	/	1.57:1	5.1:1	5.16:1
#2	A	V	/	1.27:1	/	1.1:1	5.15:1	5.96:1
#3	B	I	/	2.0:1	/	1.41:1	5.1:1	4.0:1
#4	B	V	/	0.92:1	/	1.0:1	6.6:1	5.71:1
#5	C	I	9.7:1	3.8:1	32:1	8.0:1	3.4:1	6.5:1
#6	D	I	11:1	2.7:1	37:1	1.8:1	3.2:1	4.17:1
#7	E	I	2.5:1	1.0:1	5.3:1	1.2:1	0.7:1	3.66:1
#8	F	I	16:1	5.8: 1	19:1	3.8:1	3.2:1	3.77:1
#9	G	strain	7.5:1	3.3:1	22:1	2.6:1	3.1:1	4.69:1

4. Results and Analysis

The typical contamination of the tested insulator strings is shown in Fig. 3. The measurement results of the ESDD and NSDD of the measured insulator strings exposed for one year under an energized condition are shown in Figures 4 and 5.From Figure 4, the values of the ESDD are more than 0.04 mg/cm2 except the strain insulator after one year exposure. The distribution of the contamination is uneven along the insulator from the Figure 3and Figure 5.

4.1 SIR Composite Insulators

Figure 4 shows the twice tests results of the ESDD and the NSDD of the composite insulators. From this figure the influence of the shed shape and the insulator string type on the contamination deposited is summarized as follows:
(1)After one year exposure, the ESDD of the I-type insulator strings (#1and #3) is about 25% more than that of the V-type (#2 and #4) ones. The NSDD of the #1 I-type insulator string is only a little more than that of the #2 V-type one, and the NSDD of the #3 I-type insulator string is less than that of the #4 V-type one. As for the ESDD and the NSDD of the first test, the ESDD and the NSDD of the I- type insulator strings are more than that of the V-type. It can be concluded that the I-type composite insulator shows a heavier contamination than the V-type one in this study.
(2)The 2nd test ESDD of the type A sheds insulator strings(#1and #2) is a little more than that of the type B sheds strings(#3and #4). And the ESDD growth of the #2 insulator string is more than that of the #4 one. The NSDD of the type A sheds insulator strings is obvious more than that of type B. And the NSDD growth of the type A sheds insulator strings is more than that of type B. The sheds spacing of the type A insulator is 26 mm, while that of type B insulator is 35 mm and the type B insulator shows a better aerodynamic type configuration. With a better aerodynamic shed, the type B insulator collected less contamination than the type A. It can be seen that the contamination deposited of the type B insulator is less than that of the type A insulator in the exposure time.

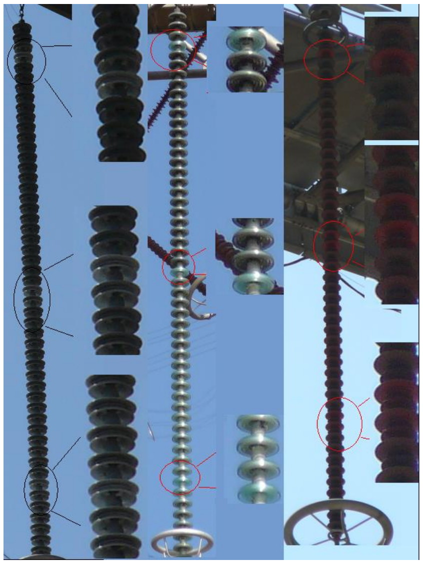

Fig. 3 The typical contamination of the test insulator strings. The left one is the porcelain insulator. The middle is the glass insulator. The right is SIR composite insulator.

4.2 Glass and Porcelain Insulators

Figure 4 also shows the twice tests results of the ESDD and the NSDD of the porcelain and glass insulators. From the figure the influence of shed shape and the insulator string type on the contamination deposited is summarized as follows:
(1) As for the glass DC fog disc insulator strings, the ESDD of the strain (#9) insulator string is about 1/3 that of the I-type #8 one. The NSDD almost has the same regulation as the ESDD. It can be concluded that the I-type insulator strings shows much heavier contamination than the strain-type ones.
(2) The #5 #6 #7 porcelain insulator strings with different shed shapes show the influence of the disc shed shape on the contamination deposited of the insulator strings. Among the three insulator strings, the ESDD of DC fog disc insulator string (#5) is the heaviest one, and the ESDD of the 3 outer-rib type insulator string (#6) is a little less than that of the #5 one. And the ESDD of the long rod insulator string (#7) is about 80% of that of the #5 one. The NSDD of the #5 string is the most serious among the three ones, and the NSDD of the #6 is about 60% of that of the #5. And the NSDD of the #7 string is the least one among the three, about 55% less than that of the #5. As for the comparison of the ESDD and the NSDD among the three insulator strings, the long rod insulator (type E) shows less contamination than the others (type C and D), and the 3 outer-rib type(type D) insulator shows less contamination than the DC fog disc insulator(type C) due to the aerodynamic type configuration. But the leakage distance of the long rod insulator string is the shortest among the three strings.

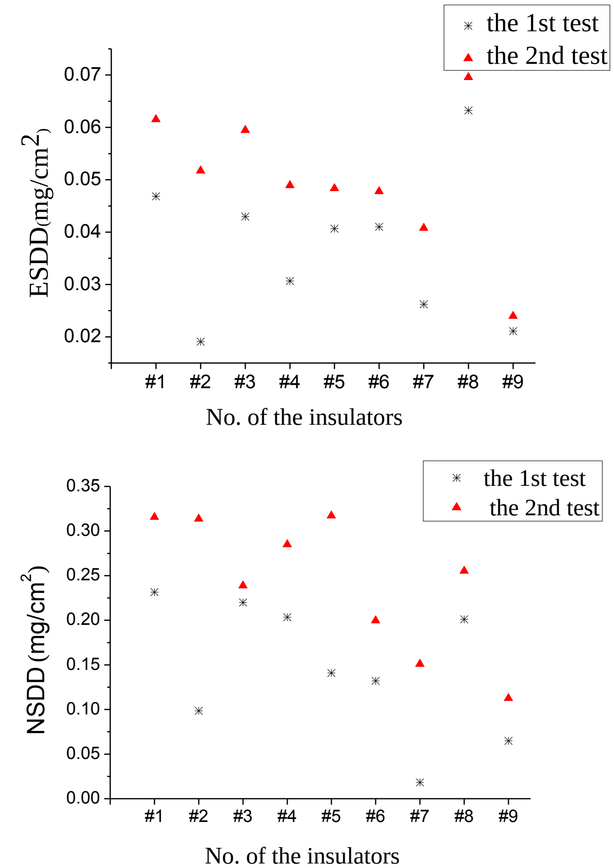

Fig.4 The values of ESDD and the NSDD of the twice tests results

4.3 Ratios of Contamination on Bottom Surface to That on Top Surface and Ratio of NSDD to ESDD

Table II shows the ratios of contamination on top surface to that on bottom surface in terms of the ESDD and the NSDD of all the insulators in the exposure period.
From the Table II, the ratios of the ESDD range from 0.92:1 to 5.8:1, and the ratios of the NSDD range from 1.0:1 to 8.0:1. The data are dispersive. The ratios of the RESDD and the RNSDD of the long rod insulator strings (#2 #4 and #7) are very close to each other after one year exposure. These ratios of the DC fog disc insulator strings (#5 #8 and #9) are quite close to each other, and that of the 3 outer-rib type insulator string (#6) is somewhere in between the two shape type insulators .
As for the comparison of these ratios between I-type glass DC fog disc insulator string and the strain type one, the former is greater than the latter. And these ratios of the I-type composite insulators (#1and #3) are greater than those values of the V-type insulators (#2 and #4).

The RESDD of the 1st test at rain season is much greater than that of the 2nd test at the dry season. And the RNSDD is similar to the RESDD. This is caused by the rain washing. The contamination on top surface of the insulator shed was washed more easily in the rain season. In the dry season, the rainfall has little effect on the contamination.

From the above, the shed shape of the insulator and the insulator string type are the influencing factors of the ratios of the ESDD and the NSDD on the bottom surface to that on the top surface. The results show that: these two ratios of insulators with the aerodynamic shed shape (Type A, B, D and E) are lesser than that of the DC fog disc insulators, and these ratios of the I-type insulator strings is greater than those of the V-type and strain type ones.

The ratios of the NSDD to the ESDD of all the insulators of the 2nd test are listed in the Table II, the maximum value is 6.5:1, while the minimum value is 3.66:1, and the average value is about 4.95:1. From the ratios, there is no evidence difference among the various type tested insulators. The data also show that the shed shape and the string type have no clear effect on the ratio of NSDD to ESDD. The data of the 1st test are not the same as that of the 2nd test, but there is no obvious difference between the two tests. It can be seen from these data that the ratio of the NSDD to the ESDD has nothing to do with the insulator shed and string type.

4.4 The ESDD and the NSDD along the Insulator Strings

The results of the ESDD and the NSDD along the insulator strings are shown in Figures 3 and 5. The distribution of the ESDD and the NSDD along the insulator
strings is uneven shown in Figures 3 and 5.It was observed that the earth side of insulator became darker and the color of surface contaminant on the earth side of insulator was different from that on the middle and line side ones from the Figure 3. The distribution of the ESDD and the NSDD along the insulator strings presented decreasing trend from the earth side to the line side. It can be seen from the Figure 5 that for all the tested insulators, the ESDD of the insulator sheds near the earth side were the most serious; the ESDD values of most strings were around 0.08 mg/cm2. The ESDD values in the middle were much smaller than those of the earth side, only around 0.04 mg/cm2. And the data near the line side were a little less than those in the middle. The NSDD of the entire insulator strings also appeared the same phenomenon. This phenomenon of the distribution of the ESDD and the NSDD is different from the former reports, which at lower voltage levels. The distribution of contamination along the insulator string is influenced by kinds of factors such as electric filed, the mass of dust particle, the diameter of dust particle and et al. In DC electric filed, the dust particles can be charged by multiple ways and move in a definite direction by the electrostatic force. And the wild force and gravity also can influence the dust particles movement. However, how the factors effect on the distribution of the ESDD and the NSDD still needs more studies.

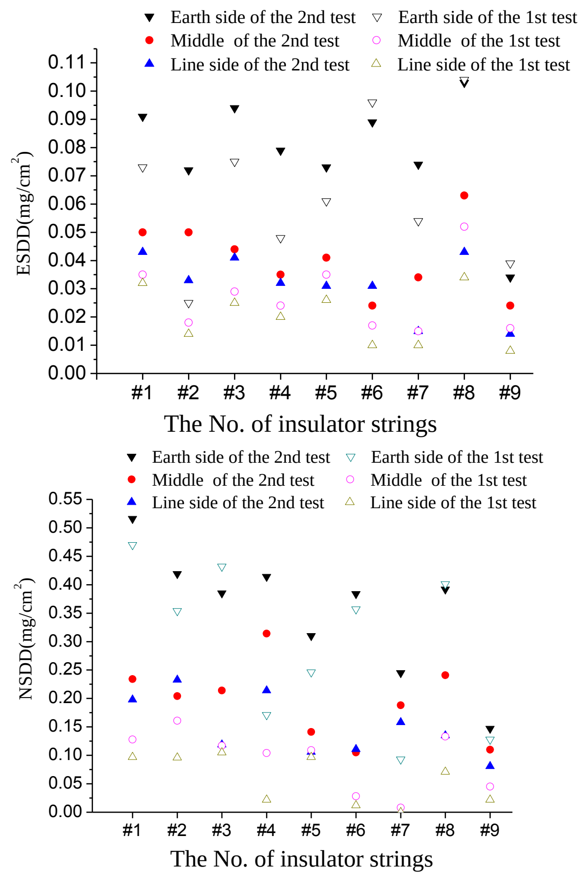

Fig. 5.The distribution of the ESDD and the NSDD along the insulator stings

4.5 Results of Chemical Analyze of Contaminants

According to the results of quantitative analysis of contaminants as shown in Fig. 6, the Ca^{2+} occupies the maximum component of the cations, and the SO_4^{2-} is the maximum one of the anions. It is recognized that calcium sulfate corresponds to $CaSO_4$ (Bassanite). So about 75% of soluble contaminants was $CaSO_4$, and also about 17% of soluble contaminants was sodium salt (NaCl). The results influenced the insulator withstand voltages according to [28].

The major compositions of insoluble contaminant were silica oxide (SiO_2), alumina (Al_2O_3) and ferrite (Fe_2O_3)

which were contained within the soil, and calcium oxide (CaO), which came from limestone near the test site. And else (mainly carbon) accounting of 31.44% of the total weight, which is the maximum component of the nonsoluble contaminants. It is found that the content of carbon increase slightly with dc voltage energization in [3], however, in this study the content of carbon increase greatly. This phenomenon may be noticed in the ±800kV projects.

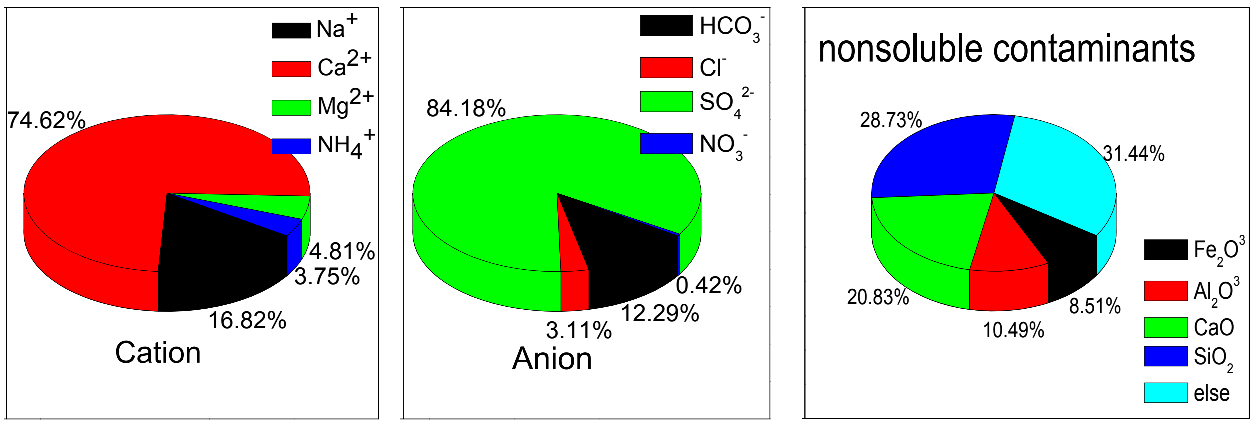

Fig. 6 Quantitative analysis results of contaminants

5. Conclusions

The ESDD and the NSDD of the tested insulator strings were measured after one year exposure under an -816kV energized condition, and the results of the ESDD and the NSDD have been analyzed in this study, the following conclusions have been reached:

1 The insulator string type influence on the contamination deposited of the insulators. The V-type insulator string has lighter contaminants than that of I-type ones, and the strain type insulator string has much lighter contaminants than that of the I-type ones.

2 The insulator shed shape was an important factor that influenced the contaminants of the insulator strings. The shed shapes with a better aerodynamic type configuration show a better contamination deposited characteristic.

3 The ratios of contamination on top surface to that on bottom surface in terms of the ESDD and the NSDD were influenced by the insulator shed shape and the string type. It showed that the insulator with an aerodynamic type configuration has a uniform contamination on both top surface and bottom surface, and the V-type insulator string also has a uniform contamination. And the shed shape and the string type have no clear effect on the ratio of NSDD to ESDD.

4 The distribution of the ESDD and the NSDD along the insulator strings presented decreasing trend from the earth side to the line side. This phenomenon was different from the former low voltage results, and more studies need making for the reason.

5 $CaSO_4$ was the dominant component of soluble contaminants by the chemical analysis. The content of carbon increased greatly than the former reports.

Acknowledgments

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Fangcheng Lv was born in P. R. China in 1963. He received the M. Sc. degree in 1989 and Ph. D. degree in 1999, both from North China Electric Power University (NCEPU), Baoding City, Hebei Province, P. R. China. Since 1987, he has been with the NCEPU as a teacher. Since 2003, he is engaged with teaching and research as a Professor and now he is the Director of the Electrical Engineering Department of NCEPU. His research interests include the study of monitoring and diagnosis of insulation.