Experimental analysis of the artificial contamination flashover characteristics of long insulator strings in 500 kV transmission lines

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The flashover voltage of short string insulator is different from long string insulator, and big error could be occurred when using flashover voltages of short string insulators to reckon the ones of long string insulators. In order to reduce this deviation, under the conditions of different equivalent salt deposit density (ESDD), non-soluble deposit density (NSDD), and uneven deposition filthy, XWP2-160 type with two umbrella porcelain insulators are used to obtain the characteristics of artificial filthy flashover voltages of the single hang string insulators, and the creepage distance effective coefficient of the type string insulators is calculated. The experimental results of V type, inverted V type insulators are compared with single hanging type string insulator, and the correction coefficient of the abnormal type insulator string is obtained. The results show that the flashover voltages of XWP2-160 type string insulators are inversely related to ESDD and NSDD, and the creepage distance effective coefficient of the type string insulators is 0.78. The maximal contamination resistance voltage of V shaped string and inverted V shaped string are larger than single hanging string insulator, and the string type correction coefficients is1.08 for V shaped string and 1.15 for inverted V shaped string respectively.

Keywords: long string insulators; Antipollution characteristic; creepage distance; artificial contamination; flashover voltages; equivalent salt deposit density (ESDD); non-soluble deposit density (NSDD).

1. Introduction

Transmission line antipollution study has always been the key point of grid disaster prevention and mitigation. A great deal of research have been conducted in the transmission line antipollution measures at home and abroad, and many effective means of antipollution are proposed, such as RTV coating, composite insulator [1-8], antipollution detection [1,9-13] and so on. In order to study the dirty ice flashover characteristics, the experiment conditions of many voltage levels, different insulator types, and various elevations have been considered [4-6, 14-16]. Under these conditions, natural pollution accumulation rule of regional transmission line insulator is also obtained. In antipollution monitoring, insulator leakage current technology [1, 9-12] and optical fiber sensor technology [13] are used to monitor the electric transmission and transformation equipment. Besides, many researchers study the electric field distribution of insulator [16], and improve the insulator appearance design in detail to optimize insulator antipollution properties, while a small number of researchers study the discharge characteristic of long insulator strings, which include impulse voltage discharge characteristics, leakage current characteristics and resistance voltage characteristic test of insulator strings.

At present, the contamination resistance voltages of insulator are obtained by artificial contamination tests of short insulator strings. According to the research results by Tao Xu, filthy flashover intensity is not linearly related strictly to the length of the insulator strings, there is a larger deviation to use the data of long string insulators flashover voltages to reckon short string insulators, and with the creepage distance increased, the filthy flashover characteristics of different types porcelain and glass insulator are not improved linearly. According to this circumstance, XWP2-160 type with two umbrella porcelain insulators are used to get the characteristics of the artificial filthy flashover voltages of the single hang string insulators under the conditions of different equivalent salt deposit density (ESDD), non-soluble deposit density (NSDD), and uneven deposition filthy, finally, calculating the creepage distance effective coefficient of the type string insulators. The artificial contamination experiment of XWP2-160 V type insulator and inverted V shaped insulator string are conducted, and compared with the single hang type string insulator, the string type correction coefficients are obtained for V shaped and inverted V shaped insulator, which provides some references for the external insulation configuration of 500kv transmission line.

2. Experiment Setup and Method

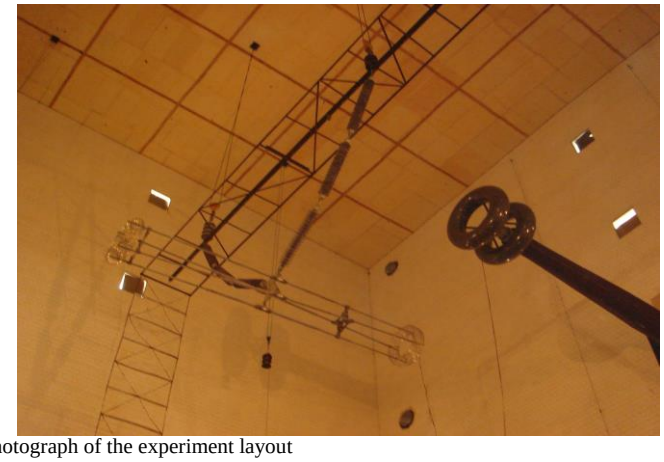

Fig.1 The photograph of the experiment layout

The experiment layout is shown in Fig.1, the experiment is conducted in 1000kV artificial fog chamber (24 m×24 m×26 m) at electric power research institute of China, experiment voltage is provided by wall bushing with 800kV (phase) nominal voltage from 2250kV transformer. Power supply in the experiment meets the provisions of GB/4584-2004. The simulation cross arm, simulation transmission line and insulator string are arranged according to the 500 kV transmission line, and the V type insulation is set according to the 500 kV transmission line with four back in a towers. The XP-160 type insulator and XWP2-160 type insulator are involved in this paper, which structure as shown in figure 2, the related parameters are shown in table 1.

Tab.1 Configuration parameters of experimental insulators

Insulator type	Height (mm)	Radius (mm)	Surface area (mm^2)	Creepage distance (mm)
XP-160	155	255	1691	305
XWP_2-160	155	300	2786	450

By using the solid coating method of IEC507 to process the surface of simulation insulator string, soluble salt material using NaCl, non-soluble material is diatomaceous earth. Salt deposit density and non-soluble deposit density are weighted by insulator surface, and stirred evenly with some distilled water, and then coated the mixture onto the surface of every chip of insulator, which is pretreated before using. After natural drying, sending it into an artificial fog chamber. In order to obtain the artificial contamination 50% power

frequency resistance voltage of insulator strings, lifting method is applied according to GB/4548-4548. The voltage in a single test is applied according to GB/T4548-2004, and then injected into steam fog. In this paper, a lot of leakage currents of insulator string are measured, one of the typical measurement of leakage current is as shown in figure 3. The voltage is 500 kV, the ESDD is 0.1 mg/cm^2, NSDD is 1.0 mg/cm^2.

According to measurement data, the leakage current continues to decline after 25 min in the insulator string tolerance experiment, and at 30 min, the peak value is far less than 70% of the maximum leakage current. In this experiment, flashover has been occurred, or the experiment needs maintain 40 min from test beginning.

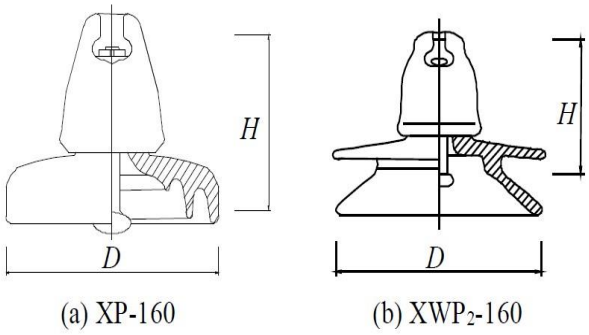

Fig. 2 Configurations of experimental insulators

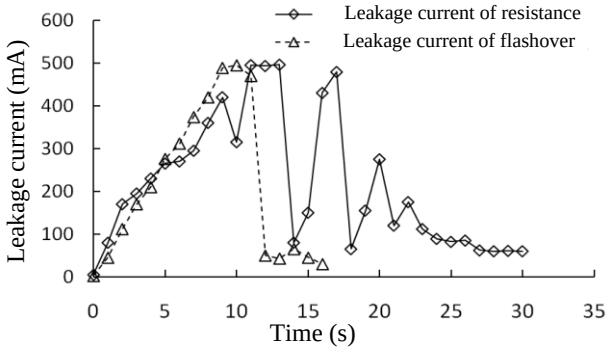

Fig.3 The trend chart of the typical leakage current

3. Experiment Result and Analysis

3.1 Artificial contamination experiment of single hang type string insulator

Artificial contamination is applied on the whole surface of insulator, and the volume ratios are 1:1 and 1:3. On this condition, the resistance voltage characteristics with artificial contamination of XWP2-160 31 chips single hang type insulator strings are studied. The structure and parameters of XWP2-160 insulator is as shown in figure 2 and table 1. NSDD are 0.1 mg/cm^2, 1.0 mg/cm^2 and 4.0 mg/cm^2 for experiment, and then acquired the artificial contamination 50% flashover voltage curve of insulator strings respectively, as shown in figure 4 and 5.

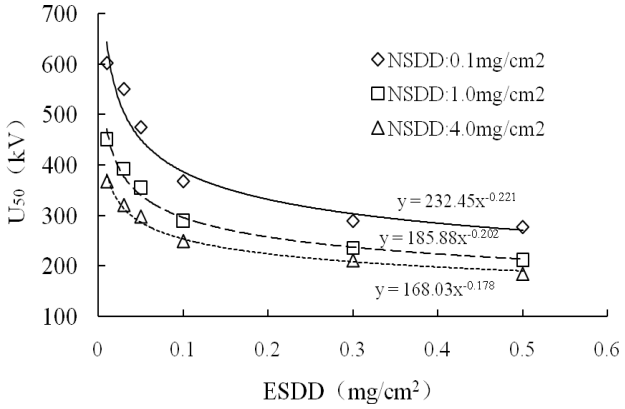

Fig.4 The curve of the artificial filthy flashover voltages (The contamination ratio is 1:1)

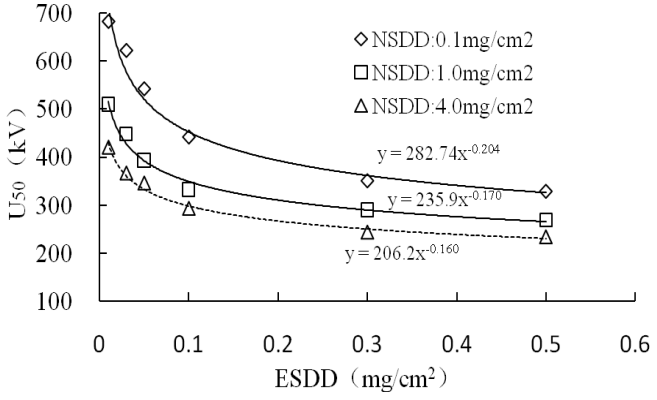

Fig.5 The curve of the artificial filthy flashover voltages (The contamination ratio is 1:3)

Combining with the figures 4 and 5, it can be found that the flashover voltages of XWP2-160 type string insulators is negative correlated to ESDD and NSDD. When the ESDD is less than 0.1 mg/cm^2, the peak of flashover voltage with artificial contamination is decreased rapidly, and when ESDD is greater than 0.1 mg/cm^2, the reduction magnitude of flashover voltage with artificial contamination is gently. Under the condition of certain product contamination ratio and ESDD, flashover voltage with artificial contamination is also negative correlation with NSDD, and the decrease of flashover voltage is the same as the condition of ESDD. Under the same ESDD and NSDD, the flashover voltage with filth ratio 1:3 is larger than that filth ratio is 1:1, and the relative magnitude is about 10% ~ 20%.

The largest fouling resistance voltage of single chip insulator U_{max} can be calculated by following:

$$U_{max} = (1 - K\sigma)U_{50} \tag{1}$$

Where U_{50} is the artificial contamination 50% flashover voltage values of single chip, the coefficient K is associated with single string flashover probability, here is 3, σ is standard deviation, which can be obtained by experiment, as is shown in table 2.

Tab.2 The chart of the standard deviations (σ: %)

filth ratio	1:1			1:3		
NSDD / ESDD	0.10	1.00	4.00	0.10	1.00	4.00
0.01	7.20	8.27	9.10	8.67	8.87	7.15
0.03	9.22	9.18	8.45	7.55	8.24	7.66
0.05	8.28	8.45	7.20	9.35	7.45	8.61
0.10	7.65	8.00	7.88	7.72	7.23	7.53
0.30	9.07	7.21	7.20	6.98	7.85	7.89
0.50	7.70	9.40	7.99	9.21	9.26	7.23

Note: the ESDD and NSDD units in the table are mg/cm^2

According to the experiment results, the largest contamination resistance voltage of XWP2-160 single hang insulator string can be calculated in different degree of filth and fluctuation uneven fouling. The largest contamination resistance voltage curves are shown in figure 6 and 7, respectively.

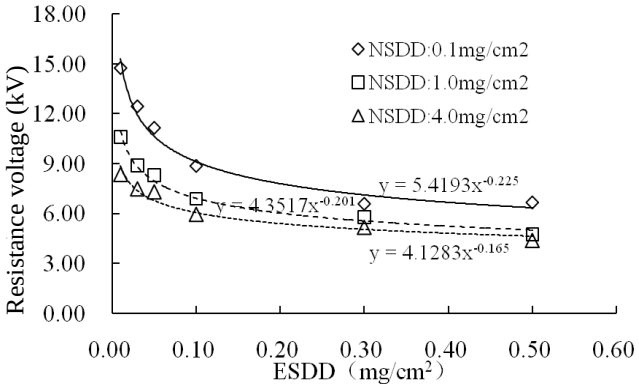

Fig.6 The flashover voltage curve of the single insulator (The contamination ratio is 1:1)

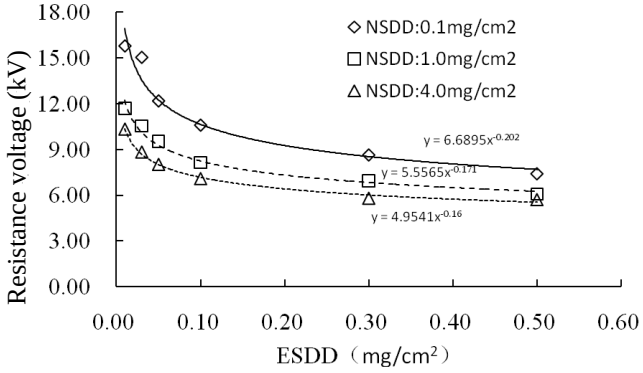

Fig.7 The flashover voltage curve of the single insulator (The contamination ratio is 1:3)

Tab.3 The contrasting between XWP2-160 type string insulators and XP-160 type string insulators (The contamination ratio is 1:1)

ESDD/NSDD	U_{50}(kV/unit)		E_0 (kV/m)	E_1 (kV/m)	K_p	K_{aver}
	XP-160	XWP_2-160				
0.01/1.0	11.65	14.09	38.18	31.31	0.82	0.78
0.03/1.0	11.09	12.27	36.36	27.27	0.75	
0.05/1.0	9.65	11.11	31.65	24.69	0.78	
0.1/1.0	7.22	9.05	23.66	20.11	0.85	
0.3/1.0	6.56	7.36	21.52	16.36	0.76	
0.5/1.0	6.23	6.62	20.43	14.71	0.72	

Note: the units of ESDD and NSDD in the table are mg/cm^2, E_0 is the 50% flashover voltage gradient of XP-160 28 chips single hang type string insulator, E_1 is 50% flashover voltage gradient of XWP2-160 32 chips single hang type string insulator, K_p

is the creepage distance effective coefficient of XWP2-160 type insulator with certain the ESDD and NSDD, equaled E_1/E_0.

Combining figure 6 with figure 7, it can be found that the tendency of the largest contamination resistance voltage of XWP2-160 single hang insulator string is the same with the flashover voltage with artificial contamination of XWP2-160 32 chips type insulator string. Under the same ESDD and NSDD, the largest contamination resistance voltage of XWP2-160 single hang insulator with filth ratio 1:3 is larger than thatfilth ratio is 1:1, and the relative magnitude is about 5% ~ 22%.

The 50% flashover voltage experiment with artificial contamination of XP-160 28 chips single hang type string insulator is conducted, and then compared with XP-160 32 chips single hang type string insulator, the results as shown in table 3, the filth ratio on up and down surface of insulator is 1:1.

Table 3 shows that K_{aver} is 0.78. According to the same method, when NSDD is 0.1 mg/cm^2, K_{aver} is 0.76, and when NSDD is 4.0 mg/cm^2, K_{aver} is 0.79. Therefore, the creepage distance effective coefficient of XWP2-160 type insulator is 0.78. According to table 2, the creepage distance of XWP2-160 type insulator is 450 mm, and then effective creepage distance of this type insulator is 351 mm.

3.2 The experimental contrast between V type, inverted V type and single hang type string insulator

When the ESDD is 0.1 mg/cm^2, NSDD is 0.1 mg/cm^2, and the filth ratio on up and down surface of insulator is 1:1, and then the artificial contamination experiment of XWP2-160 36 chips V type insulator and inverted V shaped insulator string are conducted, 50% flashover voltage is adopted at the same way. Compared with the 32 chips single hang type string insulator, the string type correction coefficients are obtained for V shaped and inverted V shaped insulator. The detail results are shown in table 4.

Tab.4 The artificial filthy flashover voltages of three type string insulators

String type	U_{50}(kV)	σ(%)	contamination resistance voltage (kV)	K_s
V shaped	308.5	7.90	7.50	1.09
inverted V	319.7	8.20	7.74	1.13
single hanging	289.6	8.00	6.88	/

In table 4, the correction coefficient of different types insulator strings $K_s=U_1/U_0$, U_1 is the contamination resistance voltage of the V shaped string (or

inverted V shaped string) single insulator, U_0 is the contamination resistance voltage of single hanging string insulator. From the results of table 4, it can be found that the maximal contamination resistance voltage of V shaped string and inverted V shaped string are larger 0.62kV and 0.86kV than the single hanging string single insulator. Therefore, the string type correction coefficients are 1.09 and 1.13 for V shaped string and inverted V shaped string in the condition of ESDD is 0.1 mg/cm^2 and NSDD is 0.1 mg/cm^2 respectively. The contamination resistance voltage of inverted V shaped string is larger than V shaped string slightly, it could be because of that this kind of insulator string is not in the same plane with simulation cross arm, which can reduce the influence of the simulation cross arm on electric field distortion of insulator string.

According to this method, the string type correction coefficients of V shaped string and inverted V shaped string can be obtained in different contamination conditions, and as is shown in table 5. Calculating the average of these data, and the average value is the string type correction coefficient, the values are 1.08 for V shaped string and 1.15 for inverted V shaped string respectively.

Tab.5 The String type correction coefficients of two type string insulators

String type	V shaped string			inverted V shaped string		
NSDD / ESDD	0.10	1.00	4.00	0.10	1.00	4.00
0.01	1.12	1.04	1.12	1.19	1.17	1.15
0.03	1.08	1.06	1.04	1.18	1.12	1.16
0.05	1.05	1.05	1.11	1.15	1.15	1.18
0.10	1.09	1.11	1.06	1.13	1.12	1.18
0.30	1.10	1.07	1.10	1.12	1.18	1.17
0.50	1.09	1.09	1.11	1.12	1.13	1.13
K_s	1.08			1.15		

4. Conclusion

There flashover voltage of XWP2-160 type string insulators is negative correlated to ESDD and NSDD. When ESDD is less than 0.1 mg/cm^2, the peak of flashover voltage with artificial contamination is decreased rapidly, and when ESDD is greater than 0.1 mg/cm^2, the reduction magnitude of flashover voltage with artificial contamination is gently. Under the condition of certain product filth ratio and ESDD, flashover voltage with artificial contamination is also

negative correlation with NSDD, and the decrease of flashover voltage is the same as the condition of ESDD. Under the same ESDD and NSDD, the flashover voltage with filth ratio 1:3 is larger than that filth ratio is 1:1, and the relative magnitude is about 10% ~ 20%.

The tendency of the largest contamination resistance voltage of XWP2-160 single hang insulator string is the same with the flashover voltage with artificial contamination of XWP2-160 32 chips type insulator string. Under the same ESDD and NSDD, the largest contamination resistance voltage of XWP2-160 single hang insulator with filth ratio 1:3 is larger than that filth ratio is 1:1, and the relative magnitude is about 5% ~ 22%.

The 50% flashover voltage experiment with artificial contamination of XP-160 28 chips single hang type string insulator is conducted, and then compared with XP-160 32 chips single hang type string insulator, the creepage distance effective coefficient of XWP2-160 type insulator is 0.78, and the effective creepage distance of this type insulator is 351 mm.

The maximal contamination resistance voltage of V shaped string and inverted V shaped string are larger than single hang string insulator, and the string type correction coefficient are 1.08 for V shaped string and 1.15 for inverted V shaped string respectively.

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